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(BIM)

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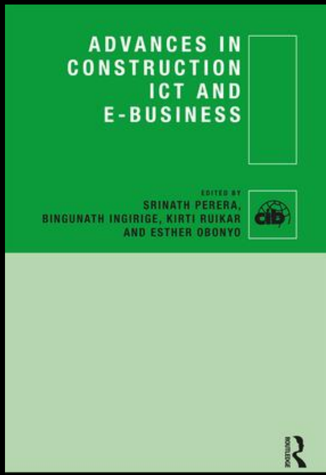

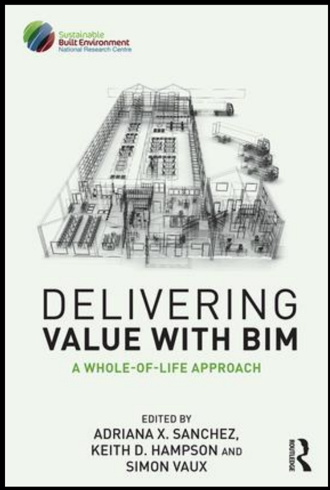

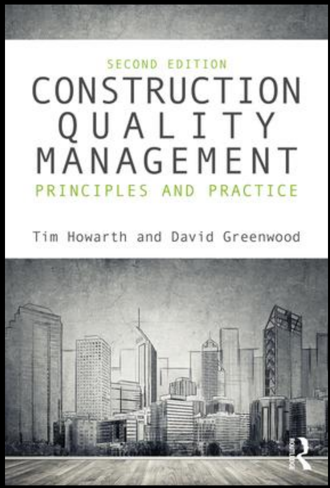

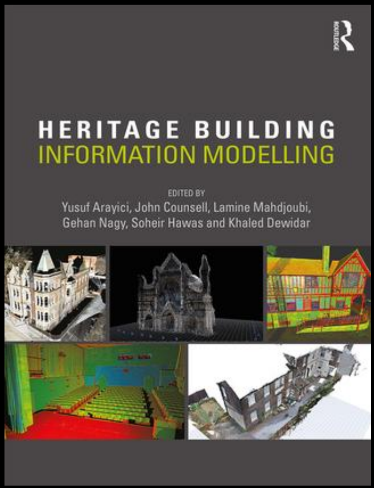

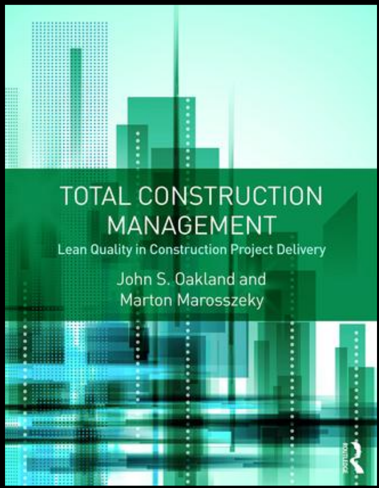

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Introduction

Welcome to *Building Information Modelling (BIM)*, a FreeBook brought to you by Routledge, containing a collection of four chapters and one case study collated from our most recent Built Environment publications. The chapters presented here provide you with a mere glimpse of the content we have available to cater to the growing interest from professionals, researchers and students in the fast-moving and disruptive world of BIM.

Chapter one provides you with a useful history of BIM and some observations about where BIM in the UK may be heading. In Chapter 2 some useful frameworks for measuring performance and capability are discussed, with the need for greater collaboration being proposed. Chapter 3 is extracted from a textbook on Quality Management and considers BIM as "a quality system for improving the competitiveness of all organisations operating within the extended construction and property sectors that relates to the whole life of all built assets." Chapter 4 presents an extract from our pioneering book on Heritage Building Information Modelling (HBIM) and grapples with defining the goals and purposes of BIM in heritage property. Finally, the FreeBook ends with a fascinating case study of Southland Industries' combined use of BIM with Lean principles (for further reading on success stories in combing Lean and BIM, see Sacks et al (2018) *Building Lean, Building BIM*).

Courses in BIM are popping up all over the Built Environment and AEC Higher Education sector and with that there is an increase in demand for reliable knowledge and critique of these evolving systems. Anyone teaching, researching or working in architecture, engineering, planning, construction, quantity surveying and building surveying will find resources that will be useful as required texts and supplementary reading throughout their studies and subsequent careers. This is just a selection of representative chapters from just five of our recent publications to give you an idea of the quality and variety of subject matter addressed in our portfolio. So, please enjoy this sample from our new books, and consider recommending them to your students, colleagues, and library.

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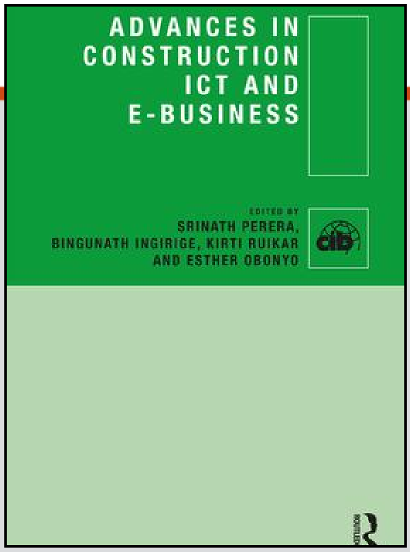
CHAPTER

1

BUILDING INFORMATION MODELLING AND MANAGEMENT



This chapter is excerpted from

Advances in Construction ICT and e-Business

Edited by Srinath Perera, Bingunath Ingirige, Kirti Ruikar, Esther Obonyo.

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BUILDING INFORMATION MODELLING AND MANAGEMENT

Excerpted from *Advances in Construction ICT and E-Business*

5.1 Introduction

This chapter is the core of a three-chapter offering on building information modelling, sometimes known as building information management, but most easily recognised under the acronym, BIM. The chapter is one of three on BIM with the other two covering, in turn, two BIM application related detailed case studies to demonstrate its uptake, issues and advantages. The aim of the current chapter is to be, as far as possible, a state of the art account with a full coverage of BIM from its origins to current level of development and beyond, to its future potential. This, in itself, brings limitations. The first of these is that with BIM we are dealing with a radical, disruptive and fast-moving phenomenon: this makes the contemporaneity of its reporting most difficult. Until BIM becomes fully established and prevalent, anything published on the topic will almost immediately require updating. Secondly, the uptake of, and progress in BIM has been different

in the different construction industries around the world. This account, out of necessity, takes a focus that is predominantly on the UK. It will, to some extent report on developments in BIM elsewhere in the world, nevertheless it should be kept in mind that a thorough global coverage is not intended.

5.2 Historical development, terminology and scope

The term *building information modeling* [note the US spelling: in UK English this is 'Modelling'] was used in an Autodesk 'Building Industry Solutions White Paper' in 2002 (Autodesk, 2002) though the term 'building information model' was in use before that (see, for example, van Nederveen and Tolman, 1992) and earlier references to the concept appear in Eastman *et al.* (1974). It has been suggested (Laserin, 2008) that the term was actually first coined from a merger of the earlier expressions 'Building Product Model' (largely used in the USA) and 'Product Information Model' (which was common at the time in Europe). In the UK, problems of interoperability and model data translation were being addressed as early as the 1990s in projects such as the European Union funded 'COMBINE' research programmes (Wright *et al.*, 1992) and explorations of n-D modelling involving Aouad and others (Ford *et al.*, 1994).

U.S. commentator and architectural director John Tobin, drawing on the terminology of Bower and Christensen (1995) notes that BIM began as a 'sustaining technology' (i.e. using 3D models to produce construction information more efficiently) but has become a 'disruptive innovation' that has 'created brand new value networks' that will 'change markets and expectations' (Tobin, 2013). Thus BIM, with its origin as a design tool, 'becomes VDC' (Virtual Design and Construction) with its adoption by contractors. Not only this, but 'smart owners' ['clients' in the U.K.] then enter the picture as they 'realize how these information-rich 3D models could be useful as an active decision-making tool during construction, and then used as stores of information for facility operations purposes' (Tobin, 2013). The process Tobin has described has caused some to question the applicability of the term *Building Information Modelling*: and variants such as *Building Information Management*, *Virtual Design and Construction* and *Digital Design and Construction* have appeared.

BUILDING INFORMATION MODELLING AND MANAGEMENT

Excerpted from *Advances in Construction ICT and E-Business*

The advantage of the last two descriptors is that they remove the early misconception that BIM was only applicable to *building* – a misconception that prompted commentators to ask questions such as 'is BIM relevant to civil engineering?' The question has,

of course, been answered in the affirmative. As Corke (2012) writing in New Civil Engineer states, 'the core principles and workflows associated with BIM apply equally to all infrastructure projects, including roads, railways, bridges, dams and water works.' There are publications specifically aimed at civil engineers (e.g. Barnes and Davies, 2014), asset managers (Shetty

et al., 2013; BSI, 2014) and the formation of sector-specific groups such as 'BIM 4...' groups (http://www.bimtaskgroup.org/bim4-steering-group/) which include Clients, Retail, Water, Health, FM (facilities management), and Housing. Although it is arguable that BIM (taken literally as *building information modelling*) is far from ideal as a representation of the concepts it has come to embody, the fact remains that it is now commonly-accepted and all-pervasive. The reader will encounter many definitions of BIM as well as a number of substitute names for the concepts that it represents. Examples of BIM definitions include, from the (United States) National Institute of Building Sciences (2007) Building Information Modeling (BIM) is a digital representation of

physical and functional characteristics of a facility.

5.3 Drivers for BIM adoption – 'push' and 'pull' reasons

Within the 'Construction Strategy' published by UK Government (Cabinet Office, 2011) was a requirement for 'collaborative 3D BIM (with all project and asset information, documentation and data being electronic)' by 2016. The twin key objectives of the strategy were 'cost reduction in the construction and operation of the built environment' and the 'implementation of existing and emerging government policy in relation to sustainability and carbon'. The report highlights BIM as an important route to meeting these objectives. This was influenced by the so-called 'BIM Strategy Report (BIM Working Party, 2011) that recommended the adoption (by the government) of a 'Push-Pull' strategy: a *push* by the supply side (i.e. the industry itself) and a *pull* from the client side (specifically the public sector client). The government's 'BIM edict' has produced an enormous interest in BIM in the UK as illustrated by the annual (since 2011) NBS National BIM Reports (2011–2015). In NBS's 2011 survey (National Building Specification, 2011) 43% of respondents were unaware of BIM, and this has reduced to 5% in the 2015 survey. There was a corresponding increase in those 'aware of and using BIM': 13% in the 2011 survey, to 48% in 2015 (National Building Specification, 2015). In the absence of client *pull*, the *push* by the industry supply side would naturally require a business case and evidence of a return on investment (ROI). Some of the earliest indications of ROI in BIM came from the United States, where Holness (2006) reports savings on construction costs of between 15% and 40%. More recently a survey of over 1,000 industry participants by McGraw-Hill has pronounced that '63% of BIM users are experiencing a positive perceived ROI on their overall investment in BIM' (McGraw-Hill, 2012: p. 39) with the most common range being between 10% and 25%. Evidence from the UK is relatively scarce and generally unquantified, though case studies are emerging on the Constructing Excellence website.[1] In all cases the evidence suggests that experienced users derive an increased ROI, or, to put this conversely, BIM adoption may show an initial productivity loss, followed by considerable gains.

5.4 Applications and uses of BIM

From its initial manifestation as an enhanced design tool BIM technology has been developed and extended into a wide range of functional applications. For example, Bryde *et al.* (2013) map the potential uses of BIM against the 'knowledge areas' specified by the Project Management Institute's (PMI) Project Management Body of Knowledge (PMI, 2008) and others have similarly examined the potential contributions of BIM. What follows is an attempt at providing a fairly comprehensive (but not exhaustive) list of how BIM-based applications can inform, facilitate and improve the operations involved in the design, construction and management of the built environment.

5.4.1 3D design and visualization

The earliest and most basic application of BIM is in design – architectural, structural, services, and so on. The integrated nature of BIM and its capability in information re-use complements the iterative nature of the building design process. Furthermore, automatic code and regulation compliance checking can be incorporated (see, e.g. Malsane *et al.*, 2015). Links are available to structural and environmental analysis software. Visualised renderings of 3D designs (to a range of realism) are useful communicators of design intent, particularly to 'lay' stakeholders, including clients. 3D renderings can be easily generated in-house with little additional effort. In addition, BIM 'viewing software' enables constructors to view and manipulate 3D design outputs.

5.4.2 Design coordination, clash detection and change management Applications have evolved to enable co-ordinators (lead designers, main contractors, etc.) to resolve design clashes or problematic interfaces between different construction systems. The use of BIM has been shown not only to reduce design clashes and subsequent requests for information (RFIs) and variations/change orders, but also, where changes do occur, BIM facilitates their management as a change to any part of the model can be coordinated with all other parts.

5.4.3 Off-site fabrication

'Shop drawings' can be readily generated and designs can be integrated into the production software used by some manufacturers. Leading examples are structural steel, precast concrete and ductwork, where manufacturers and fabricators have for many years used digital 'design for manufacture' applications. There is now a real prospect of integrating these systems with the design-procure-construct process of the individual construction project.

5.4.4 Construction sequencing ('4D BIM')

4D planning involves linking a time schedule to a 3D-model to improve construction planning techniques. Schedules can be generated by interrogating the design model(s) to identify activities, calculate durations (using automated quantity extraction), impose installation logic, schedule resource requirements and visualise the time/space relationships of the delivery process: the overall aim being to improve communication between project team members, through informative animations of the build process.

5.4.5 Estimating, cost management and procurement ('5D BIM')

Applications are available that cater for the procedures currently undertaken by quantity surveyors and estimators in the bidding, procurement and cost management and project accounting functions. This includes 'time-cost-value' analysis techniques such as earned value management (see e.g. Barlish and Sullivan, 2012: p. 153). Work is also underway to integrate BIM applications with enterprise resource planning (ERP) systems at the business level of the organisation (see e.g. Babič *et al.*, 2010) to inform their sales, purchasing and logistics functions.

5.4.6 BIM for Sustainability ('6D BIM') The potential of this application relates to sustainability targets for a building, allowing information such as energy use, resource efficiency and other aspects of sustainability from a materials and management point of view to be better analysed, managed and understood (see e.g. Hamza and Horne, 2007; Azhar and Brown, 2009; Nour *et al.*, 2012). The object-modelled data in the BIM model can accommodate information such as embodied carbon, including that created by the process of construction. Work is underway to enable the automated performance of BREEAM[2] and LEED[3] tracking and assessment (see e.g. Azhar *et al.*, 2011).

5.4.7 Whole-life and facilities management ('7D BIM')

7D BIM relates to Life Cycle Costs, and represents the management of facilities or assets. This could be delivered to the client or end-user in the form of an 'asset tagged', 'as-built' BIM model at handover, or in a more specific format (e.g. as COBie[4] information) and may be populated with appropriate component and product information, operation manuals, warranty data, and so on. Information based on BIM can thus be re-used for driving efficiencies in the management, renovation, space planning, and maintenance of facilities.

Recognising the potential for such capabilities, and seeing BIM's value in efficiency gains in OPEX as well as CAPEX, the UK Government has linked BIM with its 'government soft landings', the objective of which is 'to ensure that value is achieved in the operational lifecycle of an asset' (BIM Task Group, 2013). Mention should also be made of BIM's potential role in the retrospective modelling of existing buildings and other structures through point-cloud capture using laser scanning (see e.g. Volk *et al.*, 2014).

5.5 Technology, process and people

The familiar trio of *technology, process* and *people* is a combination based on work such as that of Davis (1993) on 'technology acceptance' (i.e. its acceptance by *people*) and that of Brynjolfsson and Hitt (2000), Bower and Christensen (1995), and David (1990) on the impact of technology on Workflow and process in organisations. In turn, this echoes earlier work on socio-technical systems by the likes of Emery and Trist (1969) that examines how people and organizations respond to technology, particularly information technology. It is probably true to say that most of the aforementioned work revolves around what happens when one of the three intervenes to cause a change in a relationship between the other two (e.g. the intervention of new technology between people and process, and so on).

5.5.1 BIM as technology

First and foremost (or at least, initially), BIM is 'a modelling technology' (Eastman *et al.*, 2011: p. 16). The model incorporates and reconciles information from different professionals (architect, structural engineer, etc.) initially in the form of graphical object data, in the form of size, shape, location and other visible characteristics. Grilo and Jardim-Goncalves (2010) refer to this as a 'surface model': however, in what they describe as a 'solid' or 'smart' model BIM can incorporate characteristics other than geometry, such as material composition, design life or other supplier information in object-based, parametric components. Such information can then be re-utilised to produce allied applications such as detailed building performance analyses, 4D scheduling and 5D modelling for cost management. The extensive range of uses to which the model could potentially be put is revealed in the term '*n*D modelling' (see Marshall-Ponting and Aouad, 2005) and some are considered later here in a little more detail. The modelling takes place within a variety of different native software platforms, usually proprietary and commercially-driven. Eastman's original 'BIM Handbook' (Eastman, 2008) lists over 70 different software companies with hundreds of different software packages. These have developed to suit the functional needs of their current users (architects, structural engineers, services engineers, constructors, and so on). Consequently, they differ structurally and semantically (Lockley *et al.*, 2013). In the 2014 NBS National BIM Report 25% of BIM users felt that 'information models only work in the software they were made on'. (NBS, 2014: p. 14). This in itself is a limiting factor in reaching fully-collaborative BIM, and is what is referred to as the issue of interoperability or, more specifically 'semantic data interoperability' (Yang and Zhang, 2006).

