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A REVIEW OF BUILDING INFORMATION MODELING PROTOCOLS, GUIDES AND STANDARDS FOR LARGE CONSTRUCTION CLIENTS

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SUMMARY: *Large construction clients (companies, public authorities and government departments) perceive the need to facilitate and accelerate adoption of Building Information Modeling (BIM) for their projects because they derive significant benefits from its use for design, construction and operation of their facilities. Preparation of appropriate BIM guidelines that can be mandated through contracts is one of the main steps they can take to promote adoption. With a view to aiding such organizations to compile comprehensive guideline documents, we present a qualitative content analysis of fifteen BIM guideline, standard and protocol documents published to date, identifying both common features and missing aspects. While the main topics covered are similar across all the standards and guides – interoperability, collaboration modes, BIM execution plan, simulation & analysis, BIM manager's role and operation & maintenance requirements – their content, specificity, frequency and level of resolution are different. The category and topic analysis led to derivation of a set of essential requirements. Recommendations are provided to help organizations/governments compile their own documents and establish policies compatible with their specific context and needs.*

KEYWORDS: *Building Information Modeling, Computer-Aided Design, BIM Implementation Guides, Interoperability, Standards, Textual Analysis.*

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1. INTRODUCTION

Building Information Modeling (BIM) represents a fundamental change to the way in which the Architecture, Engineering and Construction (AEC) industry functions and communicates. However, adoption of BIM tools by architects, engineers, builders and owners does not guarantee realization of the benefits of the technology because much of the potential benefit derives from the deepened collaboration among the participants in a construction project that BIM facilitates (Eastman et al., 2011). For design companies, the 'low-hanging fruit' of automation of drawing production is easily harvested. Yet the project wide benefits – such as reduced rework during construction, enhanced value of the building as a result of sophisticated building performance simulations informing design decisions, and improved construction productivity thanks to better communication from designer to builder – are more difficult to achieve because these require collaboration across organizational boundaries. Individual or local adoption efforts are therefore insufficient; there is a need for guided and systemic implementation.

To achieve this, construction owners publish BIM protocols in which they prescribe how their service providers should use BIM in ways that deliver them value, and they mandate the application of the protocols in their construction contracts. In terms of Kassem et al.'s BIM Knowledge Content taxonomy (Kassem et al., 2015), these documents are *mandates*. Government agencies create the regulatory framework necessary for promoting and supporting BIM adoption through national standards. Most of these are descriptive (*guides* in the taxonomy), but some are prescriptive (*protocols* in the taxonomy). The names given to the various documents by their authors are not consistent, and some of the mandates are termed 'guidelines' or 'standards'. Governmental and construction owner organizations have published a plethora of such BIM documents, including standards, collaboration guidelines and/or project-level BIM execution plans (BuildingSmart, 2016). The documents define how BIM is to be used in collaborative practice, the phases of the design and construction process and the information that must be provided in each exchange in the process, the technologies that are to be used, and other aspects of adoption.

The mandate, protocol and guide documents differ widely from one another, in their purpose (goals and vision); approach to standardization (some are highly prescriptive while others define intent and general levels of performance); scope (from national industries to individual owner or project organizations); technology requirements and specificity; definitions of the design and construction process and the level of information detail specifications. The differences arise from the variations in business context, goals and scope of the different organizations. This makes it very difficult for governmental and other public organizations starting to plan their BIM adoption strategy to draw on this pool of knowledge to compile a policy that is compatible with their specific context and needs. Policy makers ask themselves: "What issues must be covered in my organization's guidelines, and at what level of detail?"; "What are the capabilities of my organization's suppliers (contractors, designers, etc.)?"; "How can they collaborate with BIM within the constraints of local legal, contractual and professional systems?"

To help policy makers, this paper reviews the issues covered in 15 BIM documents and analyses the similarities and differences between them in relation to the type of organization. The goal is to provide a resource for governmental and public organizations efforts to develop, evaluate or update BIM documents that are best suited to the needs of their organization.

The next section outlines the role that standards, guides and protocols have played in the adoption of Information Technology (IT) in construction. It also covers the history of Computer-Aided Drafting (CAD) standards in the construction industry and the organizational changes that IT brings to business processes. Section 3 defines how the 15 BIM documents were selected and establishes the criteria for their review and analysis. Section 4 presents the results of the analysis and Section 5 discusses their implications.

2. BACKGROUND

2.1 Role of standards and guides in IT adoption in construction

Industry, national and international standards and guides enable interchangeable use of products across broad industries. They allow manufacture of products that are compatible with other products without the need for direct coordination between the manufacturers or designers of each product, thus obviating the need for design coordination and communication. Hemenway (1975) classified standards by purpose (quality or uniformity) and degree of coercion (voluntary vs. mandatory).

The construction industry is highly fragmented, with the majority of workers employed in small to medium sized enterprises (Eastman et al., 2011, p. 265). In this environment, and particularly in the domain of building construction, standards and guides are essential. Standards define design methods, performance levels for a building's functionality, methods for engineering calculations, modular dimensions of building products, and a range of other aspects. Standards are often mandatory within a given jurisdiction. Guides, on the other hand, are not mandated by a nation's law, but they may or may not be contractually binding, depending on the policies of the organization who publish and/or use them.

Adoption of information and communication technology (ICT) in construction can address many of the problems that arise from the highly fragmented business structure (Howard et al., 1989), but ICT adoption itself must be regulated by standards. In the broad ICT industry, standards play a central and essential role in product creation and competition (Gallaugher and Wang, 2002; West and Dedrick, 2000). Standards facilitate communication which is critical when working across domains, specialists, nations and time. Moreover, standards in this domain are usually adopted through consensus of organizations or individuals involved with the technology and rarely mandated by a national government agency (West, 2003).

2.2 Role of CAD standards in the construction industry

Computer-aided design and drafting became common in the Architecture, Engineering and Construction (AEC) industry after personal computers became available in the 1980's. Drawings were the primary means of communication in the construction industry for centuries, and many industry and professional organizations had developed standards and guides for drawing layout, content, dimensioning, etc. The first phase of ICT application for building design simply automated production of drawings, and was termed 'CAD' (computer-aided drafting). Thus the first standards for CAD drawings defined conventions for naming schemes, file locations, text styles, line types, units, preferred CAD software applications, dimensioning schemes, drawing organization, layer names, title blocks, archiving, and network location.

The American Institute of Architects (AIA) CAD standards were among those developed in the early 1990's (Howard and Björk, 2007). These allowed the design and construction teams in any project or company to communicate and share data between the different design and construction disciplines, facilitating cross-referencing and retrieval of information from the drawings. They also defined scheduled updates (Erdener and Gruenwald, 2001) and backup procedures. CAD standards were intended to solve communication problems within and between different organizations. Eventually, national and international CAD standards such as BS 1192 (BSI, 2007) and ISO 13567-2 (ISO, 1998) were broadly adopted, resulting in industry wide standardization in CAD drawing production.

