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Building Information Modelling in 2012:

Research Challenges, Contributions, Opportunities

Jennifer Whyte

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Design Innovation Research Centre, University of Reading, UK

www.reading.ac.uk/designinnovation

designinnovation@reading.ac.uk

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Building Information Modelling in 2012: Research Challenges, Contributions, Opportunities

Jennifer Whyte, School of Construction Management and Engineering
University of Reading, UK.

Abstract

This working paper provides an annotated bibliography of studies on Building Information Modelling (BIM), which were published in English in the first six months of 2012. It discusses the areas of focus in this international research and how the work relates to and informs changes in policy and practice. The paper is written in the context of the UK BIM task group's ambition to implement BIM in public procurement by 2016. The aim is not to provide a comprehensive review, but rather starting points for discussion about the related research challenges, contributions to practice, and future research opportunities.

Contents

Introduction

Across the international research community, there is a growing and evolving research literature on Building Information Modelling (BIM). This working paper takes a snapshot of the recently published research. Rather than discussing the longer-term evolution of the research debates, or reviewing the key texts, such as the BIM Handbook by Eastman, et al (2008), the strategy is to focus on studies published in the first six months of 2012; and use this snapshot to discuss the current areas of focus in the international research; and how these relate to and inform changes in policy and practice.

Practical attention is concentrated on the implementation of BIM by a desire to collate and use 'open shareable asset information'[1] through the life-cycle of buildings and infrastructure. For example, the UK government motivations for using BIM are to address issues of cost, value and carbon (BIS/Industry Working Group 2010, see also www.bimtaskgroup.org). The debate is shaped in terms of the strategic rather than technical issues, engaging public and private-sector clients and ensuring they understand the value of information to the operation of their business; as well as an output of capital expenditure. The Construction Operations Building Information Exchange (CoBIE) (East 2007) has become mobilised as an initial format for translating data between packages at a series of 'data drops' to the client, as it is compliant with BuildingSmart Industry Foundation Classes (IFCs).

Within the UK, this debate about implementing open shareable asset information is not only about buildings, but also about infrastructure. As many leading clients are in infrastructure, there is a strong desire from the Institution of Civil Engineers (ICE) to ensure that BIM includes more than buildings (ICE 2011). On projects such as Crossrail and by clients such as Heathrow, maps are becoming used as a point of access into model and document information. There is some tension between the use of proprietary tools and the specification of open shareable asset information, especially where the rich intelligence and linkages that clients enjoy in particular tools are hard to translate.

Because of both the speed at which the research literature is itself developing and shaping, and the desire to inform such policy and practice in the UK, this review uses a simple and fast method. Recently published research was collated as a starting point for discussion at a workshop on *'Learning from Others'*, as part of a UK BIM Task Group working group in June 2012. It is hoped this may also inform a discussion of the research challenges, contributions of research to BIM practice; and future research opportunities.

[1] This term comes from the UK task-group implementing BIM. See www.bimtaskgroup.org

Method

Research is a process of inquiry: in it, automated search is a useful tool, but judgement is vital both with regard to what and how to search and the interpretation of the findings. This study began on June 20 2012, when all 132 articles in English that refer to 'building information modelling' in 2012 were downloaded from Google Scholar. This search was then repeated on June 24 2012, with all 428 articles in English that refer to 'building information modeling' or 'building information modelling' or 'building information model' in 2012 downloaded from Google Scholar, with citations included. It is this latter search that is used in the analysis. From the 408 unique articles, 160 articles relevant to the topic of BIM that are included here in the bibliography.

The references were put into Endnotes and, on the basis of their title and abstract, roughly coded into preliminary groups. At first the aim was to organise the groups that emerged into high-level sets using the headline areas addressed by the UK BIM strategy group: a) design and construction implementation; b) lifecycle (operations and maintenance); c) clients; d) commercial, legal and intellectual property; and e) training and education. The attempt to map the literature to these areas has however been partial (with most overlap in the first two of these areas). This is both as there are important themes that are emerging in the research that are not yet reflected in policy; and because there are important areas of policy and practice that are no longer active areas of research.

Google Scholar was used, as a more inclusive search engine than traditional academic tools such as EBSCO Search, to rapidly generate an indicative snapshot of recent areas of work. Like Google searches, the boundaries and replication of the search over time are problematic; and the results needed substantial filtering and interpretation. Even in this short timeframe, the search failed to pick up on important reports and articles that were known to be published (e.g. Computer Integrated Construction Research Program 2012) included some articles that are online, but published earlier (e.g. Greenwood, Lockley et al. 2010; Gu, et al. 2010; Whyte, Lindkvist et al. 2011); and included work that referred to BIM rather than have it as a focus (e.g. Andoh, Su et al. 2012; Yeheyis, Hewage et al. 2012). The benefit of this approach is that it has uncovered interesting recent work that a knowledgeable researcher in the area might not have found in established outlets.