5.5.2 Interoperability

Interoperability is defined by the International Alliance for Interoperability (now 'buildingSMART') as 'an environment in which computer programs can share and exchange data automatically, regardless of the type of software or where the data may be residing' (Fischer and Kam, 2002: p. 14). As noted above and articulated by Cerovsek, achieving 'inter-operability between multiple models and multiple tools that are used in the whole product lifecycle' is a key challenge (Cerovsek, 2011: p. 224). The ambition to achieve the automatic and efficient use and re-use of information throughout the design, delivery and operation of a built asset is hindered by the current existence of a range of commercially available, 'native' BIM software platforms, each with its different functionalities, naming conventions and classification. The problem is particularly acute when it comes to the authoring and use of standard BIM object libraries (Howard and Bjork, 2008). To overcome this situation, the secure and reliable exchange of data is essential and this has led to work by various national and international bodies, including the International Organization for Standardization (ISO), producing 'requirements for the exchange of building element shape, property, and spatial configuration information between application systems' (Grilo and Jardim-Goncalves, 2010: p. 525). The tangible result, for AEC practitioners, is an intermediary format for exchange of data called *Industry Foundation Classes* (IFC). IFC is a 'schema' that defines and provides 'Model View Definitions' to meet the needs of information exchange between different applications. The latest version, IFC4, is registered with ISO as an official International Standard, ISO 16739:2013. According to NBS (2014: p. 17) 'IFC, as a platform-neutral, open file format, allows models to be shared among the design team, irrespective of software choices'. In its 2014 survey, NBS found that 45% of BIM-using respondents used IFC (an increase of 6% from the previous year). A detailed review of the history, development and current status of IFC is provided in Laakso and Kiviniemi (2012). Recognising the importance of IFC standards, the promoters of the many proprietary BIM software platforms aim to ensure that their products support them fully: in other words, are, through IFC, compatible with one another. The extent of this compatibility has been questioned (see, e.g. Lockley *et al.*, 2013), however, most products are undergoing continual improvement by their authors and are offered for testing and certification by buildingSMART, the organisation that champions the use of IFC. As a result, full support of IFC, and thus, interoperability is now a realistic prospect.

5.5.3 BIM as process In their 'BIM handbook' Eastman and his co-authors comment that, as well as being a 'technology' BIM has also come to represent an 'associated *set of processes* to produce, communicate and analyse building models' (Eastman *et al.*, 2011: p. 16: italics added for emphasis). Thus, in their foreword to the same work, the authors note that BIM adoption requires not just a change in technology but a 'process change' (Eastman *et al.*, 2011). It is precisely this aspect of BIM that accounts for its identification as a 'disruptive innovation'. . Reflecting this, the 2014 NBS National BIM Survey found that 92% of respondents who were BIM users agreed that 'adopting BIM requires changes in our workflow, practices and procedures' (National Building Specification, 2014: p. 21).

The extent of these changes depends on the extent to which BIM is adopted. A well-accepted measure of BIM adoption is provided by the 'BIM Maturity Diagram' developed by Mervyn Richards and Mark Bew in 2008, and subsequently adopted by the UK Government's BIM

Task Group (see http://www.bimtaskgroup.org/). Consequently, in the UK, the model has become an industry reference point for measuring levels of BIM maturity. A similar representation was produced by Succar (2009). In the Bew-Richards model, there are four maturity levels (from 0 to 3). Level 0 corresponds to Succar's 'Pre-BIM' stage (i.e. where designers work using manual methods or CAD). Bew-Richards' Level 1 sees the introduction of 3d modelling, though this is isolated (sometimes referred to as 'lonely BIM') with no collaboration between disciplines. This corresponds with Succar's 'BIM Stage 1: Object Modelling'. The essence of Level 2 in the Bew-Richards model is that there is some degree of model collaboration. Typically, this would involve 'federating' individual models to work in a 'common data environment'. In Succar's model this is described as 'BIM Stage 2: Model-based collaboration'. BIM Stage 3, In Succar's model, is 'network-based integration' and in the Bew-Richards scheme Level 3 represents the full collaboration of all disciplines in a single, shared project model.

5.5.4 Integrated project delivery

A feature of both the Bew-Richards and Succar (2009) representations is that increased BIM maturity is characterised by increasing collaboration: in order to exploit BIM technology to its utmost, requires a 'collaborative environment'. Succar explicitly has 'Integrated Project Delivery' as the 'longterm goal of BIM implementation'. The term *Integrated Project Delivery* (IPD) was coined in the construction industry of the United States, and, according to the American Institute of Architects (AIA) is 'a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimize efficiency through all phases of design, fabrication and construction.' (AIA California Council, 2007: p. 1).

5.5.5 Innovative approaches to project procurement strategies The AIA definition of IPD includes its descriptive elements but does not specify how it should be achieved or what form of project governance structure or procurement strategy might enable it. However the UK Government Cabinet Office has proposed three 'new models of procurement' that would best correspond to 'high levels of supply chain integration, innovation, and good working relationships between client and industry [and] will lead to a significant change in the costs and risks of construction projects' (Cabinet Office, 2014: p. 7).

5.5.5.1 Cost-led procurement

The basis of this, the most conventional of the three 'new models' is that two or three integrated framework supply teams develop their bids in competition. The successful proposal is then selected on affordability and quality criteria.

5.5.5.2 Two-stage open book

The aim of this approach is to enable the early engagement of the supply-side whilst deferring the commercial commitment of the client. In the first stage, contractor-consultant teams compete on the basis of a development fee and an appropriate set of qualitative elements. In the second stage, the successful team transparently develop the project proposal to the client's cost benchmark, with risks being addressed during Stage 2, but before commencement.

5.5.5.3 Integrated project insurance

In this, the most innovative of the three 'new models', there is an initial competition between integrated project teams, one of which is selected on criteria of qualitative elements and a 'fee declaration' and then develops an acceptable design solution. A single joint-names project insurance policy is executed to cover risks associated with delivery of the project; this includes

traditional construction-related insurances together with an element of cover for cost overrun. The latter may be subject to an 'excess' that is underwritten by a 'pain-share' agreement between the parties (client and delivery team). In the future, Level 3 BIM will 'raise significant legal, contractual and insurance issues' (Golden, 2015) that will undoubtedly have some impact upon procurement. Currently, however, new procurement approaches are not essential

for achieving Level 2 BIM on a project and traditional arrangements may suffice, providing that the parties collaborate sufficiently. However, to achieve Level 3 BIM, new procurement models would probably be needed.

5.5.6 Problems with collaboration The increased collaboration that is required for more effective BIM exploitation brings a variety of accompanying challenges. In terms of Level 1 ('lonely') BIM, where BIM users operate in isolation, these are few: BIM users can easily settle for a 'business as usual' attitude. But for Level 2 (model-based collaboration) to work to its best effect it is necessary to set rules, conventions and ways of working to cope with the individuality of the different participants. This comprises both technical and non-technical challenges. Technical issues revolve around data exchange and interoperability, as discussed earlier. But when BIM becomes collaborative there are also questions about *what* information is to be expected, *when*, *from whom*, *to whom*, and in *what form* or level of detail and information. Collectively known in the USA as levels of definition, the concepts of levels of detail and levels of information represent a recognised ascending order of development in models. Without guidance, there is the prospect of chaos, and, as Gu and London (2010) have recognised, the very problem for which BIM might offer a solution (i.e. the construction industry's fragmentation) would be a major factor in inhibiting its implementation.

Consequently, the UK Government, as an important industry client (and, as will be discussed later, a major influence in the uptake of BIM in the UK) has taken a lead in creating standardised solutions to some of these problems.

5.5.7 Documentary requirements for information

A number of standard protocols for BIM process have been developed in the United States, most notably the AIA's 'Digital Practice Documents' (AIA, 2012) and these were normally adapted to the specific needs of individual projects. It is from these that the central requirements for a BIM-enabled project were categorised. Some examples are listed below in order of their normal appearance in a project. For a more complete list, with fuller definitions the reader is referred to UK process standards such as PAS 1192-2:2013 (BSI, 2013) and PAS 1192-3:2014 (BSI, 2014). Also, note that the *NBS Digital Toolkit* (see later coverage of this) is a digital application that is designed specifically to address many of the requirements of these documents.

5.5.7.1 Employer's information requirements (EIR)

The EIR sets out, in terms of content and form, a client's requirements for the delivery of information by its project supply chain.

5.5.7.2 BIM execution plan (BEP) or project execution plan (PEP)

A BEP or PEP is prepared to demonstrate how the EIR will be delivered. It communicates to the client how the information modelling will be implemented and presented.

5.5.7.3 Master information delivery plan (MIDP) The MIDP is, according to the definition in PAS 1192-2:2013 (BSI, 2013) the 'primary plan for when project information is to be prepared, by whom and using what protocols and procedures, incorporating all relevant task information delivery plans'. The role of the MIDP is encompassed in such BIM management tools as the *Digital Toolkit* (see below).

5.5.7.4 Project information model (PIM)

The PIM is, according to PAS 1192-2:2013 (BSI, 2013) the information model 'developed during the design and construction phase' of a project, consisting of documentation, non-graphical information and graphical information defining the delivered project. For the purpose of managing, maintaining and operating the asset this is eventually superseded by the asset information model (AIM).

5.5.7.5 Common data environment (CDE)

A CDE, as defined by PAS 1192-2:2013 (BSI, 2013) is 'a single source of information … for multi-disciplinary teams in a managed process'. This requires the integration or federation of information from a variety of sources and in a variety of native software platforms. Most of the existing providers of file-sharing collaborative extranets are creating products to fulfil the same function with BIM databases, rather than files. Currently, there are other barriers to all project parties working in a CDE; these will be examined later.

5.5.8 Standardised process solutions

From 2011 onwards the UK Government has commissioned 'standardised solutions' for working digitally in the built environment. These take the form of eight components, in the form of official standards, implementation tools and guides that comprise the 'rules of engagement' for Level 2 BIM. These are available at, or *via* www.bimtaskgroup.org and are introduced in the following section.

5.5.8.1 PAS 1192-2:2013 (BSI, 2013) specification for information management for the capital / delivery phase of assets using building information modelling

This document builds upon the existing BS 1192:2007 (Collaborative production of architectural, engineering and construction information information) in order to specify what is required for delivering projects in Level 2 BIM. The PAS also describes how models evolve through increasing levels of development (in both graphical design detail and information content). The *level of model detail* is a description of graphical content of models at each of the stages from client's brief requirements and establishing site constraints to the stage where the model is equipped to facilitate the operation and maintenance of the asset. The *level of model information* is a description of non-graphical content of models at each of the stages.

5.5.8.2 PAS 1192-3:2014 (BSI, 2014) specification for information management for the operational phase of assets using building information modelling PAS 1192-3 extends the project information delivery cycle into extended to the operating phase of the built asset's life cycle. It specifies information requirements from the viewpoint of the operational phase of a constructed asset or group of assets. According to PAS 1192-3 itself, this includes 'data and geometry describing the asset(s) and the spaces and items associated with it, data about the performance of the asset(s), supporting information about the asset(s) such as specifications, operation and maintenance manuals, and health and safety information.'

5.5.8.3 BS 1192-4 collaborative production of information. Part 4: fulfilling employers information exchange requirements using COBie The existing British Standard – BS 1192:2007 (Collaborative production of architectural, engineering and construction information) has been revised (as BS1192-4:2014) to encompass the handling of information using COBie. COBie is a data schema presented in the form of a spreadsheet which serves as a standardised index of information about new and existing assets throughout their lifecycle. The format permits open exchange of the relevant data; thus users are able to access COBie files (and create them automatically from models) with little or no software investment cost or operating knowledge.

In the schema, data are classified spatially (into *Facility – Floor – Space – Zone*) and physically (into *Type – Component – System – Assembly – Connection*). In the case of a new facility, the COBie data file 'grows' as the project progresses, with a series of increasingly comprehensive *data drops* as the project advances through its stages. The file can be retained in its spreadsheet form or imported into decision-making tools such as an FM database.

5.5.8.4 PAS 1192-5:2015 (BSI, 2015) Specification for securityminded building information modelling, digital built environment and smart asset management

The document aims to provide stakeholders (particularly building and asset owners) with protocols and controls to ensure the appropriate security of their data whilst they are collaborating using digital information.

5.5.8.5 CIC BIM protocol and associated publications

The Protocol, produced by the Construction Industry Council is a document to supplement the contractual agreements of parties working in a BIM environment. It is expected that, in the longer term, construction contract drafting bodies will amend their documents to cater for projects at Level 2, and eventually Level 3 BIM. CIC has also produced a guide to explain how BIM relates to Professional Indemnity (PI) insurance, particularly applicable if the party insured is acting in an information management role. The scope of this role is described in the *Outline Scope of Services for the role of Information Management* which was also published by the CIC in 2013.

5.5.8.6 Government soft landings (GSL) GSL is a protocol that specifies the (gradual, where appropriate) handover of an asset (and related structured information) to enable owners and/or asset managers to make best use right from its handover. A more detailed description is available online at http://www.bimtaskgroup.org/gsl-summary/. The relationship between GSL and structured information underpins its association with BIM.

5.5.8.7 BIM toolkit and digital plan of work/digital toolkit

Following a project funded by Innovate UK, a consortium led by NBS has produced a digital framework that is able to be customised for individual projects or project types to provide a data delivery template. Set against the eight stages of the RIBA's revised Plan of Work (RIBA, 2013) the Toolkit gives the ability to specify and verify the delivery to the client of required levels of geometric and other data and documentation. As well as a specifier of information deliverables, it is seen as an enabler for collaboration between all stakeholders and at every stage. It defines and allocates responsibility and facilitates the verification of information delivery.

5.5.8.8 Unified BIM classification system

Standard classification systems are an essential component of information management and sharing data. By providing the taxonomy, or rules that govern a common language, they enable the search and retrieval of information, and its integration and aggregation. This is the very foundation of working in a common data environment. The current classification systems

that relate to construction (for example, Uniclass and NRM) have been developed at different times by different organisations and, therefore, do not entirely align. For the full implementation of Level 2 BIM this needs to be rectified and reflected in a comprehensive new classification system compliant with the revised ISO 12006 standard for Building construction – Organization of information about construction works.'

5.6 Barriers to BIM adoption

In an earlier part of the chapter, some of the non-technical (organisational) problems with operating collaboratively in Level 2 BIM were identified. Technical issues over data exchange and interoperability were also discussed earlier. As shown in the previous sections, guidance has been forthcoming and continues to emerge from government sources, professional bodies and

from solution providers, such as software developers. Some of the complex and unresolved legal and contractual challenges (including issues regarding insurance) to working in increasing levels of BIM are dealt with elsewhere in this book. Matters such as computer failure and data security will have increased importance. Finally, as shown in studies, such as those by van der Smagt (2000) and Dossick and Neff (2010) 'human factors' (such as leadership, capability, education, organisational culture, team working) play a leading part in the likely success of BIM-enabled construction operations.

5.7 Conclusions and prospects for the future

BIM has been in gestation for more than twenty years. Before 2000, and under other names, it was the province of researchers in the USA and Europe. After that, it began to take hold in the construction industry of the USA, and in the UK, following the government's 'construction strategy' and 'BIM mandate'. Such 'pushes to adoption' are now becoming more common around the world, as governments follow the example of the UK and other early adopters from the demand side of the industry. In terms of its advantages to the 'supply side', BIM has a variety of applications, exemplified by the 'dimensions' (from 3-D to n-D) by which the different applications are characterised.It is becoming clear that BIM is not simply 'new technology' but requires us to understand and respond to the effects that the technology will have on process and people

BUILDING INFORMATION MODELLING AND MANAGEMENT

In contrast with technology, these elements are often slow to change, and it remains to be seen how quickly, for how many, and to what extent BIM will become part of the normal way of working within the industry.

So much for the current goal: what has been called 'Level 2 BIM'. In terms of the 'near future' we have the prospect of Level 3 BIM. This aims at the use, on construction projects, of a fully collaborative single real-time model in which software interoperability, IT infrastructure, and contractual and legal obstacles have been resolved. In October 2014 a 'strategic plan' for Level 3 BIM, entitled 'Digital Built Britain' was published by the UK Government and previewed 'the next stage in the digital revolution … [in]…the way we plan, build, maintain and use our social and economic infrastructure'. The next steps are envisaged as the creation of new, international open data standards; new contractual frameworks for BIM-enabled projects; co-operative cultural environments; appropriate training in BIM techniques particularly for the public sector; domestic and international growth and jobs in technology and construction. The predicted technological adoptions that flow from this digital revolution will include *automated digital decisions* (i.e. those that do not require human input) and *predictive digital* (i.e. solutions that are automatically predicted based upon digital information).

In September 2014 the Construction Industry Council's BIM2050 produced a future-gazing report on 'Our Digital Future' (CIC BIM2050 Group, 2014). The following is a selection of their summarised findings that are most directly applicable to the present topic.

Cyber security: An interesting conflict is highlighted, namely that between the movement towards free and open information, connectivity and collaboration, on the one hand, and the need to secure that information; the current strategy for which is identified as 'to throttle access'. *Interoperability for smart cities*: Recognising the advent of 'intelligent infrastructure' in future smart cities, the Group highlights the need for organisations to 'review the interoperability of the products that their supply chain installs on to projects'.

Nano-second procurement and performance: Organisations are advised to 'accelerate their digitisation of business management and enterprise resource planning systems' to approach the reaction speeds that are currently in existence in the stock market.

Constructing in space: The future demands of 'extra-terrestrial construction' will necessitate ever more radical approaches in the industry.

Robotics and autonomous systems: A future that requires a minimum 'field population' of construction operatives but an increase in those managing 'people–plant interfaces in complex operations' would require organisations to 'consider automation and design for manufacture strategies as early as possible in the asset lifecycle'.