An economic benefit analysis of the adoption of the Singapore national CAD standard for construction permit applications estimated that implementation of the standard resulted in S$320m over the ten year period that was studied (BCA, 2014). This is equivalent to a 4% improvement in design productivity. The standard played a critical role in improving communication, saving time and effort by reducing the document preparation time, increasing accuracy and reducing costs by eliminating the need for redundant paper prints.

2.3 Reviews of BIM Documents in the Research Literature

Many researchers have reported on the growing number of BIM documents published around the world. Cheng and Lu (2015) provide the most comprehensive listing, reporting on 123 BIM documents published from 2007 to 2015 by non-profit agencies and government bodies in four regions. The presence or absence of four content subjects were reported for each document (Project Execution Plan (PEP); modeling methodology; Levels of Detail (LoD); Component presentation style and data organization), but no details were provided.

Similarly, the BuildingSmart 'BIM Guide Project' database listed some 81 BIM documents as of May 2016 (BuildingSmart, 2016). The goal of the BIM Guide Project is to give insight and direction to those needing, using and creating BIM Guides, Standards and Supporting Documents. The project enables volunteers to review BIM guides using a fixed review template and a set of pre-defined BIM concepts. Keenliside (2015) provides a thorough explanation of the project as a basis for comparative analysis of BIM guides. A number of reviews of guides using the method are available, but no comparative analysis.

Chae and Kang (2015) analyzed eleven BIM documents published by public construction organizations. A simple count of frequency of appearance of terms was used to determine the skills that are most important for new adopters of BIM. However, the BIM skills are undefined and as the authors' explain, frequency of terms is not necessarily an indicator of the importance of a skill. Edirisinghe & London (2015) reviewed six national BIM standardization efforts (US, UK, Singapore, Australia, Finland and Norway). They hypothesized a positive correlation and a causal relationship between the development of a national BIM standard and the rate of adoption in a country. Despite some circumstantial evidence for the US and UK, they were unable to confirm this hypothesis. A similar effort to identify the impact of national BIM adoption efforts on BIM adoption rates in Norway, Denmark, Finland and Singapore was also inconclusive (Wong et al., 2010), although it provides a broad review and analysis, of which BIM guides are just one aspect.

Kassem et al. (Kassem, Iqbal, Kelly, Lockley, & Dawood, 2014) examined 13 BIM documents. They classified them, inter alia, as relating to industry level, enterprise level and/or project level. Nine were found to be relevant at the industry level, six at the enterprise level, but none at the project level. The authors therefore proposed protocols for BIM collaborative design that can be used at project-level. The protocols are essentially tools that can be used for preparation of BIM Execution Plans and to guide their implementation at the project level. They include tables of responsibilities of stakeholders for work streams and for BIM components, flowcharts for process control, and are based on analysis of the technology, policy and process aspects. However, the scope of the work does not provide guidance for development of enterprise level guides.

Kassem et al. (2015) reviewed 57 BIM publications from eight countries and defined their intent, degree of prescription or description, and the degree to which they are mandated by their authoring organizations, using a taxonomy of ‘BIM Knowledge Content’. They reviewed the background, evolution and quality of each document, identifying its intended use. However, they do not report which specific areas each document covers nor do they provide qualitative analysis of the topics covered.

2.4 The Challenge of Interoperability

The first thrust of standardization in the area of BIM arose from the need to standardize exchange of 3D CAD information across CAD platforms from different software vendors. The ‘Industry Alliance for Interoperability’ (IAI) was established in 1995, some years before the term ‘BIM’ was coined. The IAI’s mission was to compile a set of Industry Foundation Classes (IFC) to provide a common data schema for building model exchange. This resulted in the IFC schema, which eventually became ISO standard 16739:2013 (ISO, 2013).

The origins of the IFC standard are in the early CAD graphics file exchange standards, such as IGES and DXF (Eastman et al., 2011, chapter 3), and in the product data model exchange schema from the manufacturing industry, called STEP (Standard for the Exchange of Product Information), or ISO 10303-1.(ISO, 1994). The IFC schema uses the Express schema modeling language, which it inherited directly from STEP.

As the need for specialized and highly specific data exchanges between different professional domains within the AEC industry became apparent, the inability of the IFC standard to deliver on its promise of universal exchange became clear, arising from its generality and redundancy. The mainstream solution to this problem is to compile domain specific Model View Definitions (MVD), which define the conceptual constructs that are needed and the ways in which these are to be implemented in schema such as the IFC (Eastman et al., 2010). This approach is embodied in the first steps of the process outlined by the US National BIM Standard (NBIMS-US, 2014). It requires significant efforts on the part of the BIM software industry, both for definition of MVDs and for building the necessary export modules, and is therefore still a work in progress. A complementary approach, involving semi-automated semantic enrichment of models to suit the requirements of the importing software tool, has been developed (Belsky et al., 2015), which may obviate the work of programming multiple export functions.

Note that the IFC building product model exchange standard is insufficient in and of itself for the purposes of the documents discussed in this paper. Although some of these documents have been labeled as 'standards', a clear distinction between BIM Standards and BIM Guides is called for. *BIM Standards* define the structure and mechanisms of BIM data exchanges, and include the IFC Standard and the set of domain specific MVDs. *BIM*

Guides are the national, organizational or project level documents that establish common ways of working and the contents of BIM exchanges that are appropriate within the relevant contexts and along project timelines.

2.5 Conclusion

BIM adoption is a complex endeavour, requiring preparation of a strategy that considers organizational maturity, industry capabilities, regional and national policies and regulations, education, purchase of hardware and of software, changing contract forms and more. Mitropoulus and Tatum (1999) underlined the fact that companies found that 3D CAD, the less complex predecessor technology of BIM, was challenging to adopt.

Five case studies of major construction procurement agencies in the UK (Gurevich et al., 2016) showed that even where organizations function under the umbrella of a broad governmental mandate for BIM adoption, the specific needs of each organization are different and require a customized set of guidelines to specify appropriate processes. The case studies revealed that BIM guidelines are one of five common actions that the organizations pursued in the adoption of BIM, along with leadership (formulation of strategy), training, standardization (including preparation of BIM content libraries) and preparation of appropriate contract clauses.

3. METHOD

The main method used to review and analyze the BIM documents was conventional inductive qualitative content analysis (Hsieh and Shannon, 2005; Kohlbacher, 2006). The analysis used a sample set of 15 documents. The content categories, or topics, were compiled from the documents themselves. The following sub-section lists and describes the documents, while sub-section 3.2 outlines the content topics.

3.1 Documents reviewed

In the last decade many construction client organizations (commercial companies, public authorities and governments) have facilitated the use of BIM on their projects in ways that maximize the benefits. The primary tools to achieve this have been preparation and enforcement of BIM guidelines, whether through contracts or standards. A set of 15 such documents, listed in TABLE 1, was selected for analysis from the 81 documents listed by BuildingSmart (2015). The criteria for selecting these 15 include their degree of exposure in the AEC industry, chronological precedence, and representation of client organization and associated document types. The documents in this set represent a cross-section of documents from three types:

- national, state or city standards published by governmental or other public agencies,
- owner’s guides published as contract documents by large-scale construction owners, and
- guides for design, construction and maintenance of campuses published by universities and colleges.