At this stage there has been no attempt to systematically read all the articles. Instead, a bibliography is provided, along with a commentary on the themes that emerge.

Emergent Themes

The annotated bibliography of research on BIM that was published in the last 6 months, around which this discussion paper is built, is published in Appendix A. Major themes identified in this bibliography are:

1. BIM, Lifecycle and Sustainability
2. BIM in Design and Construction
3. BIM Technologies
4. Using BIM
5. Professions and BIM

The main themes above summarise a wider set of topics identified in the literature, which are discussed in the sections below, and used to categorise the bibliography. Across these papers, there is ongoing work to customize the use of BIM to a wide range of building and infrastructure types: *hospital design* (Osan, Hule et al. 2012); *accessible homes* (Jrade and Valdez); *sustainable homes* (Mah 2012) *water transmission pipelines* (Gopala Raju Doraiswamy 2011; Alin, Iorio et al. 2012); *subway infrastructure* (Marzouk and Aty 2012); *factory planning* (Chen 2012). Other uses include *historical reconstruction* (Boeykens, Himpe et al. 2012); and the *tracking of particular materials* such as precast/prestressed concrete to the construction site (Venugopal, Eastman et al. 2012).

While some of this research is well developed and published in recognised research outlets, the bibliography also includes work in progress in the form or working papers, conference papers. There was undergraduate, as well as postgraduate, work included in the review; and a number of patents (e.g. Kinghorn and Willems 2012; Li, Chen et al. 2012; Mclean and Quincey 2012; Omansky and Kanner 2012; Shear, Awe et al. 2012).

There is also diversity in the approach to research: some research is normative, proposing frameworks and tools to guide practice; other research is laboratory based, developing new technologies; while other studies are empirical, seeking to articulate the realities of practice. Many studies propose BIM as a solution: an example is a study in which BIM is proposed as a potential solution based on a study of 145 change orders across eight projects in Georgia and Alabama rather than without evidence of the real-world impact of BIM technologies (Olsen, Killingsworth et al. 2012). Below the shape of the literatures associated with the above topics, and the associated references are briefly discussed using examples from the annotated bibliography which follows.

1. BIM, Lifecycle and Sustainability

There is a substantial emphasis in the literature on research that links BIM and sustainability with 42 articles published in the first 6 months of 2012. Though smaller in scale, there is also a notable focus on Facilities Management (FM) and lifecycle uses of BIM, with particular focus on areas such as managing waste.

1.1 Sustainability

While carbon is a motivation for policy of BIM, the connections between digital technologies and sustainability are not well developed in policy and practice. There is however research activity that is beginning to develop new tools to use BIM in order to address a range of sustainability concerns. Russell-Smith and Lepech (2012), for example, develop an activity-

based method for lifecycle assessment, through modelling and benchmarking of building construction. The sustainability concerns addressed by such tools include: *the assessment of environmental impacts* (Lu, Wu et al. 2012); *consideration of waste management issues* (Arif, Bendi et al. 2012; O'Reilly 2012; Rajendran and Gomez); *guidance to designers on environmental issues* (Capper, Matthews et al. 2012; Firoz and Rao 2012; Geyer 2012; Hetherington, Laney et al. 2012; Kanters, Dubois et al. 2012; Mirani and Mahdjoubi 2012; Park, Park et al. 2012; Peters 2012; Rekola, Mäkeläinen et al. 2012; Zeng 2012); and a *response to a government strategy* for carbon reductions in both current and future building stock (McAuley, Hore et al. 2012).

1.2 FM and lifecycle

Recent studies are also examining the use of BIM throughout the lifecycle of construction projects, addressing issues around *as-builts* (Xuesong, Eybpoosh et al. 2012); *facilities management and maintenance* (Arayici, Onyenobi et al. 2012; Ebinger and Madritsch 2012; Shen, Hao et al. 2012); and looking at the *life-cycle of particular materials such as concrete* (Borrmann, Lukas et al. 2012). There is work on *building services*, for example work on Heating Ventilation and Air Conditioning (HVAC) proposing a 3D analyser for lifecycle, with graph based modelling for fault detection (Zimmermann, Lu et al. 2012). There are also a few studies on *renovation* and on *reconstruction* (Boeykens, Himpe et al. 2012; INC 2012; Murthy, Boardman et al. 2012) and on *waste management and minimization* (O'Reilly 2012; Rajendran and Gomez 2012; Yeheyis, Hewage et al. 2012).