Demountable organisations: Overall, future business operations are predicted to show a 'shift from employers owning employees to entrepreneurs trading talent as a commodity'. It is appropriate to finish this chapter with an extract from the Executive Summary of the 'Digital Built Britain' publication. 'Building Information Modelling (BIM) is changing the UK construction industry – a vitally important sector that employs more than three million people and in 2010 delivered £107 billion to the UK economy. Over the next decade this technology will combine with the Internet of things (providing sensors and other information), advanced data analytics and the digital economy to enable us to plan new infrastructure more effectively, build it at lower cost and operate and maintain it more efficiently. Above all, it will enable citizens to make better use of the infrastructure we already have.' (H.M. Government, 2014: p. 5).

Notes

1 http://constructingexcellence.org.uk/bim/.

2 Building Research Establishment Environmental Assessment Methodology – a method of assessing, rating and certifying the sustainability of buildings, developed by the Building Research Establishment in the UK.

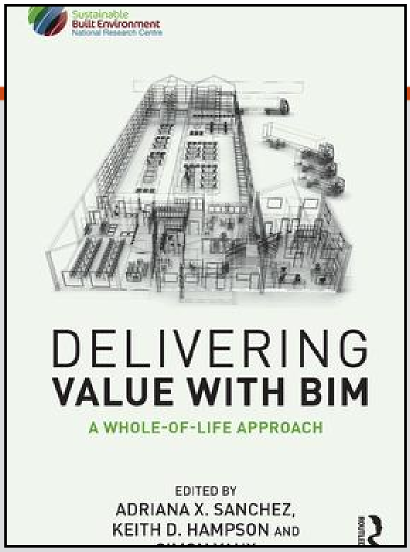
3 Leadership in Energy and Environmental Design (the US equivalent of BREEAM).

4 COBie stands for Construction Operations Building Information Exchange. The concept was developed by the US Corps of Engineers, but a UK version (COBie UK 2012) has been produced.

CHAPTER

2

BIM PERFORMANCE AND CAPABILITY



This chapter is excerpted from

Delivering Value with BIM

by Edited by Adriana X. Sanchez, Keith D. Hampson, Simon Vaux

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BIM PERFORMANCE AND CAPABILITY

Excerpted from *Delivering Value with BIM*

Starting point

A concept that is constantly evolving and adapting to new ways of usage within the architecture, engineering, construction and operations (AECO) industry is Building Information Modelling (BIM). BIM is defined in varied ways across literature; from being solely perceived as a software tool for visual information-sharing by project participants; to an elaborate methodology for integrating data-rich, object-based models across the whole project life-cycle (Succar, 2009). An elaboration of this definition has been provided in Chapter 1.

When using BIM software tools, data and information associated with an object upon its creation can be later referenced across several views or representations. When the source information is later altered, objects linked to the source are changed and are instantly visible. Through such interconnectedness, design problems and rework are greatly reduced thus saving time and money (Lee and Sexton, 2007). By adding time and cost attributes to 3D elements – referred to as 4D and 5D respectively – organisations can reduce resources needed and streamline project execution. In addition to 4D and 5D, there are other dimensions, that help extend the benefits of using BIM tools and methods. Also, multidimensional modelling or 'nD' provide avenues for including additional data (Jung and Joo, 2011) and can integrate several additional benefits such as using models to assess energy use, materials recycling and operations logistics. Using this multidimensional understanding, the term 'BIM' can be expanded to cover additional analysis areas (Lee and Sexton, 2007).

From a different perspective, BIM represents the future of integrating processes through model-based information sharing. As BIM software tools evolve, the boundaries of BIM will continuously expand and allow the creation of new applications and utilisations. However, in such a rapidly expanding technological environment, many questions arise including how best to measure the levels of BIM use and establish stakeholders' capability beyond the simple use of BIM software tools.

As technologies continuously evolve and authorities release more detailed BIM directives, the AECO industry thus faces significant challenges. These challenges are exacerbated by the absence of an agreed BIM framework for assessing and comparing basic BIM capabilities across organisations and measuring their respective BIM maturity. Developing such a framework is not a simple undertaking due to the wide range of construction industry stakeholders, their multitude of disciplines and specialties, and their varied perceptions of expected BIM benefits. To date, very little effort has been exerted to develop formal guides and tools that can be used to establish and compare organisational BIM capability and maturity.

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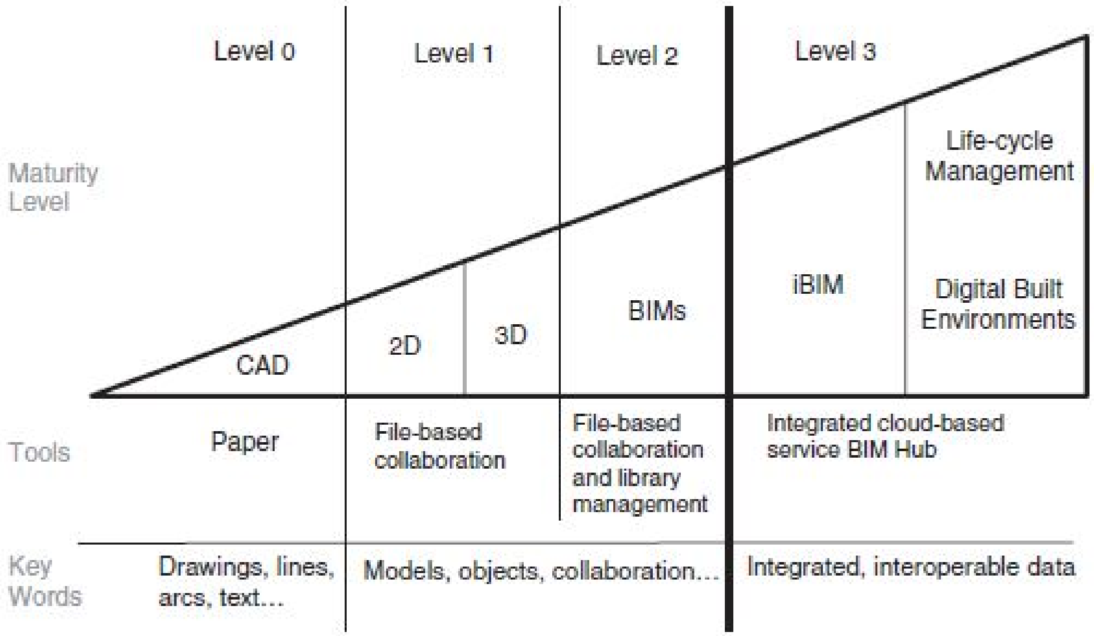
Requirements and drivers: authorities and procurement

National guidelines and incentives affect how performance and capability must be addressed. For example, by 2016, the European Union Public Procurement Directive (EUPPD) will require all 28 European Union (EU) member states to encourage, specify or mandate the use of BIM for publicly funded construction and building projects (Travaglini et al., 2014). While it remains to be seen how this directive will be enforced and followed up, the EUPPD signals how access to public funding will require higher efficiency in the form of better software tools, process transparency, information-sharing and data integration. Such directives also highlight the need for establishing common BIM performance criteria for the procurement of services. They also focus attention on the challenges facing organisations, private and public alike, as they implement BIM internally or participate in collaborative BIM projects.

This directive is not unique to the EU and, as discussed in previous chapters, has been preceded by the UK, the Netherlands and Nordic countries, which already require the use of BIM on publicly funded building projects. Since the 1980s, Nordic countries have been leading the world in information management research. Major research efforts are currently underway in Denmark (EU social funds), Norway and Finland (under the direction of public sector clients) responding to government initiatives to digitise construction processes. In the UK, the government developed a national BIM strategy for the AECO industry in partnership with the private sector and academia. The declared aim of the government is to enable the UK construction industry to become world leaders in BIM utilisation. As a first step, the government is currently mandating Level 2 as illustrated in Figure 3.1(Hooper, 2015).



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The application of BIM tools and workflows are not exclusive to buildings and infrastructure, but also applies across the larger urban setting. In this respect, Germany has been leading the development of standardised 3D city models (Kolbe, 2009), and the UK Ordnance Survey has been working on linking BIM models to their national survey map (Morin et al., 2014). In Sweden, the National Board of Housing, Building and Planning (Boverket) have also started to integrate geographical information systems (GIS) with the building permit process (Boverket, 2012).

In Hong Kong, the Housing Authority has required the use of BIM on all new projects since 2014. In South Korea, the Public Procurement Service currently requires the use of BIM on projects over SKW50 million, and on all public sector projects by 2016. Starting in 2010, Singapore developed an e-submission system that streamlines the building permissions process by requiring the submission of models for use by planning authorities (Wong and Fan, 2013).

Many authorities around the world are thus driving BIM implementation by encouraging industry stakeholders to investigate and/or adopt new technologies and processes, but even with such encouragements, many challenges remain. From the supply chain perspective, AECO organisations need to both manage their typical workloads and adhere to additional requirements for model generation and information management. From the authorities' perspective, policymakers need to identify how best to prescribe BIM use within tender documents and measure actual BIM use on projects. It is certainly not enough to mandate the adoption of certain software tools and workflows. That is, even if all companies across the supply chain adopted identical tools and workflows, clients/employers will still need clear metrics to identify and compare the BIM performance of different stakeholders.

To address supply chain BIM capability issues, it is important to acknowledge that organisations manage their performance, both internally and as part of a project team, in different ways. Some organisations opt not to adopt BIM software tools and workflows but prefer to implement workarounds to avoid the costs and challenges of adoption. These workarounds, according to Merschbrock and Figueres-Munoz (2015), reflect insufficient financial resources or inadequate know-how and may lead to messy information exchanges between project participants. Other organisations opt to develop their own workflows, protocols and standards in complete isolation from others. Such an approach is not only costly and time-consuming for these organisations, but signals their hesitance to openly share improvements and allow the spread of incompatible protocols across the industry. To improve performance across the AECO industry, stakeholders must understand the importance of adopting common BIM tools and workflows as well as sharing information and best practices.

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Organisational performance measurement

Organisational performance measurement refers, in this chapter, to measuring the effect of adopting BIM technologies and their respective processes on the performance of an organisation. While organisations within the construction industry vary greatly based on the type of business they conduct, it is important to apply unified, reliable and valid metrics that allow the measurement and comparison of their performance. Organisational performance measurement will also need to report on whether an organisation actually increases its overall productivity, delivers better outputs and meets or even surpasses its target performance improvement objectives. However, the term *performance* is relatively generic and is thus often replaced with *BIM capability* and *BIM maturity*.

As a term, *capability* describes what an organisation is able to do and what actions it can take based on its organisational competence. It combines the aspects of knowing what to do with the ability to do it. In other words, capability measurements identify what an organisation can deliver in comparison to what is specified or expected, and reflect its dynamic ability to rethink existing know-how and develop new solutions.

In the information technology (IT) sector, the development of the Capability Maturity Model (CMM) has spawned a number of similar models applied in varied industries including manufacturing, healthcare and construction (Curtis et al., 2002, 2009). As a performance measurement approach, CMM was originally developed to identify the strengths, weaknesses and risks of software projects (Paulk et al., 1993). Later model adaptations were intended to assess infrastructure projects yet proved less able to address the specific challenges of the construction industry (Jia et al., 2011).

In addition to *capability*, the term *maturity* is often used to describe how well an organisation or its members can manage their processes and tools (Andersen and Jessen, 2003; Yazici, 2009). In more general terms, maturity identifies the performance criteria to be fulfilled by assigning a maturity level or milestone that best describes the utilisation of available knowledge, best practices and innovative techniques within a business or across the whole market. There are multiple approaches to maturity measurement, including those that yield a formal certificate. For example, in the field of project management, there are a number of specialised entities that offer to certify project managers according to well-defined and commonly used guidelines. The Project Management Institute (PMI) and the International Project Management Association (IPMA) are two such global organisations providing certification and delivering courses through a network of national associations (IPMA, 2015; PMI, 2015).

Nonetheless, there are a number of ongoing efforts to measure how construction organisations perform. With increasing demands for construction efficiency and the availability of more detailed procurement protocols, the development of metrics to establish and compare organisational performance is now needed. As mentioned earlier, the development of the EUPPD will necessarily exert transformational pressures on the industry to develop such metrics, and may well drive the generation of common guidelines for assessing and improving organisational performance within and beyond the EU.

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BIM performance frameworks

There is an increasing number of frameworks that can be referred to as BIM performance frameworks. These include the Interactive Capability Maturity Model (I-CMM, 2009); BIM Proficiency Matrix (Indiana University, 2009); BIM Maturity Levels (Bew and Richards model, see BIM Industry Working Group, 2011); BIM QuickScan (Sebastian and Berlo, 2010); BIM Maturity Matrix (Succar, 2010a); Vico BIM Score (Vico, 2011); CPIx-BIM Assessment Form (CPI, 2011); BIM Excellence (BIMe, 2013); bimSCORE (2013); BIM Planning Guide for Facility Owners (CIC, 2013); and BIM Competency Assessment Tool (Giel and Issa, 2015). A short description of each is provided as follows:

Interactive Capability Maturity Model

This Interactive Capability Maturity Model (I-CMM) is part of the United States National Building Information Modeling Standard (NBIMS). I-CMM was first published in 2007, slightly modified in 2009 and released as v1.9. However, it has not been updated since then. The I-CMM establishes the maturity of the model/project by assessing 11 topics against ten maturity levels. Using either a static table or an interactive Excel tool, I-CMM generates a single maturity score. This is intended to help 'determine the level of maturity of an individual BIM as measured against a set of weighted criteria agreed to be desirable in a Building Information Model' (NIST, 2007, 2015; NIBS, 2007; Suermann et al., 2008).

BIM proficiency matrix In 2009, Indiana University developed an interactive Excel matrix to assist their own internal team and other facility owners to pre-qualify the supply chain. The matrix includes eight categories measured against four maturity levels that, upon completion, generates a single BIM Maturity Score (Indiana University, 2009). The matrix is completed by candidate project team members who must provide examples of past projects and address each of the eight BIM proficiency categories.

BIM maturity levels

The iBIM model or the 'Wedge' BIM maturity model (Figure 3.1) was developed by Mark Bew, chairman of the HM Government BIM Working Group; and Mervyn Richards OBE, member of the building SMART UK managing board (BIM Industry Working Group, 2011; building SMART UK, 2015; BIM Task Group, 2015). In its current form, the model reflects both the UK government's BIM strategy and many of the industry's ongoing BIM initiatives. The model identifies different levels of market maturity by grouping standards and working methods into three initial BIM levels. Based on this model, in 2011 the UK government's BIM Task Group mandated that all publicly-procured construction projects are to meet Level 2 requirements by 2016 (Hooper, 2015). While the terminology, standards and methods linked to the 'Wedge' model are mostly UK-specific, it has been used as a guiding framework for BIM policy development by other policymakers in a number of countries.

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BIM QuickScan

BIM QuickScan is an online tool developed by the Netherlands Organisation for Applied Scientific Research (TNO). BIM QuickScan is intended to assess the BIM performance of organisations in the Netherlands and generate a performance benchmark. The assessment is conducted against four chapters (categories) and multiple key performance indicators, and is available in two versions: a free *self-scan*, and a more detailed commercial service delivered by a BIM consultant (Sebastian and Berlo, 2010; Van Berlo et al., 2012).

BIM Maturity Matrix

Developed as part of a larger BIM Framework (Succar, 2009), the BIM Maturity Matrix is a static self-assessment tool with ten capability sets, three capability stages and five maturity levels. According to Succar (2010a; 2010b), the matrix is intended for assessing the BIM capability and BIM maturity of organisations; where BIM capability refers to minimum ability, and BIM maturity refers to the quality, repeatability and predictability of these abilities.

Vico BIM score

In 2011, the BIM software tool vendor Vico developed its own scorecard directed towards construction managers. With a focus on clash detection, scheduling and estimating, the declared aim of the tool is to assist organisations to compare their performance against their competitors. Each of these areas is graded based on functionality and capability, best practices and enterprise integration (Vico, 2011).

CPIx-BIM Assessment Form

The CPIx-BIM Assessment Form is a static questionnaire developed by the Construction Project Information Committee in the UK. The questionnaire includes 12 areas grouped under four categories and is 'based on working documentation provided by Skanska' (CPI, 2011).

BIM Excellence

BIM Excellence (BIMe) is a commercial online platform for performance assessment. It is based on the published research of Succar (2010a; 2010b) and Succar et al. (2013). BIMe includes multiple modules for assessing the performance of individuals, organisations, projects and teams. The basic free assessment generates a simple downloadable report, while the more detailed assessments generate competency profiles for comparison against project requirements, pre-qualification criteria and role definitions (BIMe, 2013).

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bimSCORE

bimSCORE is a commercial tool based on the VDC Scorecard, the research effort conducted by Kam et al. (2014) at Stanford's Center for Integrated Facility Engineering (CIFE). bimSCORE evaluates BIM practices across ten dimensions, grouped under four areas. The scorecard, which also has a free online version, evaluates the maturity of virtual design and construction practices on construction projects. It does this by comparing the performance of new projects against past projects and industry benchmarks (bim- SCORE, 2013; CIFE, 2013).

BIM Planning Guide for Facility Owners

The BIM Planning Guide for Facility Owners is a maturity matrix developed by the Computer Integrated Construction (CIC) Research Program at Pennsylvania State University. The Excel matrix is divided into six categories, five maturity levels and is intended for owners to rate their own organisation (CIC, 2013).

BIM Competency Assessment Tool The BIM Competency Assessment Tool (BIMCAT) is based on research reported by Giel (2015). BIMCAT is targeted towards facility owners and includes 12 competency categories and 66 factors measured against six maturity levels. The assessment is intended to be self-administered by a manager using an interactive offline questionnaire. Upon completing the assessment, the tool generates a single maturity score as well as a number of radar charts. For a more comprehensive comparison between these frameworks, please refer to Giel (2013), Azzouz et al. (2015) and NIST (2015).