As can be seen in TABLE 1, the first documents of this set were published in 2009 by government construction agencies and academic institutions. The national standards began to appear in 2012. Whereas US construction clients have pioneered the demands placed on suppliers, a number of countries have published national standards, some of which – as will be seen from the analysis in the following sections – are more comprehensive in scope than the US National BIM standard. Table 1 also indicates the degree of authority exercised by each document: Standards may be voluntary or mandatory within a government jurisdiction, and guidelines may or may not be given the status of contractual requirements.

Note that in the remainder of the paper the documents are referred to using the abbreviated ‘document short name’ listed in TABLE 1.

TABLE 1: BIM guides and standards selected for review.

Document Name	Document short name	Publishing Organization	Organization Type	Country	Publica-tion date	Citation
LACCD BIM standards	LACCD	Los Angeles Community College District	Academic institution	US	2009	(BuildLACCD, 2009)

Document Name	Document short name	Publishing Organization	Organization Type	Country	Publica-tion date	Citation
Georgia Tech BIM Requirements & Guidelines for Architects, Engineers and Contractors	GT	Georgia Institute of Technology	Academic institution	US	2011	(Georgia Institute of Technology, 2011)
Building Information Guidelines	USC	University of Southern California Capital Construction Development and Facilities Management services	Academic institution	US	2012	(USC, 2012)
BIM Guidelines & Standards for Architects, Engineers and Contractors	Indiana	Indiana University	Academic institution	US	2012	(Indiana University Architect's Office, 2012)
COBIM (Common BIM Requirements)	Senate	Senate Properties	Government construction authority	Finland	2012	(Senate Properties, 2012)
Statsbygg BIM manual 1.2.1	Statsbygg	Statsbygg	Government construction authority	Norway	2013	(Statsbygg, 2013)
Official Manual For BIM projects	COE	New York District, U.S. Army Corp of Engineers	Government construction authority	US	2009, updated 2010	(ACOE, 2009)
GSA BIM Guide	GSA	General Services Administration	Government construction authority	US	2010	(Matta et al., 2007)
The VA BIM Guide	VA	Department of Veterans Affairs	Government construction authority	US	2010	(Tietjen, 2010)
State of Ohio Building Information Modeling Protocol	Ohio	State of Ohio General Services Division	State government	US	2009	(State Architect's Office, n.d.)
NATSPEC National BIM Guide	NATSPEC	NATSPEC	National Standards Agency	Australia	2011	(NATSPEC, 2011)
US National BIM Standard	NBIMS	National Institute of Building Sciences - Buildsmart alliance	National Standards Agency	US	2012	(NBIMS-US, 2014)
Singapore BIM Guide	Singapore	Building and Construction Authority	Government agency	Singapore	2012	(Building and Construction Authority, 2013)
AEC (CAN) BIM Protocol	CanBIM	CanBIM	Industry non-profit organization	Canada	2012	(CanBIM, 2012)
BS 1192-4 and PAS 1192-2:2013	UK	BSI Standards Limited	National Standards Agency	UK	2013	(BSI, 2013)

3.2 Topics for content analysis

Taken as a whole, the set of documents covers a broad spectrum of issues that are relevant to owners. Each organization considers its unique needs and context, so that while the main topics covered are similar across all, some have requirements that are unique to their organizational type or even to their specific organization. The requirements also vary in their content and in their level of resolution, and different terms are used in different documents to refer to the same topics. Ten topics were selected for review as follows:

1) Each document was read and its topics were identified.
2) The contents of the topics were compared to identify instances where different names or headings were applied to the same topic. A list of synonymous or equivalent terms for the same topics was compiled.
3) Combination of topics with equivalent terms resulted in a list of 14 distinct topics. FIG 1 below illustrates the frequency of appearance of the topics in the document set (i.e. the number of documents in which each topic appears).
4) A threshold level of 2/3 was applied: the topics that appeared in at least 10 of the 15 documents were selected. Thus, nine topics that met the threshold level, as can be seen in FIG 1, were selected.
5) Two additional topics - *Integrated Project Delivery* (IPD) and *Schedule of design payments* – were developed subsequent to the publication of most of the documents, resulting in low frequency. Given special interest in these topics on the part of construction procurement agencies, they were included in the analysis: IPD was included as a sub-topic within *Modes of Collaboration*, and *Schedule of design payments* was included in its own right. This resulted in a set of ten topics.

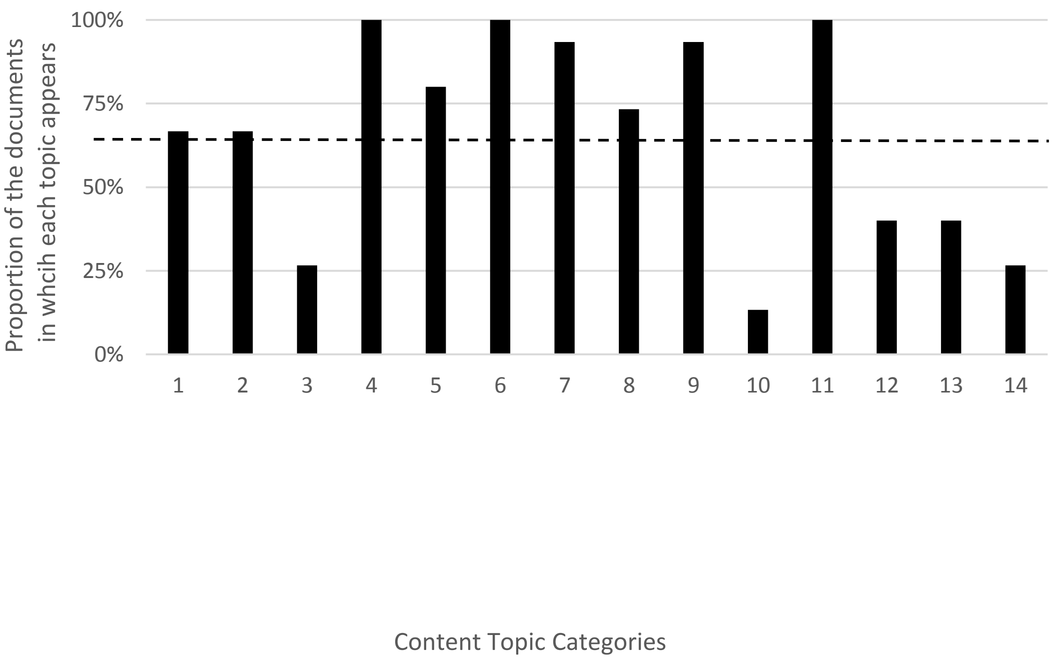

FIG 1: BIM document topics and their frequency of appearance.

The ten selected content review topics are listed below. For each topic in the list, the selected primary term is shown in bold text and the synonyms are listed in parentheses following the primary term.