2. BIM in Design and Construction

Research is split pretty evenly between a focus on the construction site, manufacturing and supply, with research on equipment and health and safety, and a focus on design and/or project or programme management. The review picked up ten papers relating to lean construction and off-site manufacturing, but these have been excluded except where they specifically reference BIM.

2.1 Construction site, manufacturing and supply

As the bibliography shows, there is ongoing work on issues relating to BIM and the assembly of buildings on site (Arayici, Egbu et al. 2012; Engström 2012; Hilbert, Scherer et al. 2012; Sidawi 2012). Examples of this work include studies on *crane instability in high winds* (Hasan, Zaman et al.); *lifts* (Lee, Cho et al. 2012; Zhang and Hammad 2012) and *site utilization using data from BIM* (Alagarsamy 2012). There is work from a supplier's perspective (Gillenwater 2012).

2.2 Construction safety

There is a notable, though small, focus on safety, with recent studies in the USA and Australia using BIM to develop new techniques for safety compliance checking as well as consideration of safety in design (Chun, Li and Skitmore 2012; Zhang, Lee et al. 2012).

2.3 Design, project and programme management

The use of BIM earlier in the process, in the design stage, is considered by a number of authors (e.g. Chun, Li et al. 2012; Fleischmann and Menges 2012; Fouchal, Hassan et al. 2012; Mela, Tiainen et al. 2012; Raisbeck 2012; Sharma 2012; Whyte, Lobo et al. 2012). These papers overlap with the work on architecture, but tend to take a broader view of the design of the built environment considering practices across occupational boundaries and professional groups. There are also a number of studies looking at effects on project managers and project management (e.g. Cheng and Wang, 2012; Di Marco, et al. 2012).

3. BIM Technologies

In the more technical literatures, there is a particular focus on developing new tools for the integration of knowledge and the interoperability of systems; on naming and code-checking; semantics, modelling; data capture and connections between geographic information systems (GIS) and BIM. There are also a number of generic papers on BIM (Isikdag, Underwood et al. 2012; Tah 2012; Vries 2012; Wang, Zheng et al. 2012); and work on developing technologies in particular focused areas such as *cloud computing* (Redmond, Hore et al. 2012).

3.1 Integration and interoperability

There is work on interoperability and the technical and social challenges of using information (e.g. Clark and Bettin 2012; Fisher 2012; Forgues, Iordanova et al. 2012; Jacob and Varghese 2012; Viljoen 2012; Wu and Hsieh 2012). This develops new tools for both the integration of knowledge in software solutions; and for interoperability between packages.

3.2 Naming and code-checking

There is a substantial literature on the *naming conventions and code checking tools* that can facilitate open shareable asset information (e.g. El-Diraby 2012; Fox 2012; Kramer, Klein et al. 2012; Laakso and Kiviniemi 2012; Lee and Jeong 2012). Within this literature there is onging work on IFCs, both in relation to their history and their future development, as well as other processes associated with open shareable asset information.

3.3 Semantics, modelling

There are a number of papers that refer to semantics (e.g. Béhé, et al 2012; Domínguez et al 2012; or investigate other aspects of modelling and simulation, including agent-based approaches. Also classified in this sub-theme are papers that use fuzzy information for tool selection (Cevikcan and Öztayşi 2012; Jiang et al, 2012), or ontology-based approaches (Karhela, et al. 2012; Lee and Jeong 2012; Venugopal et al. 2012; Zhong et al. 2012).

3.4 Data capture

There is new work on laser scanning and the interfaces between data-capture and Building Information Models (Babić, Pribičević et al. 2012; Wang and Cho 2012) with particular projects developing methods for creating semantic models (Dumitru 2012) and exploring

the potential to combine data from laser scans and Radio Frequency Identification Devices (RFID) (Valero, Adan et al. 2012).

3.5 GIS

BIM is also being mobilised with GIS in planning applications (Thompson, Horne et al. 2011; Xu, Tucker et al. 2012) and using BIM and GIS at an urban level in the Peipu township in Taipai (Lee 2012). Development research on GIS includes a study seeking to combine crowd-sourcing and GIS for multi-level interior environments (Goetz 2012); and develops new techniques for utlizing BIM and GIS (Hijazi, Ehlers et al. 2012).

4. Using BIM

Alongside the research that is focused on tool development, there is research that is examining the use of BIM, its economic, political and social implications, the attitudes and behaviours of users, and issues arising during its implementation.