The way forward

These frameworks for measuring performance are still evolving and are applied differently across the market. In some countries, governments drive the adoption of BIM, while in other countries industry groups take the lead. While the frameworks presented by Succar and Bew/Richards are among the most ambitious, the methods necessary to measure BIM capability and maturity in more depth still require additional development. If maturity is monitored through a framework such as the iBIM model, it can possibly document a historic process and describe to the outside world which steps the construction sector or company has taken. Industry organisations can position themselves according to what systems they use. Unfortunately, this does not say anything about what they are capable of doing, placing the definition of capability in the limelight. If it is used to describe an organisation's capability to deliver specific outcomes, it will then relate to the ability to deliver projects according to pre-set specification. If it is viewed in a more dynamic way, it would then inform how an organisation adapts and changes with the use of information-sharing through BIM. This is reflected in Succar's capability stages and maturity levels, which allow the assessment of organisational processes and business models.

However, such qualitative indicators may not be sufficient and provide an opportunity to develop quantitative metrics for establishing an organisation's BIM competence in a detailed and measurable way.

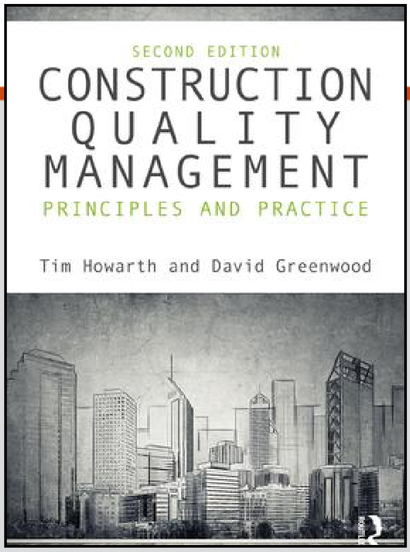
Conclusion

While the effect of national BIM mandates is still to be seen, they will certainly challenge clients to be more diligent in identifying their BIM requirements during the procurement process. By clearly identifying their requirements, they would encourage industry actors to adopt technological solutions and develop innovative ways to fulfil these requirements. As innovation diffuses across the market, the need to assess and compare performance levels becomes paramount. This is where authorities and industry actors need to collaborate to adopt, adapt or develop a common BIM performance framework. This is also where they will need to join forces to communicate the benefits of performance assessment across the construction industry.

CHAPTER

3

BIM AS A QUALITY SYSTEM



This chapter is excerpted from

Construction Quality Management

by Tim Howarth, David Greenwood.

Learn more

BIM AS A QUALITY SYSTEM

Excerpted from *Construction Quality Management*

Introduction

Building Information Modelling (BIM) is arguably the hottest topic in the field of Construction Management and attracts not only interest, but also controversy. Is it primarily a technology or a process? Does it just apply to building? And what does the 'M' stand for: 'modelling' or 'management'? In fact, given that BIM applies to assets other than buildings, should it be called BIM at all? Here, and for the particular purposes of this book, BIM is treated as a technology-enabled quality system for improving the competitiveness of all organisations operating within the extended construction and property sectors that relates to the whole life of all built assets. The aim of the current chapter is to consider BIM as a quality system and discuss its current state of development in the UK, always bearing in mind the fact that we are dealing with a rapidly moving phenomenon, and one that is global.

Learning outcomes

By the end of this chapter, the reader will be able to demonstrate understanding of:

- The background and key concepts of BIM and its aspects and applications
- The concept of BIM as a process and, in particular, as a quality system
- The advantages and key 'drivers' of BIM adoption
- The barriers to BIM adoption and challenges that need to be overcome
- The ongoing development and future direction of BIM

Background to BIM

Definitions and concepts

Competing definitions of BIM There are many definitions of BIM and explanations of what it represents. One of the first uses of the term 'building information model' was in a journal article by Van Nederveen and Tolman (1992), and an early appearance of 'building information modeling' came in a Building Industry Solutions White Paper produced by the software company Autodesk (2002).

BIM AS A QUALITY SYSTEM

Excerpted from *Construction Quality Management*

A definition from the (United States) National Institute of Building Sciences (2007) states: Building Information Modelling (BIM) is a digital representation of physical and functional characteristics of a facility. This definition is not ideal: it is actually describing the *model* itself, rather than the process of *modelling*, and in this book we are very much concerned with BIM as a process. However, it does contain two important details. First, a recognition that BIM is not only about 3D geometry but includes 'functional characteristics ' (sometimes referred to as 'non-geometric information'); and secondly that the information relates to any 'facility'; not just buildings. In terms of BIM as a process, the latest definition from National Building Specification that BIM is "a process for creating and managing information on a construction project across the project life cycle" (NBS 2016) carries too much of an implication that BIM is for new projects. It isn't: there is massive potential for incorporating BIM into the management of existing built assets as well as using it to create them. This growing awareness of what BIM can or could mean has caused some to question the applicability of the term *Building Information Modelling.* Variants such as *Building Information Management*, *Virtual Design and Construction* and *Digital Design and Construction* have appeared, but only the first avoids the notion that BIM stops once a facility is constructed. Although it is arguable that BIM (taken literally as *Building Information Modelling*) is far from ideal, the fact remains that it is now commonly accepted and all-pervasive. Of course, outside the English-speaking world, this simply doesn't matter. The expression 'BIM' can embrace all of these meanings without any need for justification (see *Figure 7.1* for an example).

What is involved in BIM?

Having emphasised the idea of BIM as a process, and settled upon the word 'BIM' as it stands, the next step is to go deeper into what exactly is involved. We will do that by looking at the elements of the name itself.

B is for 'building' The use of digital technology to support industrial processes did not originate in the Building Industry; other industries, such as Aerospace and Automotive, were earlier adopters. Neither is the potential of BIM limited to creating the assets we call 'buildings', or the sector we call 'Building'. As noted in New Civil Engineer 'the core principles and workflows associated with BIM apply equally to all infrastructure projects' (Corke 2012) and the increasing number of BIM interest groups (representing, for example, clients, retailers, water engineers, health providers, facilities managers and city planners) demonstrates the pervasive nature of BIM.

BIM AS A QUALITY SYSTEM

Excerpted from *Construction Quality Management*

I is for 'information'

BIM is about the "sharing, analysis and re-use of information" (RICS 2013) and to access information we need to make sense of data. In the case of BIM the data are held digitally in the database (or set of databases) that is the model. As mentioned earlier, the data (and the information that it represents) can be geometric (for example, the dimensions of a window) and non-geometric (e.g. the materials, manufacturer or model number of the window). The information sources from which model data are derived as inputs and the information uses to which the model data can be put, as outputs, are numerous.

FIGURE 7.1 BIM is global

M is for 'modelling, or management'

Once again, this is a rather restrictive term. It emphasises the creation of the model, rather than its use, which is the whole point of its existence. Consequently many people prefer the word 'management' rather than 'modelling'.

BIM AS A QUALITY SYSTEM

Drivers for BIM adoption – 'pull' and 'push'

Innovations are adopted in a variety of ways and for a variety of reasons. There are inevitable barriers, and for new ways of working to be adopted, these must be overcome. In economic theory, an innovation might be adopted because of a push by the supply side (i.e. the industry itself) or a pull from the demand side. The UK 'BIM Strategy Report' to the UK Government (BIM Working Party 2011) recommended a combination of both approaches. *The government 'pull'* Within the 'Construction Strategy' published by the UK Government (Cabinet Office 2011) was a requirement for 'collaborative 3D BIM' by 2016. The two key objectives were "cost reduction in the construction and operation of the built environment" and the "implementation of . . . policy in relation to sustainability and carbon". As the public sector in the UK represents a significant portion of construction demand, this 'BIM mandate' could not be ignored by the industry.

The 'push' from the supply side

The criteria for an effective push by the supply side are a business case for adoption and the prospect of a return on investment (ROI). The earliest indications of BIM ROI are from the USA, where Holness (2006), for example, reports savings on construction costs of between 15 percent and 40 percent. In a survey of over 1,000 industry participants in 2012, McGraw-Hill indicated that "63% of BIM users are experiencing a positive perceived ROI on their overall investment in BIM . . . with the most common range being between 10 and 25%" (McGraw-Hill 2012: p. 39). Evidence from the UK is still relatively scarce but suggests that experienced users derive an increased ROI: a realistic suggestion being that BIM adoption may show an initial productivity loss, followed by expected gains later.

The results to date

The Government's 'BIM edict' has produced an enormous interest in BIM in the UK, as illustrated by the annual (since 2011) NBS National BIM Reports (2011– 2016). In NBS's 2011 survey (National Building Specification 2011) 43 percent of respondents were unaware of BIM, and this has reduced to 4 percent in the 2016 survey. There was a corresponding increase in those "aware of and using BIM": 13 percent in the 2011 survey, to 54 percent in the 2016 report (National Building Specification 2016).

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Excerpted from *Construction Quality Management*

BIM applications and uses

From its initial use as a 3D enhanced design tool, BIM has extended into a wide range of applications through the project life cycle, some of which have attracted the use of the word 'dimension' as a descriptor: for example '4D BIM' involves linking the 3D model with a time schedule. The following is a reasonably full (though not exhaustive) list of how BIM-based applications can enhance the operations involved in the design, construction and management of built assets.

3D Design and visualization

The earliest application of BIM was in design – architectural, structural and engineering. The design process – iterative in its nature – is made more efficient by the ability to re-use BIM information. Links are available to Structural and Environmental Analysis software, and visualised renderings can be produced for clients and other stakeholders. Because different aspects of design can be integrated within the model, so-called design clashes can be identified and resolved at an early stage, reducing the need for more costly changes on site.

Off-site fabrication

The digital nature of the design data permits the transmission of designs into the automated software-to-manufacturing systems used by some component manufacturers (e.g. structural steel, precast concrete, ductwork), thereby increasing the potential for more efficient off-site manufacture. Referred to as Design for Manufacture and Assembly (DFMA), this brings the benefits of factory production to construction projects, with potential from improvements in health and safety, productivity and the reduction of waste.

Construction planning (4D BIM) '4D BIM' involves linking a time schedule to a 3D model to improve the time planning and control of construction activities. Schedules can be generated by interrogating the design model(s) to identify activities, calculate durations (using automated quantity extraction), impose assembly and installation logic, schedule resource requirements and visualise construction through animations of the process.

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Commercial management (5D BIM)

'5D BIM' caters for estimating, cost management and procurement. This includes 'time-cost-value' analysis techniques such as Earned Value Management (see e.g. Barlish and Sullivan 2012: p. 153). Work is also under way to integrate BIM applications with enterprise resource planning (ERP) systems at the business level of the organisation (see e.g. Babič et al. 2010) to inform their sales, purchasing and logistics functions.

Sustainability (6D BIM)

BIM for Sustainability ('6D BIM') allows information such as energy use, resource efficiency and other aspects of sustainability to be better analysed, managed and understood (see e.g. Hamza and Horne 2007; Azhar and Brown 2009; Nour et al. 2012). The BIM model can accommodate information such as embodied carbon, including that created by the process of construction.

Facilities management (7D BIM)

7D BIM tackles the management of facilities or assets. An 'asset tagged' BIM model, delivered to the client or end-user on completion can be populated with appropriate component and product information, operation manuals, warranty data and so on. Information based on BIM can thus be re-used for driving efficiencies in the management, renovation, space planning and maintenance of facilities. This potential applies not just to the handover of new built assets but to the retrospective modelling of existing ones through point cloud capture using laser scanning (see Volk et al. 2014).

Aspects of BIM: technology, process and people

A common approach to examining any production system (including the impact of innovation on it) is through the three aspects of *technology, process* and *people*. Most discussion is over what happens when one of the three intervenes to cause a change in the relationship between the other two (e.g. the impact of a new *technology* on *people* and *process*). Furthermore, as US architect John Tobin observed, BIM was initially used as "a sustaining technology"; as a 3D tool that uses models to produce construction designs more efficiently: it has moved on to be a "disruptive technology", one that invites the

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re-imagining of the whole process, allowing us to "change markets and expectations" (Tobin 2013). The main focus of this chapter is on BIM as a process, but the other aspects require a few words before considering this in detail.

BIM as technology

BIM is supported by a variety of software platforms, usually proprietary and sold commercially. Eastman's original *BIM Handbook* (2008) lists over 70 different software companies with hundreds of different software packages. These have been developed to suit the functional needs of their target users (architects, structural engineers, services engineers, constructors . . .) and thus differ structurally and semantically (see Lockley et al. 2013). In the 2014 NBS National BIM Report, 25 percent of BIM users reported that "information models only work in the software they were made on" (NBS 2014: p. 14). This is referred to as an issue of 'interoperability'. It is a limiting factor in achieving fully collaborative BIM, and various organisations, including the International Organization for Standardization (ISO), have worked to improve the reliable exchange of data between 'native' software platforms. The result is an intermediary format called *Industry Foundation Classes* (IFC). The latest version, IFC4, is registered as ISO 16739:2013. Recognising the importance of IFC standards, most producers of BIM software platforms now aim to ensure that their products support them fully and are, through IFC, compatible with one another.

BIM and people

For any innovation to be successful, people must be willing to adopt it, and in many cases this requires a commitment to acquiring new skills and knowledge. Evidence from the 2016 National BIM Report shows that although 27 percent of those yet to adopt BIM would 'rather not', most industry professionals are positive towards BIM, with only 6 percent of those who have adopted BIM saying that they wished they hadn't (NBS 2016: p. 37).

BIM as a process

In the foreword to their *BIM Handbook*, Eastman and his co-authors note that BIM adoption requires not just a change in technology but a 'process change' (Eastman et al. 2011). Reflecting this, the 2016 NBS National BIM Report shows that 92 percent of BIM users agreed that "adopting BIM requires changes in our workflow, practices and procedures" (National Building Specification 2016: p. 37). It is precisely this aspect of BIM that accounts for its identification as a 'disruptive innovation', and we will explore what this means in the following sections.

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Collaborative production and use of information

The UK Government's 'BIM mandate' was for 'collaborative 3D BIM'. In other words, to exploit the full potential of BIM, collaboration is required. An earlier drive towards collaborative design was exemplified in the British Standards Institute's 'Code of Practice for Collaborative Production of Architectural, Engineering and Construction Information' (BS 1192:2007) but in the BIM era this collaboration has been extended beyond the production of information to its *use*. A key component is the concept of a Common Data Environment (CDE) – "a single source of information . . . for multi-disciplinary teams in a managed process" (BSI 2013). CDEs are not limited to digital data, but most of the providers of fi le-sharing project extranets offer products that fulfil the function with BIM databases, rather than files.

Innovative approaches to project procurement

It could be argued that traditional approaches to the way projects are procured compromise the ability to collaborate right from the start. The American Institute of Architects (AIA) have advocated a project delivery approach called 'Integrated Project Delivery' (IPD) that "integrates people, systems, business structures and practices into a [collaborative] process . . . through all phases of design, fabrication and construction" (AIA California Council 2007).

In an initiative that runs parallel to its commitment to BIM, the UK Government Cabinet Office has proposed three 'new models of procurement' that would best correspond to "high levels of supply chain integration, innovation, and good working relationships" (Cabinet Office 2014: p. 7). These are: *Cost-led procurement*: The most conventional of the three 'new models' in which an 'integrated framework supply team' is selected from up to three competing bids, based on affordability and quality criteria. *Two-stage open book*: A first stage, in which contractor-consultant teams compete on the basis of a development fee and qualitative elements is followed by a second, where the successful team openly develop the project proposal to the client's cost benchmark.

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Integrated Project Insurance: Following competition based upon qualitative criteria and a 'fee declaration', an integrated project team is selected to develop an acceptable design solution and a single joint-names project insurance policy is executed to cover all risks associated with delivery of the project.

BIM procedures and protocols

The increased collaboration that is required for more effective BIM exploitation brings a variety of accompanying challenges. For projects to achieve 'Level 2 1 BIM' (i.e. meet the requirements of the UK Government BIM mandate) it is necessary to set rules, conventions and ways of working to cope with the individuality of the different project participants. There are technical issues around data exchange and interoperability, as discussed earlier. But when BIM becomes collaborative, there are also questions, up and down the project supply chain, as to *what* information is to be expected *when*, *from whom*, *to whom* and in *what form* or level of development. Without some form of standardisation, there would be the prospect of chaos, and the UK Government has taken a lead in creating standardised solutions to some of these questions. Earlier, a number of standard protocols for the BIM process had been developed in the United States, most notably the AIA's 'Digital Practice Documents' (AIA 2007), and in these the key requirements for a BIM-enabled project were identified. These include:

• *Employer's Information Requirements (EIR)*, which sets out a client's requirements for the delivery of information by its project supply chain.

• *BIM Execution Plan (BEP)* or *Project Execution Plan* (*PEP*), which demonstrate how the EIR will be delivered and which can contain a *Master Information Delivery Plan* (MIDP) to indicate when project information is to be produced, by whom and how.

• The *Project Information Model (PIM)*, consisting of all the documentation, nongraphical and graphical information that defines the delivered project and which (for the purpose of managing, maintaining and operating the asset) is eventually superseded by the *Asset Information Model* (AIM).

• A *Common Data Environment (CDE)* that, amongst other things, will contain all of the above.

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Standardised process solutions and systems

Since 2011 the UK Government has commissioned 'standardised solutions' for working in BIM. Currently, these take the form of nine components – official standards, implementation tools and guides that comprise the 'rules of engagement' for Level 2 BIM. Some are designated as 'British Standard' (BS) whilst others are named 'Publicly Available Specification' (PAS 2). They are:

• *PAS 1192 – 2:2013 (BSI 2013) Specification for information management for the capital/delivery phase of assets using building information modelling*: This document builds upon the existing BS 1192:2007 (see above) by specifying what is required for delivering projects in Level 2 BIM and describes how models evolve through increasing levels of development.