1. **Interoperability** (open architecture, data management): requirements that stipulate how service providers are to provide their building model data, and specifically in what formats, so that information can be exchanged between providers in any given project team and between the project and downstream information clients, such as facilities maintenance and operations.
2. Role of the **BIM Manager** (project coordination manager, project model manager, BIM model manager, DB team BIM facilitator): what are the responsibilities and functions of the person or persons nominated to manage the building models in a project?
3. **Modes of Collaboration** (Coordination, Clash detection): some guides dictate how project partners are to collaborate, in some cases defining technical information sharing arrangements, and in others going so far as to define the contract forms that are to be used (such as IPD).
4. **Pre-qualification of Designers** (BIM proficiency): what is the minimum set of skills and experience in BIM required for designers and other partners to participate in a construction project, and what are the methods for establishing conformance to that set?
5. **BIM functions through project phases** (design phases): what are the major phases of the project, what are the deliverables in each phase?
6. **Level of Development/Level of Detail** (level of maturity, modelling requirement, level of model definition): most guides specify the degree to which a model should be developed or detailed by each design discipline at each phase of the project.
7. **Operation and Maintenance Requirements** (COBie): what are the contents and formats of building information required for handover to the operations and maintenance functions?
8. **BIM Execution Plan** (Project BIM work plan, BIM management plan. BIM data acquisition guidelines, Asset information model (AIM) maintenance): many guides call for each project team to establish a formal and specific plan for integration of BIM in a project's information flows, rather than stipulating these conditions in the document itself.
9. **Simulations** (analysis, simulation, energy modelling): much of the value of BIM lies in the ability to run software simulations of the behavior of the designed building to check compliance to specifications. Some of the documents seek to ensure the use of these tools by mandating specific simulations and analyses.
10. **Schedule of Payments** (changes to design fees) – when designing with BIM, designs are generally developed in greater detail earlier in the project than they would be using traditional design tools. Some documents, particularly those prepared by construction client organizations, stipulate changes to the payment schedules for designers to recognize this, moving some percentage of the designers' fees to be paid earlier in project life-cycles.

Additional topics of the documents were inferred from the ways in which each treats the above topics. These include the maturity of the document relative to the others in the sample, the extent to which the document was influenced by earlier CAD standards and guides, their evolution over time and the stage of adoption.

4. SIMILARITIES AND DIFFERENCES

4.1 Interoperability

Project teams using BIM have two possible paths to share their building models: 'Open BIM' (Liebich, 2010), which implies broad exchange of models with minimal restriction of the choice of BIM software tools used; or a single platform path, which restricts all project partners to use applications from a vendor-specific suite of BIM software. The only existing possibility for the Open BIM path is to specify compatibility with the IFC standard (ISO, 2013), including the need for BIM tools to provide import and export of IFC format files. Although IFC is broadly recognized in the AEC industry, it still does not provide complete data exchange in all situations (Belsky et al., 2015), and it is this limitation that leads some organizations and projects to opt for the vendor-specific path.

All of the BIM documents reviewed contemplate the use of IFC for building model exchanges, and this is one of the few universally recognized recommendations. It reflects the understanding of BIM as a process that is both an enabler of but also dependent on information exchange across disciplines. Effective information exchange supports collaboration, and this is a major focus of the organizations that aim to improve efficiency of the entire building procurement process.

However, although all of the documents lay out some form of IFC compatibility requirement, they vary in the level of detailed specification they prescribe. Organizations with well-defined business purposes like the VA, GSA, GT, LACCD, Senate and Statsbygg, have the greatest focus on interoperability of the model and compatibility with open standards. These construction client organizations all have specific requirements, with the latter two demanding provision of models that are compliant with IFC 2x3 certification. Statsbygg goes even further, listing extensive tables that focus on different aspects of IFC documentation. The LACCD guide specifies in detail which IFC object classes must be used and which parameter values need to be provided, although the process is not well laid out and no mention of a checking mechanism was found. Others are not as stringent and simply mention IFC as a tool to achieve greater interoperability between the models. The documents of the other comparable organizations, such as Indiana, are conspicuous in that they do not have specific open BIM requirements. Statsbygg also recognizes that there are inherent difficulties in making the models fully interoperable and this theme can be seen across all documents as they struggle to articulate the step by step process of integration.

National level standards like CanBIM, Singapore, UK, and NBIMS approach interoperability thematically with little specifics but emphasize the topic's importance. CanBIM recommends a Common Data Environment (CDE) to share work efficiently across disciplines while maintaining integrity of the model. The UK document classifies the interoperability capability of the model into not capable, some capability and fully capable. This approach makes implementation of BIM a step-by-step process for owners and contractors, avoiding the challenges of one-step change.

4.2 Role of the BIM manager

TABLE 2 below details the composition of the BIM team and the responsibilities of the BIM manager as they are specified by the 15 documents. With only one exception[1] all of the organizations take the position that responsibility for the implementation and management of BIM in a project must be carried by a designated professional whose job description is distinct from all the regular professional roles in a construction project executed without BIM.

The documents vary widely, however, in their definitions of the way in which this role is to be fulfilled. Some stipulate a BIM manager who is employed directly by the owner, others envisage a BIM manager appointed by the architect, and others see the role as the responsibility of the general contractor. Ohio is unique in that it requires the BIM manager to be employed by the architect who coordinates the design and assigns the BIM manager responsibility for the entire BIM model throughout the project. There appears to be no relationship between the organization type and the assignment of responsibility to owner, designers or contractor.

As the table shows, most of the documents do not detail which project partners must be active members of the BIM management team. Five documents distinguish the role of BIM modeler from those of BIM manager and of designers. The implication is that BIM modeling is a specialized task, not necessarily performed by the designers themselves. This is primarily seen in the earlier documents, (LACCD, COE and Ohio), which may have been written within a business context in which adoption of BIM by these organizations service providers was still uncommon. The later documents all assume that BIM models will be compiled by the designers.

[1] The Statsbygg BIM Manual focuses on the technical information requirements for BIM model delivery. It does not specify any management processes and does not mention the role of BIM Manager.

The BIM manager’s responsibilities can be divided into organizational and technical aspects, although not all of the documents address both of these aspects. UK, CanBIM and USC do not specify any technical responsibilities; GT and UK do not specify organizational responsibilities. Of the remaining 10 documents, the primary focus is on the technical aspects. The most commonly cited technical aspects are model and data synchronization, interoperability practices, model quality control, data security/backup protocols and clash detection/ spatial coordination. Three organizations assign responsibility for clash detection (spatial coordination) to the BIM manager (VA, Ohio, LACCD and NBIMS), whereas others assign this task to a specialized project coordinator (CanBIM and UK).

The documents for most of the government construction authorities thoroughly define the organizational aspects: coordination of the BIM team’s activities, strategic planning, control of model editing permissions, and design of the information process workflow. Surprisingly, the academic organization guides do not stipulate the organizational roles as thoroughly. Some of the documents (Indiana, GT, LACCD, NBIMS, NATSPEC) require regular meetings for coordination of the model, while others prefer to view the BIM manager as the central hub through which information flows.