4.1 Economic impact

There is now work developing tools and metrics to assess the economic impacts of BIM (e.g. Lee, Park et al. 2012; Love and Sing 2012; Schiuma, Carlucci et al. 2012; Succar, Sher et al. 2012). This is an area of particular practitioner interest, as BIM implementation becomes mandated in some regions, and as firms seek to understand the commercial benefits of the technologies.

4.2 Political and social implications

There is also considerable research on the political and social implications of these technologies (Gajendran and Brewer 2012; Grilo, Zutshi et al. 2012; Gustavsson and Gohary 2012; Lahdenperä 2012; Nawaz, Efstratiou et al. 2012; Neff, Jordan et al. 2012). This work looks at how the technologies change and mediate interactions across the networks of workers that become involved as multiple parties collaborate.

4.3 Attitudes, behaviours and implementation

Other research explores the attitudes and behaviours (Brewer and Gajendran 2012; Hatem, Kwan et al. 2012) experimentally to examine the effectiveness of different strategies for communication. There is also more contextual work, that examines a range of issues of implementation in relation to changes within different countries and contexts, such as Australia, Ireland and the UK (Kraatz and Hampson 2012; McAuley, Hore et al. 2012; Underwood and Khosrowshahi 2012).

4.4 Education

As BIM strategies are implemented by governments, there is interest within the higher education sector in new ways of teaching BIM. Papers report on experiments with BIM in the academic design studio (Ambrose 2012); studies of student visualization (Glick, Porter et al. 2012); teaching sustainable building (Korkmaz 2012) and interoperable learning (Leed

and del Puerto 2012); as well as the learning cycle of graduates and the industry expectations (Ahn, Annie et al. 2012; Chen and Shaurette).

5. Professions and BIM

Some of the research on BIM takes a particular disciplinary or professional perspective. There is a literature specifically written *for* particular professions, which provides practical guidance to help them to make sense of BIM; and another literature, which is *about* professional interactions and thus more theoretically focused on understanding the changes in roles that accompany BIM. This work can be crudely categorised by professional area:

5.1 Architecture

There is a growing literature about architecture and BIM (Boyd 2012; Ceccato 2012; Coates and Arayici 2012; Coenders 2012; Fouche, Smallwood et al. 2012; Leeuwis 2012; Lillicrap 2012; Segonds, Nelson et al. 2012; Svoboda, Novák et al. 2012). While this overlaps with the literature described above in section 2.3 on design, it is distinguished here as the focus on the architect, and questions about how to use BIM in architectural practice, is particularly, salient in some of this writing.

5.2 Quantity surveying and cost estimating

There is also a literature that sets out frameworks for guidance of quantity surveyors and cost estimators (Cheung, Rihan et al. 2012; Marzouk and Hisham 2012; Quek 2012; Towey 2012; Tse and Wong 2012). There are expectations that this work will be changed by the widespread use of BIM and consideration of how these activities can be achieved through the new tools.

5.3 Civil engineering

While there are no papers that specifically focus on BIM and the civil engineer, as shown in the bibliography, there is research on the use of BIM in transport, bridge construction and subways. Hence there are a number of reserachers using the term BIM to refer not only to buildings, but also to similar developments in information management for infrastructure and heavy civil engineering projects. This enables a cross-fertilization of ideas across infrastruction and buildings.

Research Contributions and Opportunities

The approach to this review reveals the sheer scale of the research literature, which makes it difficult for any individual or small team to read everything related to the BIM topic, even over such a short timescale. This may lead to both specialization within particular themes, and to authors referring to seminal papers to represent concerns within a wider theme within the literature.

These studies reveal strong current research interests, for example in developing new BIM tools that address lifecycle and sustainability concerns; in helping professionals to make

sense of these tools in practice; in the political and social implications of new ways of working and new techniques for checking models. Work examining technical aspects, of the use of standards such as IFC or COBIE, or technologies such as laser scanning and data-bases, may not be fully captured in this where it does not use the more generic term 'Building Information Modelling' though the annotated bibliography does indicate this as a strong ongoing area of research. There are also a set of studies that respond to policy making in various countries, Australia, Ireland, UK, and seek to critique and make sense of the industry developments, from the perspective of various professional stakeholders.

Consideration of the themes in this literature does indicate some possible directions for future research. There is, for example, a lack of work that examines the use of BIM strategically from the client perspective. This work is needed both to provide a practical guide and to understand the client role in different models of practice. There are also promising new directions of research that explore the synthesis of data from data capture, modelling and GIS, and that examine data over the life-cycle of buildings and infrastructure assets.

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