• *PAS 1192 – 3:2014 (BSI 2014) Specification for information management for the operational phase of assets using building information modelling*: PAS 1192–3 extends the project information delivery cycle into the operating phase of the built asset's life cycle. It specifies information requirements from the viewpoint of the operational phase of a constructed asset or group of assets.

• *BS 1192 – 4 Collaborative production of information. Part 4: Fulfilling employers' information exchange requirements using COBie* : This represents a revision of BS 1192:2007 to encompass the handling of information using COBie. COBie is a data schema presented in the form of a spreadsheet which serves as a standardised index of information about new and existing assets throughout their life cycle.

• *PAS 1192 – 5:2015 (BSI 2015) Specification for security-minded building information modelling, digital built environment and smart asset management*: The document provides stakeholders with protocols and controls to ensure the security of their data whilst they are collaborating digitally.

• *PAS 1192 – 6:2015 (draft) Specification for collaborative sharing and use of structured hazard and risk information for health and safety*: The aim of this draft PAS is to specify the H&S requirements that should be 'embedded into all BIM projects' at their outset. • *CIC BIM Protocol (CIC 2013)*: This is a document, for projects in a BIM environment, to supplement the standard forms of contract that parties use.

• *Government Soft Landings (GSL)*: GSL is a protocol that specifies the handover of an asset (with its information) to assist owners and their asset managers.

• *BIM Toolkit and Digital Plan of Work/Digital Toolkit*: This a customisable digital delivery template for project information. Set against the eight stages of the RIBA's Plan of Work (RIBA 2013) it allows users to specify and verify the delivery of geometric and other data and documentation to the client of required levels of development. It defines and allocates responsibilities for this and assists in verification of information delivery.

• *Unified BIM Classification System*: Standard classification systems are an essential part of information management and data sharing, as they provide the logic to enable the search for and retrieval of information, and its integration and aggregation.

BIM prospects, barriers and future

The current state of BIM adoption and the immediate future

The 2016 'deadline' set by the UK Government has now passed. The most recent available information on how the industry has responded is to be found in NBS's 6th annual BIM Report (NBS 2016). It reveals that a majority (54 percent) of the 1,000+ construction industry professionals who responded are 'aware of and using BIM' on some of their projects and 86 percent expect to be doing so by 1 year's time. Just under half (49 percent) feel 'confident of their BIM knowledge and skills'. Of those, 70 percent use BIM (they produce 3D models) and of these, 56 percent have shared models with external designers and 45 percent with parties across different disciplines. Most use of BIM appears to be still restricted to the design stages (only 37 percent use models from the start to end of a project) and only 16 percent pass on a model to FM). Almost all (90 percent) respondents feel that BIM requires (or would require, in the case of non-adopters) changes in their workflow. In terms of the influence of BIM on the 2011 Government Construction Strategy targets: 63 percent believe a 33 percent reduction in cost is possible; 57 percent a 50 percent reduction in time; 39 percent a 50 percent reduction in BE greenhouse gas emissions; less than 1/3rd that BIM will help create a trade gap reduction.

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Barriers and challenges

In an earlier part of the chapter, some of the problems with operating collaboratively in BIM were identified. As shown in the previous sections, guidance has been forthcoming and continues to emerge from government sources, professional bodies from software developers. Matters such as computer failure and data security will have increased importance. Finally, as shown in studies, such as those by van der Smagt (2000) and Dossick and Neff (2010), 'human factors' (such as leadership, capability, education, organisational culture, teamworking) play a leading part in the likely success of BIM-enabled construction operations.

The future of BIM

A strategy for the future of BIM entitled 'Digital Built Britain' was published in October 2014. It previews the extension of the digital revolution to the "the way we plan, build, maintain and use our social and economic infrastructure". The predicted technological adoptions that fl ow from this digital revolution will include *predictive digital decisions*; i.e. solutions based upon digital information which in some cases can be automated, that is, require no human intervention. A month earlier, the 'BIM2050 Group' produced its own report on 'Our Digital Future' (CIC BIM2050 Group 2014). The summarised findings include:

• *Cyber Security*: the conflict between free and open information, connectivity and collaboration, on the one hand, and the need for information security;

• *Interoperability for Smart Cities*: which recognises the advent of 'intelligent infrastructure'

in future smart cities; and • *Nano-second Procurement and Performance*: the ability of more businesses to approach the reaction speeds that are currently in existence in the stock market through digitisation of their business management and enterprise resource planning systems.

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Excerpted from *Construction Quality Management*

Summary

It is appropriate to finish this chapter with an extract from the Executive Summary of the 'Digital Built Britain' publication. Building Information Modelling (BIM) is changing the UK construction industry – a vitally important sector that employs more than three million people and in 2010 delivered £107 billion to the UK economy. Over the next decade this technology will combine with the internet of things (providing sensors and other information), advanced data analytics and the digital economy to enable us to plan new infrastructure more effectively, build it at lower cost and operate and maintain it more efficiently. Above all, it will enable citizens to make better use of the infrastructure we already have. *(H.M. Government 2014: p. 5)*

Questions for the reader

Here follows a number of questions related specifically to the information presented within this chapter. Try to attempt each question without reference to the chapter in order to assess how much you have learned. The answers are provided at the end of the book.

Question 1

What are '5D' and '6D' BIM?

Question 2

The key requirements for a BIM-enabled project have been identified as including?

Question 3

What is COBie?

Question 4

The UK Government Cabinet Office has proposed three 'new models of procurement' that would best correspond to 'high levels of supply chain integration, innovation, and good working relationships'. Identify these three 'new models of procurement'.

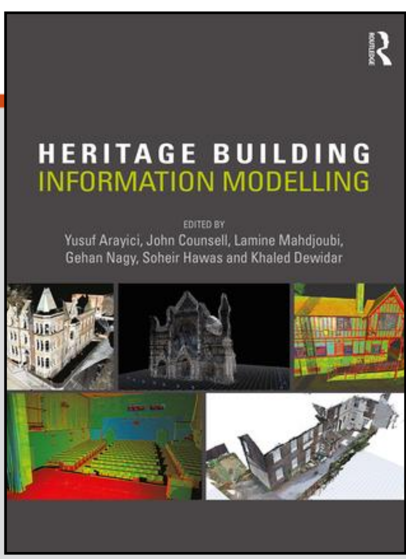
Notes

1 A fuller description of the different levels of BIM maturity is provided in Chapter 8.

CHAPTER

4

WHAT ARE THE GOALS OF HBIM?



This chapter is excerpted from

Heritage Building Information Modelling

Edited by Yusuf Arayici, John Counsell, Lamine Mahdjoubi, Gehan Ahmed Nagy, Soheir Hawas, Khaled Dweidar.

WHAT ARE THE GOALS OF HBIM?

Excerpted from *Heritage Building Information Modelling*

3.1 Introduction

This chapter outlines some of the challenges in defining HBIM, with the limited recent progress that has been made, while clearly outlining challenges yet to come. Some of the gaps between 'parametric parts library based' commercial BIM and HBIM are discussed. It outlines geospatial information and decision making, and the strengthening relationships between GIS and BIM in the context of heritage buildings, cultural landscapes and virtual and intangible heritage. The chapter starts by indicating the 'demand' for HBIM; proceeds to outline the 'cutting edge' of current practice and challenges still to be met; and ends by analysing some supporting case studies.

3.2 An 'information resource for future generations'

There are few if any current published case studies of sophisticated, well-defined HBIMs. The Sydney Opera House is one of a few emergent case studies. Chris Linning (2014), the Sydney Opera House manager for Building Information, has recently been presenting his view of the Sydney Opera House (SOH) goal of ensuring the effective sustainable conservation and management of the heritage complex for a projected further lifespan of 250 to 300 years. He titles his presentation 'BIM – An Information Resource for Future Generations'. This seems an excellent overarching goal for HBIM – 'an information resource for future generations'. With Schevers et al. (2007), Linning defined the need for an evolutionary approach to establishing a fully formed 'Digital Facility Information Management System'. "Introducing a full scale Facility Management System is hardly feasible or desirable. A more evolving approach is necessary where the digital facility model evolves from a relatively simple information system to a more integrated and knowledge intensive system." As with the goals of the more conventional new construction focused BIMs, they also see the need for the resulting information model to act as a 'single source of truth'. "Ideally, the digital facility model should be the integrated data source for all information systems at SOH. This means that when one information system processes or changes some data, all other systems are aware of that change, eliminating information redundancy." They further point out that "an integrated information model opens up the way for more automated intelligence in the model incorporating rules and best practices."

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From that definition of scope and ambition, the SOH surveyed available software and systems (via several partial trial iterations of BIMs from various consultant organisations, together with a recent point cloud survey by the 'Scottish Ten' [2013]). They concluded (McTaggart 2015) that "there was no single BIM solution that could be applied to both development and construction projects as well as ongoing facilities management of the Opera House." SOH has since tendered for a bespoke solution, and consultants are now working on the phased delivery of modules within a framework (Knutt 2015).

3.3 What should be the focus of HBIM?

Building Information Modelling is still variously defined and described, so it is not surprising that HBIM approaches show equal or greater diversity. Kemp (2014) provides a useful summary of the value that lies in BIM as a 'process':

- It converges information production with sound engineering judgement and design
- It provides wider, faster access to comprehensible and integrated information
- It fosters instinctive but rigorous collaboration and better decision making
- It harnesses innovative technologies and harvests intelligence from big data
- It enables reflective, adaptive thinking to incorporate whole life and integrated systems approach within the wider geographic context.

(Kemp 2014)

The American Institute of Architects defined a broad goal for BIM within Integrated Project Delivery (IPD), a mechanism for involving all key participants for optimal results. They stated that IPD

"is a collaborative alliance of people, systems, business structures and practices into a process that harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction"

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That definition is particularly helpful as a benchmark against which to analyse the goal of HBIM, if all key participants are focused via HBIM on the social, economic, environmental and cultural sustainability of built heritage during its lifetime management and maintenance.
Maxwell (2014) defined the current state of the art in HBIM as 'in the shadows'!

With conservation, repair and maintenance (CRM) currently amounting to some 42% of all industry activity, the current emphasis on new-build orientated BIM risks leaving related developments in the CRM sector in the shadows. At the heart of an HBIM / CRM approach is a fundamental requirement to establish value, significance and accurately surveyed data of the asset that is anticipated being worked upon. With little progress having been made by BIM (in its currently common accepted sense in accommodating the more difficult world of dealing with long-established existing buildings of many architectural periods, styles and structural compositions), the emergence of a meaningful Historic Building Information Modelling (HBIM) approach is virtually non-existent. In pursuing this comparatively untouched avenue, a detailed and fundamental understanding of existing structural conditions, material degradations, and performance-in-use circumstances is essential for each structure being incorporated into the approach.

3.3.1 Support for primary interpretation

Primary interpretation is defined by ICOMOS (1990) as the expert recording process via which the historic structure is analysed and comprehended. ICOMOS (op. cit.) defined robust mechanisms for 'on-site' expert recording, with the explicit focus of establishing value, significance and analysing materials, structure and pathology. The ICOMOS guidelines (op. cit.) state the "record of a building should be seen as cumulative with each stage adding both to the comprehensiveness of the record and the comprehension of the building that the record makes possible."

They conclude that "recording should therefore so far as possible not only illustrate and describe a building but also demonstrate significance." This was summarised (Worthing 1999) as "the recording of an historic building is not a 'one-off ' event but a continuous process that is a prerequisite of many management activities. It is important to recognise that recording is not value free. It is part of the process of understanding and interpreting the building – and in therefore attributing value to the structure." Molyneux (1991) stated similarly, "The purpose of analytical recording is not merely to ascertain the initial form of the building but rather how the use of the structure has responded to and reflects social, cultural and economic change through time." Recording should therefore, so far as possible, not only illustrate and describe a building but also demonstrate significance. At any level above the most basic, a heritage record is thus a mixture of description and analysis. There are now multiple media available for data acquisition and entry. More overt and explicit classification and codification of facts is necessary when using computers, but also clarity when evidence is uncertain or capable of multiple interpretations (such as concealed parts of the fabric, pathology not fully visible on the surface, or detectable via non-destructive tests). The chosen media and descriptors will enhance or limit the later use of that data.

3.3.2 Cultural landscapes and intangible heritage as well as heritage structures

Fai and Graham (2011) widen the scope of Heritage BIM beyond the 'expert eye' defined by Maxwell. They similarly identify the limited progress currently towards HBIM. "Despite the widespread adoption of building information modelling (BIM) for the design and lifecycle management of new buildings, very little research has been undertaken to explore the value of BIM in the management of heritage buildings and cultural landscapes." They particularly identify cultural landscapes as well as buildings and structures. The HBIM requirements of Cultural Landscapes are likely to be broader than those of infrastructure in general. However, even BIM for Infrastructure remains poorly developed. "Buildings are much better served than the infrastructure side at present in terms of BIM implementation. . . . Infrastructure is more challenging – more ambiguous, no set boundaries and consistently moving and changing – how do current BIM technologies tackle that?" (Schofield 2015).

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Excerpted from *Heritage Building Information Modelling*

3.3.3 Intangible heritage

Fai et al. (op. cit.) describe the need to record performance data, and what they define as qualitative assets, such as historic photographs, oral history, or music, for example. "To that end, we are investigating the construction of BIMs that incorporate both quantitative assets intelligent objects, performance data and qualitative assets historic photographs, oral histories, music." Yet even for performance data Niskanen et al. (2014) state more generally that "the benefits deriving from the integration of static BIM data to dynamic facility monitoring data are not extensively exploited or understood."

UNESCO (2001) gave a broad description of such 'qualitative assets'. They defined 'intangible cultural heritage' as "among others, language, literature, music, drama, dance, mime, games, hunting, fishing and agricultural practices, religious ceremonies, traditional skills in weaving, building and carving, cuisine, extrajudicial methods of dispute resolution, traditional medicine and traditional knowledge applied to plants and their medical, biological and agricultural properties."
UNESCO (2003) then identified in particular the need to record and store (and georeference), for future generations, the emerging palimpsest and marginalia of digital and 'Web 2.0' recordings of heritage sites, such as photographs, tweets, and other 'comments'. "Digital materials include texts, databases, still and moving images, audio, graphics, software and web pages, among a wide and growing range of formats. They are frequently ephemeral, and require purposeful production, maintenance and management to be retained."

These are all potential ingredients in the establishment of ongoing value and significance, and HBIM should enable them to be scrutinised, particularly in establishing how the cultural landscape or heritage artefact is a 'response to and reflection of social, cultural and economic change through time'.

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3.3.4 Support for 'secondary interpretation' and 'bottom-up readings'

In a 2006 UK research council workshop on "Preserving Our Past", (EPSRC 2006), the crossdisciplinary experts present confirmed continuing need for research to -

move away from the concept of one-way push of information to (two-way) interactive participation and inclusion. They stress the need to embrace social inclusion, interpretation, storytelling, authenticity, and interactive design. They further enquired: is there space for multiple readings of heritage (alternative interpretations); is there opportunity to present these alternatives; How do we challenge top-down interpretations; Can we encourage bottom-up readings; Can we get away from socio-economic and political readings; Can we accommodate personal and cultural readings; and how can we make heritage more immediate – tactile / auditory / experienced?

3.3.5 An evolutionary fusion towards HBIM

Counsell (2002) argued that BIM processes alone were not enough for the full range of necessary functions in recording and using heritage data, and that GIS processes are also needed. Leading practitioners (Kemp 2015a) now identify that geospatial information (via GIS) is as critical as BIM information (via parts libraries and BIM software), referring to that integrated goal as Geo-BIM. The current state of the art appears to be that GIS is seen as complementary to BIM, but in a separate silo at a different scale, so implicitly 'less detailed' than BIM. "The next big challenge leading to 2020 will be to Geo Enable BIM" (AGI 2015), i.e. to achieve a synthesis where the silos and perceived issues of accurate detail no longer exist. There is still a tendency in this approach to focusing on the building or structure. For heritage such a focus needs to be broader, embracing cultural landscapes and the landscape curtilage of heritage buildings in a more seamless manner. This is more akin to the seamless scaling that should in future occur between BIM building units and Smart City, but the cultural landscape contains many particularly challenging ephemeral elements.

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3.3.6 Who are the key participants?

In identifying the future scope for Geo-BIM, Plume (2015) states that we "may have a stewardship responsibility toward a place, or we may be required to design or plan a place, and of course, in our everyday life, we are users of places", going on to ask "what if we were to collect, store and make available in an explicit fashion all that we know about how places are valued, both collectively and personally?" and "If we are able to find a way to collect and capture our understanding of place in a structured way, would that provide a useful conceptual framework for an integrated digitally enabled environment?" This appears to be even more essential for HBIM. The ICOMOS Burra Charter, for example, states that those "with associations with the place as well as those involved in its management should be provided with opportunities to contribute to and participate in identifying and understanding the cultural significance of the place. Where appropriate they should also have opportunities to participate in its conservation and management" (Australia ICOMOS 2013). Silberman (2015) similarly refers to ongoing paradigm shifts as "process, not product; collaboration, not passive instruction; memory community, not heritage audience". There is little research literature that evidences such wide user engagement in the development of HBIM. A notable exception that does engage a broad range of 'users' is identified in the work of Fassi et al. (2015). A consequence of wider and more ad hoc user engagement will be that ease of use of HBIM, particularly by occasional users, will become increasingly critical, probably far more so than for conventional 'new construction' BIM.

3.4 A clear framework for HBIM

ICT systems tend to fail if they are too prescriptively narrow to support the full range of practice, because then users have to develop and deploy approaches beyond that ICT system's scope. Hence it is important that a framework is defined that is sufficiently embracing, even if not all modules are initially implemented. That framework does not appear to yet exist for HBIM.