TABLE 2: Role of the BIM manager

	Employer	BIM team members							BIM manager's responsibilities											
									Organizational				Technical							
	Owner/Architect/ Contractor	BIM manager	BIM modelers	Construction	3D Detailers	Designers	Coordinator	Data management	Coordination of BIM team	Strategic planning	Control of model editing permissions	Information process design	Model and data synchronization	Interoperability practices	Model quality control	Data security/backup protocols	Clash detection/ spatial coordination	Cloud or other storage	Updating the as-built BIM model	Specification of software tools
LACCD	C	✓	✓		✓	✓			✓	✓	✓		✓	✓	✓	✓	✓	✓		✓
GT	C	✓				✓							✓		✓					
USC	O	✓				✓			✓											
Indiana	A	✓				✓			✓				✓							
Senate	O	✓				✓			✓	✓	✓	✓	✓	✓	✓					
Statsbygg	ND					✓														
GSA	O	✓				✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
COE	O	✓	✓			✓			✓	✓	✓	✓	✓	✓		✓		✓		
VA (design)	A/E	✓	✓			✓			✓	✓			✓	✓	✓	✓	✓			
VA (construction)	C	✓				✓			✓	✓		✓	✓	✓		✓			✓	
Ohio	A	✓	✓	✓		✓						✓	✓		✓		✓			
NATSPEC	C	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓			✓		✓	✓	
NBIMS	O/C	✓				✓			✓		✓		✓	✓			✓			
Singapore	O	✓				✓			✓				✓	✓	✓					
CanBIM	ND	✓	✓			✓	✓		✓	✓										
UK	O	✓				✓	✓	✓												

A = Architect; E = Engineer; O = Owner; C = Contractor; ND = Not defined

4.3 Modes of collaboration

Collaboration among the different construction disciplines is a necessary condition for exploiting the benefits of BIM adoption; this is one of the primary motivations for development of BIM guides and standards at all levels. It is not surprising therefore that all of the documents provide guidance of one sort or another regarding the modes by which project partners are expected to share information and collaborate in both design and construction.

About half of the documents reviewed mandate regular meetings to coordinate all the activities of the BIM team, while others prescribe physical or digital common spaces to share information and ideas between the team members in order to foster collaboration. One trend seen in the approach to collaboration is that many standards specify that design and/or detailing should be pursued in a "Big Room" (Alhava et al., 2015), in which designers and builders of all disciplines are co-located for some or all of the duration of a project. Only two of the documents (Senate and Statsbygg, both state-owned property development companies), do not prescribe how partners are to collaborate, leaving the choice of mechanisms for the partners to determine themselves.

TABLE 3 shows the functions expected to be fulfilled through collaboration in the project. File sharing and model management are two of the important functions of collaboration while quality control and reviewing is used by only some of the documents.

TABLE 3: Modes of Collaboration

	Mode of collaboration			Scope of functional requirements		
	Mandatory meetings	Big Room	Digital collaboration	Model management	File sharing	Review & quality control
LACCD	✓	✓	✓	✓	✓	✓
GT	✓		✓	✓	✓	
USC		✓	✓			
Indiana	✓		✓	✓	✓	✓
Senate					✓	✓
Statsbygg					✓	
GSA	✓			✓	✓	
COE		✓		✓	✓	✓
VA		✓	✓		✓	
Ohio			✓	✓		✓
NATSPEC	✓	✓	✓	✓		✓
NBIMS	✓		✓	✓	✓	
Singapore	✓				✓	
CanBIM			✓	✓	✓	
UK			✓			

The central theme of the reviewed documents was increased integration in the project implementation process. While traditional design-bid-build (DBB) is still the most common procurement method for the majority of the organizations, some documents specifically discuss Design Build (DB) (such as USC). This is because of the relative ease of implementation and clear demarcation of responsibilities and liabilities in these methods.

However, there is also a trend to consider Integrated Project Delivery (IPD) contracts to create project collaboration environments in which BIM can be exploited in full (Eckblad et al., 2007; Sacks et al., 2010), and different guides approach this in different ways. Indiana requires an IPD implementation plan that highlights co-ordination and mutual gain while the VA leaves it to individual projects to determine the appropriate contracting method. All others either do not mention IPD or acknowledge that although IPD is preferable where BIM is used, there are many logistic, legal and practical hurdles that make IPD unviable. For government organizations the barriers include public procurement processes and anti-corruption laws.

4.4 Pre-qualification of designers

The competence of project participants with BIM is a pre-condition to exploitation of its benefits and thus ensuring a minimum level of ability is an essential concern for construction clients (Barison and Santos, 2011). Clients take for granted that their service providers possess general professional skills acquired through professional training and witnessed by registration. However, the same cannot yet be assumed for BIM, as evidenced by the explicit requirements for pre-qualification regarding BIM skills that appear in ten of the 15 documents reviewed.

Years of experience using BIM is the standard yardstick used to measure competency, especially for the BIM manager. However, there is no clear quantitative enumeration of the value of experience. Two guides (Indiana and NBIMS) provide comprehensive BIM competence matrices in the form of Excel worksheet templates that project managers can use to evaluate competence. The worksheets compute numerical scores that allow assessment of a candidate designer's BIM skills on a scale that ranges from *Working towards BIM* to *Ideal* (Indiana) and *Minimum BIM* to *Platinum* (NBIMS).

The Indiana "BIM Proficiency Standards" has two sections ((Indiana university Architect's office, 2012). The first level simply grades BIM users with a score from 1 to 4 for eight topics which mix model quality (model accuracy, location awareness (geospatial), construction data, as-built modeling and facility management data richness) with organizational skills (IPD methodology, calculation mentality, content creation). The second level uses the same categories and marking system, but breaks each category down into more detailed items.

The NBIMS system is called the "Interactive BIM Capability Maturity Model" (NBIMS-US, 2014 Ch. 5.2). It requires assessors to score their organization on a scale of 1-10 for each of 11 aspects which also mix technical considerations (data richness, business process, timeliness/response, delivery method, graphical information, spatial capability, information accuracy and interoperability/IFC support) with organizational aspects (life-cycle views, change management, roles or disciplines). In this case, however, the aspects are given different weights.

The UK standards adopt a unique system that defines the qualifications of the designers and the design teams by evaluating the BIM process they implement against a chart that defines four levels of BIM process maturity. As shown in FIG , the four levels are:

0 – CAD: basic CAD features using only drawings, lines, arcs and text

1 – 'Lonely BIM': includes some basic 3D elements, beginning of BIM modeling

2 – 'Collaborative BIM': includes the required information, supply chain management, and collaboration between the parties.

3 – 'Intelligent BIM': full integration of the BIM model into the life cycle management of the project.

The UK government directive demanded use of BIM at level 2 by the year 2016, and the government BIM task group is now working toward defining the goals for level 3.