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Excerpted from *Heritage Building Information Modelling*

Plume (2015) proposes a BIM-focused "information framework to support the digital enablement of the built and natural environments", a fusion between emergent BuildingSMART and Open Geospatial Consortium approaches. The AGI Foresight Report 2020 (2015) identifies the need for a 'geography of everything': - Identifying and exploiting the linking of multiple technologies and policies – based strictly on an outcome based approach. This will include BIM, indoor navigation, asset management, internet of things, smart cities, artificial intelligence and big data, integration of data science and analytics, creative visualisation and analytics. Location Intelligence can and should become critical ('the geography of everything') and provide the foundation on which business decisions are made.

Plume goes on to describe - two technologies that form the foundation of these ideas: the digital models that are used to represent aspects of the physical world; and the Internet technologies that collectively capture, hold, find, interpret and deliver the information [. . . incorporating] the Internet to transport the information; the semantic Web to enable smart ways to find and retrieve information; geolocation technologies to enable searching based on geographic context; and RFIDs with sensors to facilitate the Internet of Things to realise a sensate environment. This framework would need to support the full range from cultural heritage landscape to specific structure, including:

• accurately surveyed data with: recording of value, and significance; analysis of materials, structure and pathology; as well as how the use of the structure has responded to and reflects environmental, social, cultural and economic change through time;

• 'development and construction projects as well as ongoing facilities management' (the wider definition of BIM level 2 in the UK);

• the ephemeral and ambiguous, lacking set boundaries, consistently moving and changing, including infrastructure, trees, planting and water courses;

• the 'Internet of Sensors', responsive systems, and related actuators;

• location-specific 'intangible cultural heritage' and virtual heritage;

• secondary interpretation, community engagement and community-based bottom-up readings, and alternative interpretations, based on potentially ambiguous 'fuzzy' evidence;

• a structure and standards that support continual retrieval and reuse for decades if not centuries.

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Excerpted from *Heritage Building Information Modelling*

3.5 Some evolutionary stages for HBIM development

In the field of geospatial information, Maguire (1991) defined its development as evolving through three generations: in the first, data are entered to form an inventory; during the second, the continuing addition and updating of data to that inventory over time makes analysis of change possible; in the third, sophisticated spatial analytic tools enable various forms of 'what if?' analysis. Extrapolating on this theme Gardels (1997) defined a fourth evolutionary stage as a 'Web library model' where the data are 'just out there' and are found and deployed using special spatial search tools. Each of these generations supports more refined and broader analysis and decision making. Inventory supports filters and enquiries such as 'what is at . . .?', 'where is . . .?'. In 2D and to some extent in 3D this has become commonplace. OpenStreetMap has 3D prototypes; Google Street View and Google Earth take different approaches to Microsoft Bing in creating 3D cityscapes; and in-vehicle satellite navigation systems contain increasing blends of 2D and 3D. The outstanding challenge is navigation and discovery in multi-level complex built structures. There is also a prevailing lack of open standards and interoperability that keeps these in separate silos.

There are few heritage case studies that have reached the second generation and accessibly show 'what has changed?' The Walton Basin study (CPAT & Smith 2014), one of these few, is now unsupported and may shortly expire. It shows in web-based interactive VR (VRML) the changing appearance of cultural landscapes over millennia, with archaeological simulations of monuments and settlements in the Walton Basin in Wales, from the Late Glacial period to modern times. The study was generated from 3D data held in a GIS (MapInfo), using extensions in the MapInfo API to generate the VRML, so capable of ready amendment and update over time. The third GIS generation, deploying spatial tools for 'what if?' analysis, does not appear significantly in any heritage case studies, although elements appear in a range of funded research projects, and the London Charter (2009) is an implicit critique of much current practice.

The semantic web is predicated upon a more collaborative and interactive engagement by users. Alderson (2015) states that "location is the DNA that runs through all data". However, there is little open standard development to be found for cultural heritage buildings, let alone cultural heritage landscapes, intangible or virtual heritage, which evidences this, and few spatial search tools for 'just out there' data.

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Excerpted from *Heritage Building Information Modelling*

The DURAARK (2016) project has recently prototyped applications of emerging semantic web standards such as the Resource Description Framework and the OWL web ontology language in order to provide a sound basis for the very long-term archiving, retrieval and reuse of architectural information, in particular point clouds and BIM. Similar approaches are analysed in the 'Linked Heritage' (2013) project report on 'Geocoded Digital Cultural Content'.

3.6 Taking inventory

HBIM research and development appears to be a very early point in an evolutionary tree, primarily focused on 'recording' and even more on 'accurate survey' (e.g. point clouds), which may be seen as taking inventory, the first of Maguire's (op. cit.) developmental GIS stages. Penttila et al. (2007) retrospectively applied 'architectural information modelling' to the Alvar Aalto School of Architecture in Helsinki, prior to renovation. They concluded that an 'inventory model' was necessary to support the renovation process, as well as later facilities management, and that "the information structure of renovation projects differs remarkably from the structures of new buildings." In particular, unlike new construction where the ingredients are known, much of the detail of construction below the surface is unknown, and difficult to define using non-destructive techniques. Thus there is a need for more effective non-destructive techniques, methods of recording, and analysis of 'building pathology'. In their paper on the relation of recording to digital 3D modelling focused on the buildings in the Tower of London environs, Worthing and Counsell (1999) listed among reasons for recording: to enable the reconstruction of part or the whole of the building (or 'object') in the event of its damage or destruction (also examined in relation to the Welsh National Museum of Life laser scan project [Counsell et al. 2008]); to identify the changes that have occurred to an historic building over a period of time; where the information is used to inform decision making about the effect that proposed changes will have on the historic fabric; as an archival record of that which is inevitably lost or changed (even routine maintenance work can involve loss or change); or as a record of works actually undertaken to capture the chronological evolution of the building.

For HBIM, such (digital) record repositories require tools that support: capture/upload with data quality assurance and validation; storage (repository); retrieval including filters; tools for measurement, archaeometry and other analysis; display (in '3D' not just '2D'); with feedback loops for added semantics, e.g. significance, commentary and narrative.

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Excerpted from *Heritage Building Information Modelling*

Significantly different data and processes may also be required depending on which outcomes are required. For example, Maxwell (op. cit.) points out that "conservation; restoration; rehabilitation; repair and maintenance [. . .] require different degrees of information and detail about the building, or area to be worked upon. This, in turn, will dictate the level of sophistication and depth of understanding that will be required from the survey activity".

One may also distinguish and perhaps even deploy different recording techniques by distinguishing between data that changes at different paces, from slow and steady to rapid. "While buildings are relatively slow to change and decay, so past records and now computer modeled analogues stay valid in the long term, yet their contexts, settings, gardens and grounds are open to rapid change. Effective recording of potentially rapid change is highly resource intensive, justifying exploration of automated data capture" (Counsell 2001). This is the particular challenge of recording cultural landscapes and heritage curtilages.

3.7 Near real-time data

"In 2016 Planet Labs will have enough satellites in orbit to image the entire globe, every single day" (Planet Labs 2016). While the 3–5 metres per pixel data that will be provided is not precise enough for BIM purposes, it may well be highly useful in detecting change in cultural heritage landscapes. To the developing range of precision remote-sensed data, including that offered by drones in the future, fusion needs to be achieved with the 'Internet of Sensors' or 'Sensor Systems' for near realtime data capture, which also offer great potential for automated analysis. "When you cut through the hype around the Internet of Things (IoT), it's the Internet of Sensors (IoS) and resulting data that matters most" (TTP 2015). "This means using modern technologies to continuously monitor the condition and operation of infrastructure and to intervene before problems arise and to develop better solutions for the future" (AGI Foresight Report 2020, 2015). At the Luxor workshop, real-time sensor data collections relating to Heritage Cottage (Cadw) and other case studies were described, and questions posed about the future relationship of HBIM to 'Smart Cities'. 'Once there are sensors, real-time data, and consequential analysis, will an added feedback loop and actuators or the like make a heritage building or structure into an automatically responsive (i.e. smart) building, and is this a necessary step towards developing a fully smart city?' For example, Kolokotsa et al. (2011) argue that "integrated control and optimization tools of sufficient generality using the sensor inputs and the thermal models can take intelligent decisions, in almost real-time, regarding the operation of the building and its subsystems."

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It may be argued that data automatically available from such 'Smart Heritage' and via 'participatory sensing' (see Chapter 17) may eventually lead us to Gardels's fourth stage of HBIM, where the data are 'just out there', often now described as 'Big Data', and where the challenges become those of automated filtering and analysis. This is similar to the "Internet of Places" described by Plume (2015), but with the wider dimensions (including intangible heritage) needed for a fully developed HBIM. The developing trend towards this fusion is described as "cyber-physical" (Bosche 2016). Bosche further defined this for BIM as more than 'linked digital and physical elements', in that changes in the digital will be automatically reflected in the physical and vice versa.

3.8 Semantic information

The current state of the art appears to be substantially achieving accurate geometric surveys of heritage assets. It does not appear to offer effective approaches to complementing this with robust methods of establishing value and significance, or enhancing with semantic information. One of the authors has been informally discussing this with BIM software focused heritage architecture practitioners across Europe and beyond. Now many BIM software focused heritage architecture practitioners segregate the recording process, to its apparent detriment. In this current practice the laser scanner operator attends site, focused on achieving a fully comprehensive sequence of integrable 3D point cloud scans. The scans are then processed back at the office, off-site, usually merged into a single coherent combined point cloud survey. Errors in accuracy occur via calibration issues, the quantities of scans, the distance from the scanner, and even operator errors. For ease of use in the BIM software, the merged point cloud may well then be extensively thinned or culled. Experts describe, for example, using one-ninth of the original points, with consequent reductions in data quality, i.e. points at an original distance accuracy of up to ±2 mm are discarded prior to modelling. The BIM software is used to create a 3D parametric model that closely matches the thinned point cloud via a manual tracing process, but may well further simplify it.

In these recent discussions these practitioners explain that the modelling process helps them to analyse the materials, structure and pathology, and may assist in assigning value and significance to key elements. The benefit of an expert studying the physical reality and carefully noting each detail of value, significance, material form, structural condition, and potential pathology in situ is devolved. These BIM software heritage practitioners now do this off-site from a simplified partial geometric point cloud record, usually with RGB (red-green-blue) values for each point. This represents a substantial degradation of the on-site expert analytical recording process.

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Excerpted from *Heritage Building Information Modelling*

A few are instead arguing for greater ease of use of a mobile in situ ICT process, an amalgam of automated geometric recording, mobile instrumentation and logging, enhanced by simultaneous expert semantic analysis and annotation, to digitally speed and enhance that qualitative manual recording process defined by ICOMOS (op. cit.).

3.8.1 The question can be asked, "How much to model?"

A related question that is relevant to the evolutionary process identified for the Sydney Opera House is: Why model everything rather than just what is required at the time? Models are often significant simplifications of the actual heritage building, with some consequential major challenges for data quality and assurance. In this respect Hichri et al. (2013) state that - historical buildings are characterized by very complex and varied shapes, mostly not responding to classical geometrical laws. For example, walls are not always vertical and can be tilted in many cases. Some elements are even more complex such as capitals which have specific characteristics and different architectural styles. Modeling them becomes even harder because of their deterioration over time.

As with new construction focused BIM, the models might be formed from discrete elements, but due to the complexity and deterioration of many structures, the separation of the structure into such components risks even greater simplification. There is a recognised need in BIM for tagging with semantic information, and such components appear to many to be the only currently practicable approach to tagging with what is described as "non-graphical" information in many software solutions. Thus Murphy et al. (2009) focused on matching parametric elements from Georgian architecture in Dublin to laser point cloud survey data. This approach has been particularly challenged by Maxwell (op. cit.), who stated that - its limitation in not having the precise individual architectural details recorded, as opposed to utilising a standardised catalogue of library based features, need to be borne in mind. As a result, the approach is perhaps best suited to streetscape and urban planning considerations, rather than building specific conservation requirements where an accuracy in understanding the building details is important.

Yet it becomes valuable to model when:

a. the actual building/artefact is not accessible in the present – whether covered up, demolished or destroyed, dangerous to access or subsequently changed;

b. for virtual access, providing an overview or comprehension is not achievable on the ground; that is for simplification of complexity (e.g. the UK National Trust applied unsuccessfully for millennium lottery funding to create interpretative visitor centres at the entrance to a number of their buildings, in order to provide the visitors with a comprehendible overview before immersion in the maze of rooms and levels thereafter);

c. for visual pattern matching, "both kinds of sources, original input and enhanced imagery, can be draped onto the 3D models to analyse thoroughly the whole object in three dimensions" (Lerma et al. 2011);

d. for analysis of historic construction processes (e.g. Guedelon 2015, Reeves & Paardekooper 2014);

e. for analysis of performance, for example, thermal/energy, structural, pathological;

f. for determining methods of reassembly, for example, following earthquake destruction, or anastylosis (Canciani et al. 2013b);

g. for predicting the future reconstruction, repurposing or, for example, predicting the future effects of climate change.

3.8.2 Models composed of (parametric) objects

There is still debate about the extent to which parametric product libraries of building components, the basis of most current commercial BIM packages, can be deployed for HBIM. There are still different schools of thought about the extent to which parametric modelling should be aligned to laser scan surveys. Murphy et al. (2009) began with a parametric architectural object best-fit approach to point cloud data. Yet Murphy more recently concludes (Dore and Murphy 2012) that there is a need to blend their best-fit 3D models into 3D GIS in order to enhance the process of tagging with semantic information, documentation and analysis. There is still much research to do to optimise the addition of semantic information to point cloud data, and no clear agreement on the best way forward. Automated approaches have been tried, but yet have often less than 90% success, or lead to gross simplification of the shape and form of the actual heritage structure, thus are seen by some as denying the history of the artefact over time, including the dimensional distortions that emerge as aging and settlement take place.

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3.8.3 Minimum stratigraphic units – a form of 'cookie cutting'

BuildingSMART in the UK reports that "we generally found that while there is a good understanding of the benefits of 3D modelling, this is not converted into a deeper technical understanding of how to exploit all digital data as the lowest and reusable common denominator of information, beyond just the graphical output" (Kemp 2015b).

A more precise approach than adding non-graphical attributes to parametric object representations of deteriorated heritage materials and forms is a form of disaggregation into distinct elements that has been proposed based upon archaeological stratigraphic units. This appears to be the 3D equivalent of the 2D spatial selection 'data-clipping' tools used in GIS termed 'cookie cutters'. Canciani et al. (2013a) describe their prototype for heritage buildings, stating that "one of the crucial problems is the definition of 'base units', meaning base elements presenting homogenous characteristics, for the association of further data . . . the current study resolving the problem of the base unit by instead defining a minimum stratigraphic unit."

Much of the time and cost in modelling from point clouds is taken in painstakingly replicating the visual appearance of the building in segmented elements, before 'discarding' the point cloud. The point cloud data with associated RGB colour is already a very effective visual representation. The challenge remains how to segment it and associate semantic information with it. The EU-funded DURAARK (2016) project and subsequent investigation suggest that the time-consuming process of detailed modelling could in future be reduced by a much simpler, even crude, semantic BIM model (partially automatically generated) that is more loosely linked to the scanned point cloud data but serves as a filter to retrieve point cloud data.

3.8.4 Automated segmentation and semantic labelling of point cloud data

Other researchers point out how much can be achieved with laser point clouds combined with photographic and similar non-destructive testing records for analysis and understanding, without transformation into 'simplified models'. Emerging technologies such as CloudCompare (n.d.) permit new repair/refurbishment solutions to be checked for fit against point clouds without full digital modelling, although many seek to use the same 'clash detection' process to validate the accuracy of their fully constructed modelling against the original point cloud data. Bosche et al. (2015), in exploring automated analytical tools for masonry structures, point out that "point clouds (or generated meshes) are just 'raw' data, and the information truly valuable to experts needs to be extracted from that data, through its segmentation and semantic labelling."

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Bosche et al. report on development and testing of their algorithm that detects each individual masonry surface and distinguishes it from the adjacent mortar bonding surface. On a broader scale, the Felis Research Centre (Wang et al. 2008, Weinecker 2008) developed software that can automatically, without operator intervention, distinguish between evergreen and broadleaf trees, and extract simplified coplanar surfaces of building exteriors with reasonable accuracy from high-resolution aerial Lidar data. The DURAARK (2016) project has prototyped the automatic extraction and semantic identification of the planar surfaces of rooms (floors, walls, ceilings), with detection of doorways to relate one room to the next. Detailed models resulting from amalgamation of these approaches could support geo-tagged semantic information overlays, without deploying parametric constructional elements that make overprecise assumptions about the invisible construction deployed behind the surfaces.

3.8.5 Geo-tagged 'comments and narrative'

It should be noted that a visualisable model is not necessarily required in this process, and a case needs to be made if one is to be constructed primarily to support georeferencing. In their development of the Non-Domestic Building Stock GIS (solely a 2D GIS), Steadman et al. (2000) successfully captured, via street and internal surveys, adequate descriptions both 2D and 3D, with semantic information about construction occupancy and use, for subsequent analysis of energy efficiency, without recourse to a visualisable '3D model'. The Sydney Opera House as a facility was managed effectively for its first decades by a text-based inventory colour coded to elements of the building. Now augmented reality techniques might provide the same functionality.

Fai et al. (2011) used Navisworks commercial software to fuse data from a variety of sources, to geo-tag semantic labelling and to test the georeferencing of intangible heritage to their 3D digital modelled heritage reconstructions. Fai went on to state, "If the 'facts' change, the model can integrate this new material without having to be completely rebuilt." This does not however enable the user to determine the 'level of certainty' or ambiguity of data underlying semantic labelling, nor permit different and even conflicting interpretations supported by the same evidence. Both of these situations are likely in heritage, since it is often not possible to tell what lies below the surface without demolition.

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Excerpted from *Heritage Building Information Modelling*

While it does not yet sufficiently meet the wide range of needs for semantic heritage 'labelling' and narratives, there is now a more open source approach developing that may with extension and development effectively support semantic labelling, via the new construction focused BIMCollaboration Format (BCF). BuildingSMART (2015) has now released the second generation of BCF as a standard. Many of the concepts behind BCF were explored during the Virtual Environmental Planning (VEPs) project to fully address full community-based participation online, described as Comment Markup Language (CoML) (Schill et al. 2007). CoML was partially built upon an earlier heritage-focused georeferencing landscape prototype, explored in the Framework 5 EU project Valhalla. An interface was - developed that permits archived video clips to be retrieved following a search and viewed alongside the model. The model viewpoint can then interactively be matched to the view or views in the archive clip to generate metadata about field of view, zoom and comments with which to tag the clip, for later search and retrieval by context or content. The same approach has also been implemented for static digital images, thus enabling scanned historic images or digital photographs to be incorporated in the database and retrieved using the same search parameters. Thus images that were not originally annotated with locational data can be rendered retrievable by searching the database for instances of plants or other objects. (Counsell et al. 2003)

Some of the cross-disciplinary concerns expressed in the 2006 UK research councils' workshop (EPSRC 2006) still have currency. Among potential digital solutions is a requirement for tools that enable open ad hoc semantic labelling of a variety of media in ways potentially not anticipated by ICT system designers. One may, for example, need to distinguish between semantic labelling that is planned by the author of a document, and post-publication labelling that is more difficult to predict. 'Hot-spot' tools would be needed to draw attention to each nexus where multiple 'labellers' have commented or expressed interest or views. Tools would also be needed to locate in sequence or conduct an animated tour of a series of related 'labels' with their associated views that might form a narrative, or even develop further, akin to a Web 2.0 'mashup'. Labels might therefore need to be audible. These aspects were also trialled in the development of CoML.

3.9 Some recent indicators

The EU-funded Framework 7 DURAARK (2016) project, which has just ended, mapped 'Durable Architectural Knowledge', and particularly the long-term preservation of BIM models. The site contains a wide range of reports, with links to open source resources and tools that were developed within the project that the project partners hope will instigate a longer-term open source community development. Although not specifically focused on heritage, it defined a range of standards and approaches that would be valuable for heritage platforms or frameworks, particularly in addressing the substantive challenge of enabling an information resource for future generations without reentry of data or rework.

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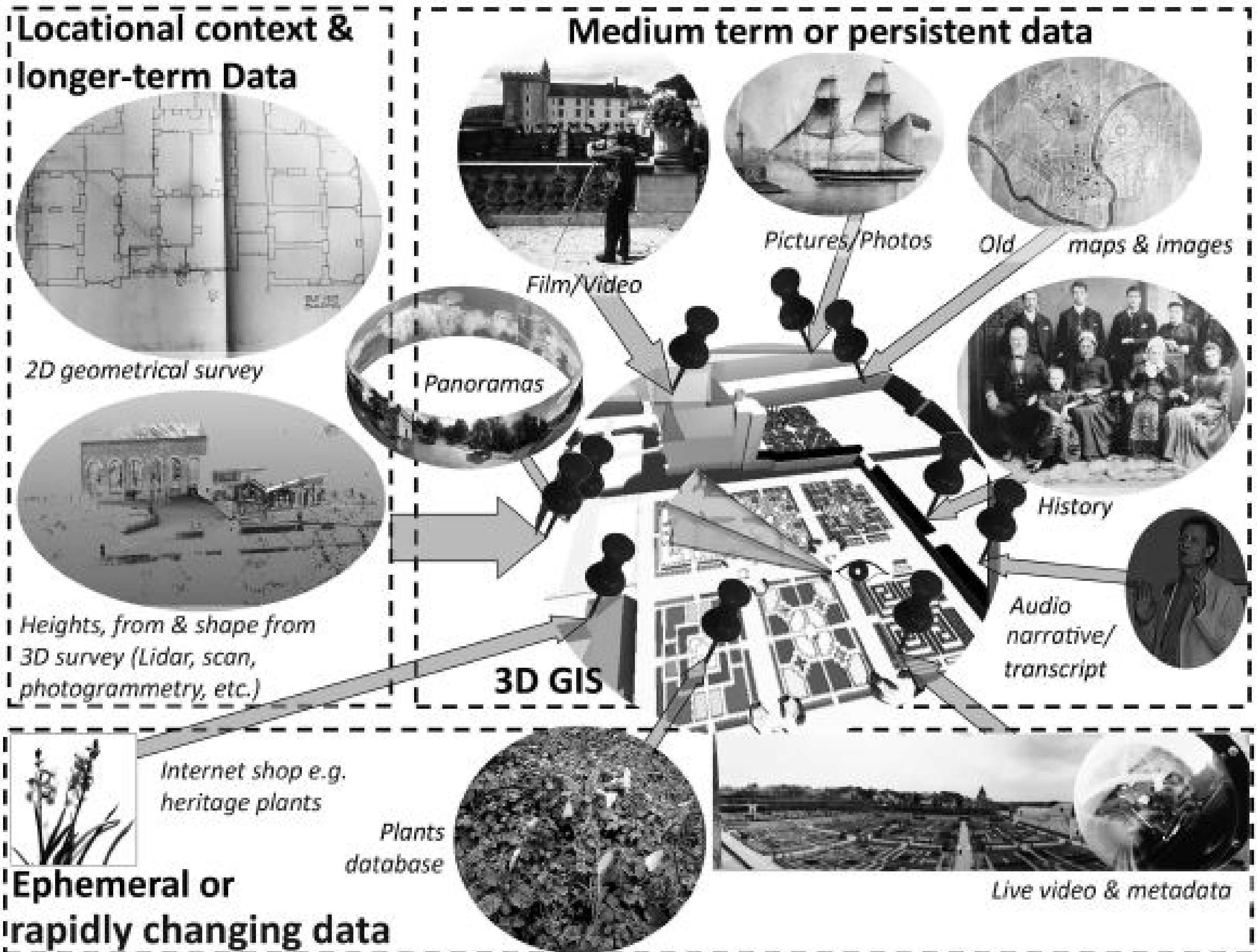

Tangible/intangible heritage 3D GIS diagram based upon EU FP5 Valhalla Project 2003

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The Valhalla project (Counsell et al. 2003) remains one of a very few that have focused on the 3D GIS-based information needs of capturing and recording the diurnal and seasonal changes of planting in heritage landscapes. It used earlier versions of the GIS linked to VRML software later deployed for the Walton Basin (CPAT & Smith 2014) to blend streamed real-time data from security cameras with navigable web-based VR models. This approach was further enhanced in the VEPs project, where a case study was made of St Teilo's Church, rescued and reconstructed at the National Museum of Welsh Life. The church was virtually placed back into its original site (fusing Lidar data of the site with point cloud data from the reconstructed building), and a timeline tool deployed that allowed online users to explore back through time to its original medieval single cell structure, with adjacent motte and bailey castles and villages (Counsell & Littlewood 2008). While the focus of the VEPs project was community engagement, independent evaluation revealed major ease-of-use issues for all three prototype web technologies trialled. Richman and Holding (2008) found the "perception of how 'user-friendly' a 3D tool is depends very much on the experience a user has with 3D applications." Their report on VEPs evaluation revealed significant further research challenges, particularly regarding ease of use.

As a multidisciplinary design, engineering and project management consultancy, Atkins has extensive experience of applying BIM and geospatial techniques at all scales, from the restoration of important historical buildings up to major infrastructure projects and cultural landscapes. Significant projects, such as the development of a site management plan for the Bahla Fort and Oasis World Heritage Site and master plan for the National Botanic Reserve in Oman, can involve both extensive recording and modelling activities that are embedded in participatory processes. Collaboration platforms and visualisation tools are increasingly essential elements for HBIM practitioners, and Atkins has a strategic plan to migrate all the company's systems to the cloud by 2020 as well as trialling innovative technologies such as Microsoft HoloLens to enable virtual data to be experienced. Other innovations by Atkins in this area include the Digital Imaging for Condition Asset Management (DIFCAM 2013) platform that enables rapid acquisition of digital data for a structure that can be used for automating condition monitoring processes. This type of technology is inherently efficient, accurate and safe and may indicate the future for preventative maintenance of infrastructure with historical and cultural significance, i.e. it provides the capability for an asset to report its state to management systems that learn and adapt in response.

Batawa (Fai et al. 2011) is a recent case study of an early twentieth century factory and worker housing complex in Canada. The case study claims to have successfully prototyped the integration of accurate survey data with quantitative and qualitative virtual and intangible heritage, and the visual display of change over time. It demonstrated significant barriers: multiple expensive software packages were used, each requiring significant expertise.

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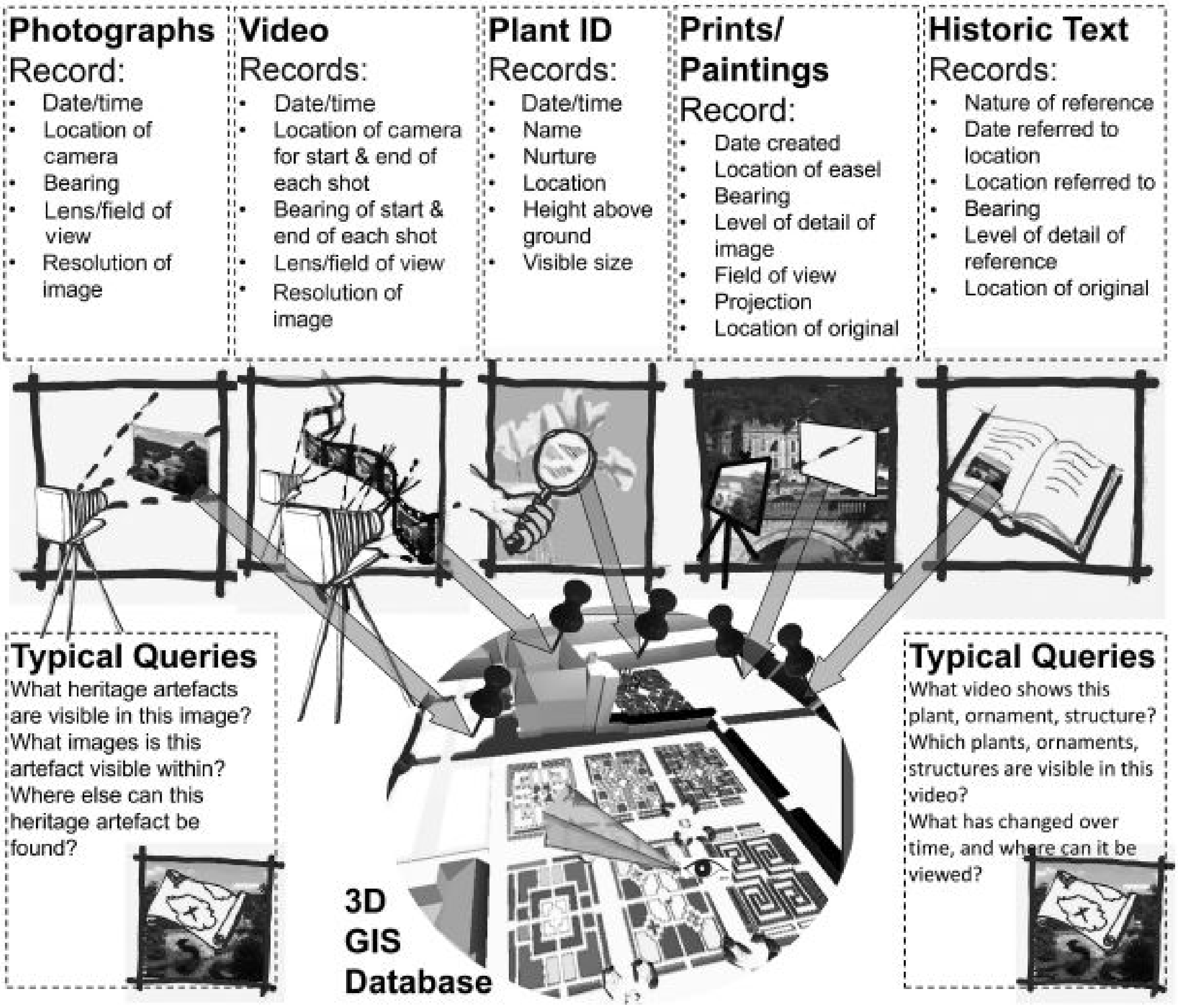

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Indeed, without support from Autodesk Research, its limited success would probably not have been achieved. It successfully made a case for further funding intended to develop a far more accessible web development, in a project that appears to have ended in 2014. They describe the project, "Cultural Diversity and Material Imagination in Canadian Architecture (CDMICA)", as focused on "knowledge creation and mobilization for both tangible and intangible conservation, documentation, and digital archiving". However, the material now accessible on the web from this project (CDMICA 2014) is a limited gazetteer of some heritage cases, without heritage case-specific timeline (although there is a listing of initial construction dates for each case), georeferencing or intangible heritage. It provides highly limited interaction with 3D models of each case, if users are prepared to wait for the massive files generated by similar expensive 3D modelling software to download. When judged against the criteria of inclusive engagement of and ease of use by the stakeholder community, it does not display progress, and indicates a need for a research portal that collates development towards HBIM to avoid these regular reinventions of the wheel.

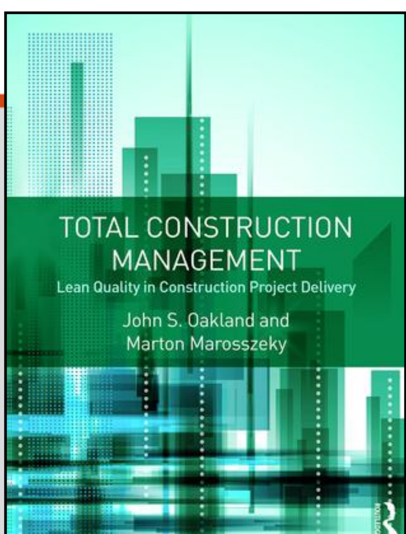
3.10 Conclusion

It can be argued that GIS and BIM appear still to be in silos, while HBIM, to be successful, will need fusion. Current BIM practice in particular still appears predicated upon the one-way push of information from expert to participant, inadequately supporting wide interactive participation and inclusion. On the other hand GIS practice has long enabled users to engage with data and perform their own analysis. With the increasing use of mapping services online, web users are becoming increasingly accustomed, but more in 2D than 3D. It may be that the step change forecast soon from the increasingly low-cost VR and AR technologies will at last result in widespread familiarity with 3D usage. Common standardised access to data remains a major barrier. Even at the inventory level, heritage data generally remains in silos, without common standards. For example, the National Trust in the UK publishes a gazetteer app, but the data is locked and proprietary, so difficult to fuse with information about heritage in other ownerships. Google specifically publishes 'Street Views' of National Trust properties, so legal registers of heritage can be linked via Web 2.0 'mashups' to create a much more substantially complete embryonic inventory of UK heritage. Yet the long-term persistence of such inventories is unlikely, and will not serve as an 'information resource for future generations', without clear standards for long-term retrieval and reuse. Few have downloaded the DURAARK project resources, but their approach to standardisation urgently needs to be built upon to deliver the goals of HBIM.

CHAPTER

5

BIM AND LEAN PRACTICES DRIVE LEAN TRANSFORMATION AT SOUTHLAND INDUSTRIES



This case study is excerpted from
Total Construction Management
by By John S. Oakland, Marton Marosszeky.

Learn more

BIM AND LEAN PRACTICES DRIVE LEAN TRANSFORMATION AT SOUTHLAND INDUSTRIES

Excerpted from *Total Construction Management*

INTRODUCTION

Founded in 1949, Southland Industries (SI) provides innovative engineering, construction, service and energy service solutions through a holistic approach to building performance. Advocating a design–build–maintain model, Southland believes in offering customers the option of optimizing each stage of the building lifecycle through an integrated, customized project or by selecting any of its services and capabilities to be implemented individually. For jobs large and small, SI's in-house experts remain connected, sharing knowledge and information in order to produce the innovative, practical solutions that have earned Southland its unmatched reputation as one of the top design-build firms in the nation. Utilizing a variety of progressive tools such as building information modelling (BIM) and lean methods, Southland specializes in the design, construction and service of mechanical, plumbing, fire protection, process piping, automation and controls systems as well as comprehensive energy service needs. As a company that has always prided itself on innovation and collaboration, Southland, as an industry leader in sustainability and energy efficiency, continues to pave the way towards improved building design, build and maintenance.

Beginning as a Southern California-based supplier of residential heating solutions, SI has organically grown and exponentially expanded its services and capabilities over the years to serve a wide variety of markets and industries. Recognized as one of the nation's largest building systems experts, today Southland delivers superior results for commercial, data-centre, education, healthcare, government, hospitality, industrial, life sciences, enter -tainment, and mixed-use buildings and clients.

This case study focuses on the lean construction aspects of SI engineering, fabrication and construction activities.

ENGINEERING

Southland's engineers are respected thought leaders in the architectural, engineering and construction community. Combined with Southland's experience in construction and facility operations, its engineers understand actual system performance, total costs and opportunities to improve construction and maintenance services. Believing deeply in the power of collaboration, Southland's people recognize that the best solutions are inspired when people with many differing perspectives work together to drive innovation.

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With extensive industry documentation of the benefits that accompany a collaborative and an integrated approach, Southland is well versed in collaborative project delivery methods such as integrated project delivery (IPD), design-build (DB) and design-assist.

Additionally, process and technology tools such as lean principles, modular methods, and construction processes streamlined for efficiency, maximize value and improve team interaction. Through ongoing research and partnering with a wide range of industry experts, Southland Industries continues to innovate and drive next generation solutions.