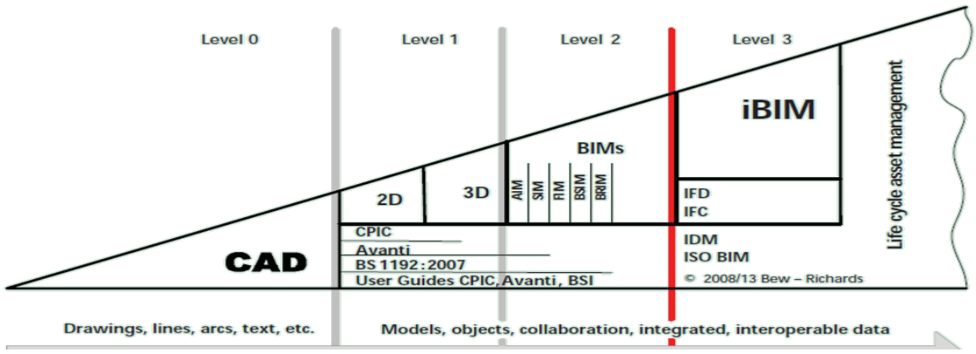

FIG 2: BIM maturity levels 1-4 (BSI, 2013).

4.5 Required design and construction functions

Only nine of the 15 documents reviewed break down the implementation of the project into different stages. Some of the documents cover the project life-cycle comprehensively, detailing al of the required functions, whereas others are BIM-specific, focusing only on those functions that are to be performed differently with BIM. Naturally, the stages in all of the documents roughly follow the natural progression of projects including pre-design, schematic design, detailed design, bidding, construction documentation, construction, post-completion documentation and facility management. In each of these stages, some of the documents have added requirements that reflect the capabilities arising from use of a BIM model.

Having a BIM model from the inception of the project enables the parties involved to conduct simulations and analyses that were not possible with CAD, and to perform other analyses much earlier in the process. The

LACCD, GT, Indiana, Senate and Singapore guides reflect this innovation: they require modelling of existing buildings and site conditions, energy, acoustic and shading analyses already in the pre-design phase. The USC, GSA and Statsbygg guides also implement this principle, but they introduce these applications from the schematic design phase.

All nine documents encourage exploitation of the possibility for increased accuracy and detail in the schematic design phase. Three go so far as to specify the nature and the extent of the data required for site conditions and geospatial modeling (USC, Senate and Statsbygg), and five provide a framework of requirements for early energy and lighting analyses (GT, Indiana, Statsbygg, Senate, GSA).

Toward the end of the detailed design there are two approaches. A "conservative" approach that requires preparation of traditional 2D drawings for the bidding and contracting (GT, and Indiana) and a "progressive" approach that allows use of the 3D BIM models for bidding and contracting (Senate). This is surprising because GT and Indiana both prioritize IPD procurement, which enables collaborative use of the BIM model throughout the project, yet require 2D drawings. The Senate guide does the opposite – it does not contemplate nor encourage IPD, yet allows sharing of the model for procurement.

In the construction phase all nine documents cover a similar range of functions. The most common utilization is for 4D scheduling (LACCD, GT, USC, Indiana, Senate, Statsbygg, GSA and Singapore). Other functions used extensively include as-built documentation, quantity take-off and resource allocation. The final project phase – post completion – receives less attention. Only five documents address this topic, focusing on provision of data for operations and maintenance activities through documentation (GT, Indiana and GSA) and/or in the COBie format (GT, USC, Indiana, Senate, GSA).

The nine documents that break down the implementation into phases and provide specific requirements are all published by organizations that manage construction projects directly. Most of the remaining six are national or state government bodies: their guides remain at a higher level of abstraction, and focus more generally on the design and construction phases, leaving individual construction projects to detail their phases, functions and information exchanges in their BIM execution plans.

4.6 Level of Development

Defining the 'Level of Development' (LOD) required for a BIM model's component parts at each stage of a project's design and construction lifecycle allows project participants to properly plan, co-ordinate, monitor and control their work (Reinhardt and Bedrick, 2015). With BIM, highly detailed objects can easily be drawn from object libraries and placed in models as design intent placeholders. They may thus contain more detail than their author intended at that stage of design. Although they may be highly detailed (in terms of geometry and attributes), the intended level of development may be less than that suggested by the level of detail. Without specific LOD definitions that are tied to project phases, designers cannot be sure about the maturity of the information contained in the BIM models that they receive, and are liable to progress design on the basis of erroneous or unintended assumptions.

A good BIM Execution Plan should therefore specify the LOD that is to be achieved for each building system and its elements at each milestone in each project. In so far as an organization may wish to standardize the deliverables provided by designers at each stage across all of its projects, the LOD can be specified in an organizational BIM guide.

Of the documents reviewed, six (Statsbygg, VA, Ohio, NATSPEC, Singapore and UK) lay out the LOD specifications and their relationship to project stages in full. The VA guide's 'Object Element Matrix' (Tietjen, 2010) and the NATSPEC 'BIM Element Matrix (NATSPEC, 2011), for example, provide extensive tables of building systems and elements. Both are organized according to the UniFormat classification standard.

Other documents deal with the LOD specification by referring to the BIM Forum LOD Specification (Reinhardt and Bedrick, 2015). This document lays out a method for BIM managers and teams to detail level of development progressions that are specific to their projects within the framework of their BIM execution plans. This maintains flexibility by leaving the actual specifications to be set by the BIM manager at or close to contract signing, allowing for coordination with all members of the design and construction team.

4.7 Operation and maintenance requirements

The ability to carry digital information from the construction phase (CAPEX – capital expenditure) to the operations phase (OPEX – operations expenditure) of a building represents a potential benefit for the AEC industry that stems entirely from the use of BIM. The two main functions are a) use of the data for future renovation of a facility and b) use of the data to support operation and maintenance activities (IFMA, 2013). However, from the review of the documents it is clear that all these functions are at a very nascent stage of implementation in the organizations and the framework of implementation still has to be formulated.

As TABLE 4 shows, the documents specify these two functions in varying levels of detail. Some of the documents provide guidance on the use of laser scanning for capture of existing conditions and on the formats to be used for export of OPEX phase data from as-built models using the COBie data standard (East, 2007).

With the exception of Senate, Ohio and Singapore, all of the 13 documents that detail requirements for operation and maintenance use the COBie exchange standard (East, 2007). The GSA guideline is particularly detailed in regard to the use of BIM for facility management. In many cases the documents require data collection using COBie from the beginning of the project and throughout the construction phase. Some of the documents prescribe tools other than COBie spreadsheets. Ohio has a specific list of requirements to compile a minimum model for maintenance, as do GSA and GT. Others focus on different aspects of maintenance that are specific to their organizations; COE for instance focuses on the data needed to ensure the ability to operate equipment.

TABLE 4: Renovation, operation and maintenance using BIM.

BIM document	Renovation	Laser scanning	Operation & maintenance	COBie requirements
LACCD	●●●	●●		
GT	○	●●	●●	●●●
USC		●	●	●●
Indiana			●	●●
Senate	●●	●●	●	
Statsbygg		●	●	●
GSA	●	●●●	●●	●●●
COE			●	○
VA			●	●●●
Ohio			●●	
NATSPEC	●	●	●	●●
NBIMS			●	○
Singapore	●	●	●	
CanBIM			●	●
UK				

Legend: ●●● = highly detailed; ●● = some detail; ● = few details, ○ = only mentioned.

The use of BIM for renovation is apparently even less developed. The documents recommend as-built modelling and laser scanning for acquiring information for renovation activities, although these are not detailed in the majority of the cases. Beyond that the requirements are varied. GSA has the most detailed requirements for the use of laser scanning and the LA guide details the use of as-built information. Cost effectiveness, accuracy and efficiency are the three major perceived advantages of using BIM.