CONSTRUCTION

In the crucial stage when designs become reality, Southland approaches construction with proven procedures to execute objectives efficiently and, ultimately, deliver the best project value. By utilizing available resources and the wealth of lessons learned, Southland Industries is able to consistently achieve outstanding results.

With personnel that are adept at handling the manpower planning required for large, complex projects, Southland installs each new project with the goal of making it SI's best project yet. Experienced foremen work with the construction manager and trade super -intendent to develop a plan of bringing on the appropriate number of skilled craftsmen with the specific specialties a project requires.

One of Southland's biggest opportunities for improving construction quality and controlling a project schedule is through implementing high levels of prefabrication and modular construction. With fabrication facilities located near each of its divisional offices, SI's goal is to manufacture and pre-assemble as much material as possible in order to provide more efficient logistics, materials handling, superior installation and site work that is safer overall.

Utilizing process and technology tools like BIM, SI streamlines its efficiency, maximizes value and improves team interaction. Taking a holistic approach to all projects, SI continues to innovate and drive next generation solutions that elevate building operations, lower energy consumption and reduce overall owner costs.

BIM AND LEAN PRACTICES DRIVE LEAN TRANSFORMATION AT SOUTHLAND INDUSTRIES

Excerpted from *Total Construction Management*

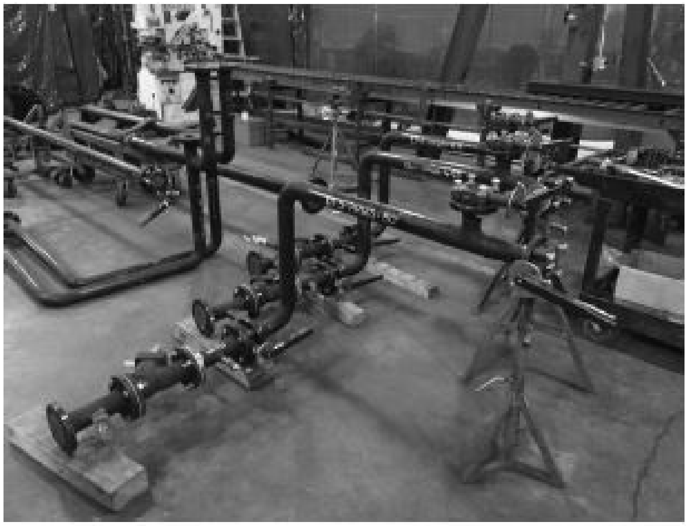
BUILDING INFORMATION MODELLING

Southland's building information modelling (BIM) strategy is fully integrated with its engineering, construction and maintenance services. The company utilizes a streamlined process that leverages technology to share information and improve collaboration during the design, construction and operation phase for any facility. To achieve these goals and maximize the benefits, Southland focuses on the following three key components of its successful BIM strategy:

• People – Southland's commitment to BIM is evident through the key resources, including an engineering lead, a constructability lead and a BIM lead, who are assigned to every project supporting its BIM goals. The engineering lead provides technical leadership, while the constructability lead provides constructability knowledge to the design team. The BIM leader is responsible for managing the technology that supports the process. Ongoing BIM training is also provided to employees in order to keep South -land in step with process and technology changes as well as improve its use of BIM.

• Process – By championing the use of a single model to achieve the requirements of both design and fabrication, Southland has established a single source for project inform ation. To support this approach, Southland has integrated its design-coordination and spooling resources as well as adjusted its internal workflow. This approach has led to exceptional solutions, highly collaborative and well-informed teams, fully coordinated facilities, fabrication-ready models and a streamlined workflow that produces real and actionable intelligence for the entire team.

FIGURE CS6.1 Complex prefabricates enabled by BIM



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Excerpted from *Total Construction Management*

The degree of prefabrication illustrated on the adjacent components can only be completed with confidence that there will be no rework through the use of advanced 3D BIM technologies.

Technology – The strategic use of technology is a critical component of Southland's BIM strategy. Southland's modelling, coordination and fabrication software is based on several Autodesk products. In addition, the business has developed many tools and standards to improve interoperability with other modelling solutions as well. Leveraging a proprietary database, Southland engineers are able to manage a wide array of information associated with the model on their projects. Technical solutions also incorporate the use of radio frequency identification (RFID) and mobile devices to support its fabrication, construction and facility service activities. Expanding its use of data sharing models and cloud computing has allowed SI to leverage its talented workforce across the country.

As its clients' needs change and technology evolves, so will Southland's BIM capabilities. As leaders in the industry, SI will assist others in recognizing the value of BIM, expanding its adoption and influencing key players and software developers to create products that support the ideals of a BIM-enabled world.

MANUFACTURED AND MODULAR CONSTRUCTION

At Southland, staff go to great lengths to keep pace with the most recent manufactured and modular construction trends in this industry. Manufactured construction provides benefits in all key cost-driving aspects of a project. With a focus on creating repeatable units and a highly standardized approach to design and construction, regardless of the project type, costs are reduced. By keeping a large portion of the labour that is required to build a project within an on-site (or off-site) manufacturing facility, significant improve -ments to labour productivity, quality, safety and project duration are achieved.

FIGURE CS6.2 Sophisticated multi-service modules prefabricated

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Excerpted from *Total Construction Management*

Figure CS6.2 illustrates a large prefabricated module with multiple services incor -porated into the modular assembly.
Southland has also invested significant time and resources into understanding and producing multi-trade assemblies that allow the efficiencies already identified to occur across an entire project. Multi-trade assemblies like overhead pipe/conduit racks and bathroom pods allow for multiple design and construction entities to benefit from a manu -factured construction mindset. Southland is experienced in collaborating with architects and structural engineers for solutions to integration challenges that present themselves early in the project lifecycle. Southland has implemented several examples of multi-trade construction, overhead racking (mechanical, plumbing, electrical, framing and fire pro -tection), and equipment skids (mechanical and electrical) on a number of projects and actively looks for the opportunity to do more during the design phase of a project.
Southland has travelled the globe in search of the best and most challenging modular implementations. Its research has improved SI's ability to develop ideas and solutions which improve the efficiency of construction through manufactured strategies. SI believes that there is much to be gained through the better alignment of construction techniques and the installation of bigger, more complete elements.

LEAN DESIGN AND CONSTRUCTION

In 2004 Southland Industries was introduced to the ideas of lean construction on the Sutter Health El Camino medical office building (MOB). On this project, Last Planner® System was implemented and 3D BIM was used. Since that time, lean thinking has permeated the entire business. It is used in the fabrication shop, on site and to integrate shop and site operations. More effort is applied to gain a fuller understanding of the client's needs as early as possible.

An early lesson about the need to better understand the client's expectations was received on an office building where SI installed the HVAC system. When the client walked the site with the SI job foreman, he asked, 'What can you see that is wrong with that ductwork?' The foreman replied, 'not much'. The owner then went on to complain that the standard of finish on the ductwork was far too good, he did not want to pay for the unnecessarily high standard of work that had been delivered. Southland recognized that there was a need to better understand client needs so that the right level of quality was provided and the work is not 'gold plated' in the eyes of the customer.

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Since the implementation of lean, labour productivity in the fabrication shop has increased by 15 per cent and on certain activities on site it has improved by 20 per cent. Southland site foremen implement LPS® regardless of the owner or general contractor. The benefit that the company receives from this practice is that improved scheduling on site gives reliable advance notice of demand to the fabrication shop and allows the shop to run more efficiently. Each general foreman on site has a schedule with dates for detailing, shop fabrication and delivery, as well as a reference to the relevant drawing.

Southland foremen get training in 5S and in LPS®. They are taught to lead and pro -mote innovation, identify waste and find opportunities for improvement. The company has developed 5S tools to support its processes in the shop and in the field. It has also developed a stock re-order process to improve the reliability of ordering, and it has implemented the use of shadow boards both in field toolboxes and in the fabrication shop. SI continually invests in upgrading its fabrication facilities. In one case, research students from the UC Berkeley Project Production Systems Lab (P2SL) helped to design workflow within one of its factories. Throughout Southland, there is a focus on identifying waste and maximizing customer value. Metrics are used to measure productivity both in the fabrication shop and in the field. Measures such as panels/hour, weld inches/hour and fabricated hangers/hour are kept so that improvements in productivity can be measured and productivity can be compared between fabrication shops.

There is a real focus on innovation that will simplify and error proof site operations. Tradesmen throughout the organization are encouraged to come up with new ideas and to record them in a two-minute video, on their smartphones. These are posted on the company intranet and evaluated, and the best ideas are rewarded.

Innovations are spread throughout the shop and field operations: one theme is around prefabrication, packaging and kitting for the field. Another is to improve efficiency, error proofing and improving quality. Yet another is improving production processes in the shop. In all cases, ideas come from the shop floor or site. Innovations include:

- a motorized lift for lifting duct in the field;
- clamps used to attach wheels to sectioned ductwork enable it to be easily moved on the jobsite, and yet are reusable for future duct sections;
- a trolley for moving toilet pans and cisterns to position on-site functions in the following way: all packaging is removed so that it does not have to be collected and removed from site; up to eight pans are seated in padded saddles on a single wheeled trolley together with all the required fittings; they are loaded onto a truck for delivery to the site; and, wheeled to the location where they are to be installed.

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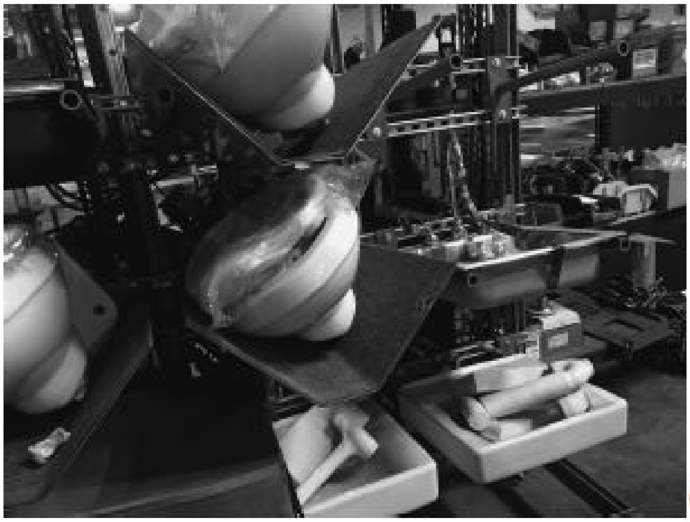
A further innovation was the development of an adjustable trolley in which a single pan can be positioned ready for mounting to the wall. This enables the tradesman to adjust the pan to the right height, wheel it into position and simply fix it to the wall. There is no strain on the worker to hold the pan in position while it is being fixed. It makes a two man operation into a one-man operation and installation is much more efficient.

Southland's Piping Supports (hangers) have had many improvements made to them over the past 5–6 years. Some of these improvements were due to BIM modelling pro -cesses. BIM allowed the coordinatation of supports in the above ceiling spaces of a building and the confident fabricatation of hangers without fear of rework. Using BIM enabled the use of Trimble technology and resulted in a much faster layout time than our conven-tio nal way. Reports detailing components could be extracted from models and then broken out by cut length, area, size, and floor section, or system type. Identifiers (labels) are also extracted from these reports and used to identify each individual hanger which correlates to an install plan. Reports lead to fabricating 'like' supports to optimize repetition in the shop and eliminating wasted steps and wasted materials.

The next step was to see what innovations could be made in shipping and in field installation. New pipe support carts were created allowing 40 per cent more hangers per cart than in previous renditions to be shipped but maintaining the same overall size cart. For field install, a scissor lift attachment was created that would receive a row of hangers from the shipping cart and reduce the trips on and off the lifts when installing han gers. Due to these changes the hanger install has been improved by roughly 40 per cent and in the true spirit of lean practices, much less wasted hardware and threaded rod has been seen.

FIGURE CS6.3
Trolley devised for moving sanitary china to site protected but without packaging



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Shop site integration

Since 2012, all designs have been modelled in 3D BIM to assess accessibility for workmen, to identify spatial constraints during installation and operational maintenance, to assess safety as well as ergonomic issues for workers. 3D BIM is also used to drive an increase in prefabrication and the standardization work. There has been a move to more complex and larger prefabricated elements including multiple services. Such components may take a week to prefabricate, but as little as 15 minutes to install on site.

There is always a tension on site around the demand for crane time for the assembly of large and heavy services components, as this can add a few weeks to the crane schedule. However, at the end of a project, prefabriaction can help to bring a project to completion up to six months early. Furthermore, field labour can be reduced by up to 50 per cent. To capture the benefits of prefabrication, it is important to start planning early, using virtual modelling, to identify opportunities for standardization and for a modular approach as it is critical to guide the design in this direction as early as possible. HVAC tends to have the greatest influence on the design within SI because it dominates in terms of complexity and size. Hence there is a greater need to plan ahead.

3D BIM is also being used to design clash avoidance into the building rather than for clash detection after the design is completed. Laser scanning is used in the field to check the accuracy of construction against the BIM design. There are still challenges in the use of this technology as many operators do not have sufficient experience in setting targets correctly to create an accurate scalable model. However, this is an area of rapid development and is seen as beneficial because it enables rapid assessment of existing services in an existing installation and provides a measure of the consistency between construction and design.

In the design process A3 analyses are used to set out alternative design solutions. This process helps SI engage with the owner and opens up the decision-making process within the whole design team, helping them to make more informed comparisons between different design solutions.

Transferring lean practices across the business

As a part of the overall lean initiative, there has been an increase in management coordination and review. In each region, there is a quarterly meeting of all foremen in the office to share lessons, and to drive best practices and innovation across all projects.

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At this time, outstanding contributions are identified and recognized within the business. In every region within SI, there is a lean board where lessons derived locally as well as from other regions are shared, benchmarking is displayed and challenges to be solved are listed. Finally, superintendents from SI fabrication shops around the country meet twice a year to compare improvement initiatives and operational challenges.

Each year there is an internal development programme in which six people are given a problem to study: in 2014 focus was on leadership, in 2015 it was on lean and the challenges for the organization to transition globally towards lean practices.

Overview of lean achievements

As a founding member of the Lean Construction Institute, Southland has long embraced the lean principles as part of its core operating philosophy. SI continuously seeks the systematic removal of waste in its processes and the efficient use of materials, resources and personnel to improve performance. By applying lean principles over the past 15 years, Southland's efforts have directly translated to the following benefits for Southland, its business partners and clients:

• Process Improvement – as a design–build–maintain provider, Southland has the opportunity to leverage lean principles throughout each stage of the building lifecycle in order to fully maximize the lean approach. A centrepiece of this effort lies within the BIM strategy, which focuses on a single model that addresses the needs of engineering, fabrication, construction and maintenance. This approach reduces waste, aligns project goals and improves communication amongst the entire team while providing clients with a faster and more flexible delivery model that reduces cost and improves schedule.

• Efficient use of materials – working to reduce the use of raw materials, Southland starts with the appropriate selection and design of innovative HVAC, plumbing and fire protection systems and utilizes prefabrication and modular construction to eliminate redundant support systems and improve coordination. Through its extensive use of virtual construction, SI ensures systems are coordinated while mitigating potential rework and waste on the jobsite. With state-of-the-art fabrication facilities, Southland also eliminates scrap and raw material waste along with its associated energy, labour and ongoing operational costs.

Integrated schedules – Southland recognizes that integrated schedules improve communication and maximize the efficient use of resources for all phases of a project.

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SI personnel's deep understanding of the design, coordination, fabrication and con -struction process coupled with the use of technology and lean tools create a unique opportunity to plan, communicate and track progress across the entire project. In doing so, SI is able to further optimize the project schedule, improve communication and assist the entire team to meet the schedule commitments made to clients.
• Productive workforce – essential to remaining competitive and cost-effective, South -land invests heavily in the continual training of employees to keep pace with rapidly changing technology, means and methods, and tools. SI's lean approach naturally focuses attention on prefabrication and modular construction to leverage the potential for improvements in quality, safety, productivity and scheduling. The efficient scheduling techniques adopted by SI allow Southland to retain talented employees through varying work-cycles.
• Cost savings – the culmination of SI's process improvements, efficient use of materials, increased productivity and efficient scheduling tools not only directly reduces costs for Southland but also for other project team members and the owner.

INTEGRATED PROJECT DELIVERY

Southland has been one of the core group of early adopters of lean construction practices in the Sutter Health supply chain. It is a partner in the Van Ness and Geary Campus (VNGC) project, a major Sutter Health project in downtown San Francisco, and the subject of another case study in this book. Southland has participated in many IPD projects, particularly for Sutter Health.

Southland has a history of both integrating its in-house engineering, construction and maintenance expertise and collaborating to develop innovative and cost responsible solutions. SI sees integrated project delivery (IPD) as a natural extension of that philosophy. Essentially expanding its natural approach by aligning the entire project team with those same principles at the start of the project, the use of IPD and the multi-party integrated form of agreement offers significant benefits to the owner:

• Optimized solutions – Forming an alliance between the owner, architect, engineers and contractors at the start of an IPD project, project decisions are made with valuable input from all team members to ensure solutions are optimized project-wide. By leveraging its own internal engineering, construction and maintenance resources, Southland is recognized for its ability to support IPD teams explore and discover new solutions.

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Shared risk and reward – A key tenet of the IPD approach is to use relational contracts that reinforce and reward team collaboration as well as distribute risk amongst the team to those in the best position to manage that risk. Proactively taking accountability for the risks that it is best suited to control, Southland utilizes a variety of tools and technologies to assist in risk management and keeping our team partners informed of progress.

Cost savings – Using target value design to establish scope and project costs, IPD teams pursue solutions that maximize the value for the owner within the funding limits. Given its experience as a design–build–maintain firm, Southland is very skilled at conceptual design and cost estimating and is able to help the team establish realistic solutions and goals. Throughout the design and construction process, Southland engineers utilize their engineering and construction experience to track costs and ensure the client receives maximum value for money.