4.8 BIM Execution Plan

The BIM Execution Plan (BEP) is a central component of the preparation for any construction project using BIM. It defines the desired modes of collaboration and information sharing, covering the roles and responsibilities of all partners involved, the software applications to be used, the scope and level of development of the different aspects of the model required at each stage for each design discipline, the management of the model itself, quality control procedures, object composition and naming conventions, etc. The BEP is also used to specify the data management / model management plans in the VA, AEC and Canada guides.

Seven documents provide a basic template for their users to compile their own BEP. In six cases (except for LACCD), the templates are highly prescriptive in nature, and in four of them the BEP had the status of legally binding contracts. The Senate guide incorporates most of the aspects of the BEP within the guide itself, and thus does not require a project BEP. In contrast, the documents without templates gave only descriptive recommendations. Among the prescriptive templates there is wide variation in terms of the structure of the BEP. While some require fixed content (GT, VA and UK), others prefer the document to be more flexible. Most of the documents (except for GSA and NBIM) require submittal of the BEP for approval by the owner.

Creating a BEP document allows the owner and the design companies to coordinate their expectations from each other and to set clear goals for using BIM in the project. For example, minimum modeling requirements and the expected deliverables over the project lifecycle can be set from day one. The opportunity to formalize specific requirements for simulations such as energy analysis, lifecycle costing, sustainability assessment, clash detection, quality control, and constructability analysis allows owners to maximize the value of the BIM process.

In principle, BIM facilitates communication and collaboration. The BEP can play a central role in regulating the working process between the project participants. It lays out the protocols for collaboration, communication and information exchange during the project and is thus mentioned in some form in 10 out of the 12 documents which include a BEP.

TABLE 5: BIM Execution Plan

BIM Documents					Aspects defined or prescribed by the BEP							
	Template provided? (Yes/No)	Descriptive/ Prescriptive	Legally binding? (Yes/No)	Owner approval required? (Yes/No)	Roles and responsibilities	Collaboration/ communication /information exchange	Analysis tools	Document update procedures	BIM project scope	Deliverables/ documentation	Modeling requirements	Model management
LACCD	Y	D	N	Y		✓			✓			
GT	N	D	N	Y	✓		✓	✓				
USC	Y	P	Y	Y		✓	✓					
Indiana	Y	P	Y	Y	✓	✓	✓					
Senate	N	N	N	N	✓	✓	✓		✓	✓	✓	✓
Statsbygg	N	N	N	N			✓			✓		
GSA	N	D	N	N			✓					
COE	Y	P	Y		✓	✓	✓		✓	✓	✓	
VA	N	D	N	Y	✓	✓		✓	✓		✓	✓
Ohio	Y	P	Y	Y		✓			✓			
NATSPEC	Y	D	N	Y	✓	✓			✓		✓	✓
NBIMS	N	D	N	N		✓						
Singapore	Y	P	Y	Y	✓							
CanBIM	N	D	N	N	✓	✓						✓
UK	N	D	N	Y		✓		✓		✓		✓

4.9 Simulations

The ability to use BIM models to interface with building system simulation and analysis tools is one of three key aspects of their use in building design (Eastman et al., 2011, p. 203). BIM enables a range of simulations and analyses to be applied to designs as they develop, providing rapid feedback to designers, and thus potentially influencing the design earlier than is possible in traditional processes. That designers and planners will take advantage of these opportunities cannot be taken for granted, and therefore all of the documents prescribe the use of some of the analysis types and tools, because they are perceived to add value for owners by improving the conformance of the building designed to specified requirements and by removing waste from the construction process.

The documents differ in the range of simulations they prescribe, in the levels of detail they require for each simulation type, in the data exchanges that must be supported and in the software tools they specify. The two simulations most commonly called for are clash detection and building energy use. Yet, as TABLE 6 shows, many of the documents go beyond these more easily accessible opportunities for owners to leverage the use of BIM and call for additional simulations. These include 4D construction process simulation, cost estimation based on automated quantity take-off, and a variety of functional architectural analyses.

TABLE 6: Simulations and analysis (●● Simulation type and software specified; ● simulation type specified; ○ simulation is mentioned).

BIM document	Energy model and simulation	Model correctness /clash detection	4D simulation	Cost estimation and analysis	Lighting	Acoustics	Security	Accessibility
LACCD	●	●	●	●	○			
GT	●●	●●		●	○	○	○	○
USC		●●		○	○	○		
Indiana	●●		○	○	○	○	○	○
Senate	●●	●	○	○	●			○
Statsbygg	○	●	○	●	○	●	●	●
GSA	●●	○	○	○	○			
COE	○	●	○	○	○		○	
VA	●●	●●	●●	●			●	●
Ohio	●	●						
NATSPEC	●	●	●	○	●			
NBIMS		○		○				
Singapore	○	●	○	○	○	○		
CanBIM		○						
UK	●	●		●				

Fully 12 out of 15 of the documents acknowledge the importance of energy modelling deal with it in various levels of detail. Among the educational institutions, Georgia Tech, Indiana and LACCD have detailed requirements. All three call for the energy modeling and simulations to be performed using gbXML format and LEED certified. The other nine documents that require energy simulation allow each project to select its own tools; some require that they be named in the BEP.

All 12 documents treat energy modeling as a dynamic design process. They expect, and in some cases require, that the energy model should mature through the different phases of the project design, such that the energy consumption estimation becomes more accurate as the design is detailed. The requirements of Senate properties in particular are extensive, laying out detailed energy simulation requirements for each stage of the project.

Clash detection is a universally recognized feature of BIM utilization and is specified in all of the documents. Specifications include coordination between the different trades with regards to clash detection, clash detection reports and differentiation between soft clashes and hard clashes. There is a special focus on clash detection for mechanical, electrical and plumbing systems (MEP) and coordination of these systems with the other models. There is no single universally recognized software for clash detection.

BIM models are commonly used for construction management applications such as cost estimation, construction sequence planning and detailed scheduling. Cost estimation using BIM quantity take-off is considered to be more accurate than traditional methods. Some documents go beyond the first construction cost estimation, calling for life-cycle cost analysis which considers simulation of operations and maintenance aspects. Despite its popularity in BIM education, 4D schedule simulation is mentioned in only nine documents, and only three prescribe detailed requirements.

Many of the guidelines also include other functional analyses, such as lighting, acoustics, security and accessibility simulations. The Statsbygg guide in particular provides extensive details in these areas.

4.10 Schedule of Payments

In general, when using BIM, information is generated earlier in a project lifecycle than was the case when using CAD. MacLeamy (2004) explained this phenomenon, hypothesizing that the investment of greater effort earlier in the design process would reduce waste in the construction phase. This has subsequently been confirmed in empirical research (Lu et al., 2015).

TABLE 7: Singapore and Ohio BIM documents - design fee schedule adjustments.

Project Stage	**% change from non-BIM to BIM payment**	
	Singapore	Ohio
Preliminary Design/Schematic Design	+2.5	+5.0
Planning Approval	0	-
Design Development	+2.5	+5.0
Tender/Bid and Award	0	0
DESIGN STAGES *	+5.0	-10.0
Construction Administration	-5.0	0
Post construction	0	0
CONSTRUCTION STAGES *	-5.0	0
Percentage change in total fees	0	0

* refers to cumulative percentage fees

Earlier and more intensive investment of effort requires adjustment of the fee schedules that governed design work performed using CAD. Of all the documents reviewed, only the Singapore and Ohio guides support this position and set a different cash flow that compensates designers for earlier effort. TABLE 7 shows the adjustments to the fee schedule recommended by the Singapore and Ohio BIM documents. The other documents do not relate to this issue, yet fee schedule adjustments to better suit the earlier development of detail that is a hallmark of the use of BIM, are a potentially important enabler of BIM adoption.

4.11 Summary of findings

As can be seen in TABLE 8, most of the documents cover most of the ten review topics (see section 3.2 above), although they vary in the emphasis they place on the different topics.

TABLE 8: BIM documents summary review (●● Highly detailed; ● detailed; ○ few details).

	LACCD	GT	USC	Indiana	Senate	Statsbygg	GSA	COE	VA	Ohio	NATSPEC	NBIMS	Singapore	CanBIM	UK
Year of publication, recent update	2009	2011	2012	2009, 2012	2012	2013	2009	2009, 2010	2010	2013	20 11	2012	2012	2012	2013
Organization type	University				State owned company		Government dept.			State	National				
Interoperability	○	●	●	○	●●	●●	●	●	●	●	○	●●	●	●	●●
Role of the BIM manager	●●	○	○	○	●●		●●	●●	●●	●●	●	●●	●	●	○
Collaboration modes	●●	●	○	●●	○	○	●	●	●	●	●●	●	○	●	○
Proposes IPD		●		●●							●			●	
Pre-qualification of designers	○	○	○	●●	○				○	●	○	●●		●	●
LOD Specifications		○	○		●	●●	○	○	●●	●●	●●		●●	●	●●
Operation and Maintenance requirements	●	●●	●	●	●	●	●●	○	●	○	●●	○	●	○	
BIM Execution Plan	○	●	○	●	●●	○	○	●●	●●	○	●●	○	○	●	●
Simulation & analysis	●	●●	●	●●	●●	●●	●	●●	●●	○	●	○	●●	○	○
Schedule of Payments										●●			●●		

The following topics appear in at least 14 of the 15 documents: interoperability, role of the BIM manager, collaboration modes, operation and maintenance requirements, BIM execution plan, and simulation & analysis. These topics form the core of the BIM documents. Of the remaining four topics, IPD and fee schedule changes are not well developed, appearing in very few of the documents. Prequalification of designers for BIM competence is clearly an issue of importance to most organizations, but only two of the documents provide highly detailed recommendations.

5. DISCUSSION

The results reveal the relative importance of the different topics and the degree of detail with which they are specified. They also allow analysis of the importance of the topics to the different types of organization and show the progression of BIM guide development over time.

5.1 Content aspects

Table 9 shows the degree of specification of the topics over all fifteen documents. The specificity values are a measure of the degree of detail with which each topic is treated overall. It is obtained by averaging the scores for degree of detail from TABLE 8 over the number of documents in which each topic appears. The scores for degree of detail were computed from TABLE 8 by assigning a score of 1 for highly detailed topics, 0.5 for detailed topics and 0.25 for topics with few details. Note that specificity values do not necessarily reflect the quality of the treatment, only its relative degree of detail.

Table 9: BIM document topics and their degree of specificity in the documents. The Specificity values are obtained by dividing the Degree of Detail values by the Frequency values.

Review Topics	Frequency (Count)	Frequency (%)	Degree of Detail (0 - 15)	Specificity (0-1)
Simulation & analysis	15	100%	10.00	0.667
Interoperability	15	100%	8.75	0.583
BIM Execution Plan	15	100%	7.75	0.517
Modes of collaboration	15	100%	7.75	0.517
Role of the BIM manager	14	93%	9.50	0.679
Operation and maintenance requirements	14	93%	7.50	0.536
LOD Specifications	12	80%	8.00	0.667
Pre-qualification of designers	11	73%	5.00	0.455
BIM function through project phases	10	67%	9.00	0.900
Integrated Project Delivery	4	27%	2.50	0.625
Schedule of Payments	2	13%	2.00	1.000

Clearly, the topics of simulation & analysis, interoperability, BIM execution plan, collaboration modes, role of the BIM manager and operation & maintenance requirements are the most frequent, but not the most detailed. In fact, the topics of schedule of design payments and BIM functions through project phases are the most detailed, but they are less common.

LOD specifications appear in 12 of the 15 documents. In those documents in which this topic is specified, the topic is covered comprehensively, either directly or by reference to the AIA LOD specification (Reinhardt and Bedrick, 2015). Of the three that lack LOD specification, two were originally published in 2009, and are among the earliest BIM documents. Their preparation may have predated the broad understanding of the LOD subject that developed after the first publication of the AIA specification in 2008.

Pre-qualification of designers is relatively frequent but is treated superficially in all but two 11 documents in which it appears. Its absence from the documents of GSA, COE and VA, and its weak treatment in those of LACCD, GT, USC, Senate and VA is striking because all of these are client organizations with many years of experience working with BIM in their projects, yet they seem to suffice with specification of BIM deliverables without discriminating amongst potentially weak service providers.

The remaining two topics (IPD and Schedule of design payments) may be considered relatively esoteric topics. IPD is not yet a common project delivery method. The reason that some of the documents discuss this procurement method and contract type and no others stems from the perception that the degree of collaboration that can be achieved using IPD is significantly greater than other methods, and in particular that such collaboration improves the ability to leverage the benefits of a BIM process. Changes to design fee structures appear to be warranted in all BIM projects, assuming that the MacLeamy curve (MacLeamy, 2004) accurately represents the generation of information. It is therefore surprising that most of the other BIM documents ignore this aspect.

5.2 Organizations

There appears to be a relationship between the scope of construction managed by the organization and the degree of specificity in the documents: university construction departments have more specific requirements for the design process, simulations required and the software to be used than do government agencies or national standards. Some of the national codes do not refer to the design process phases at all, restricting the scope to model content definitions. On the other hand, the role of the BIM manager in smaller organizations, such as the universities, is more restricted, extending only to design team coordination and synchronization of model and data. This is related to the limitation that smaller projects may not be able to justify employment of a dedicated BIM manager.

The guidelines differ in the allocation of responsibility for design coordination. Some adopt a technology-centered approach, viewing the task primarily as clash detection, while others adopt a construction-centered approach, viewing the task as one of building design. The latter is preferable from the point of view of design quality. It reflects an attitude toward BIM as a design tool and to building designers as having technical competence, as opposed to a view of BIM that assumes that the software should be operated by people with technological expertise (BIM experts).

The fact that ten of the 15 documents detail minimum BIM competency requirements is evidence of the early stage of BIM adoption perceived by the authors of the documents. BIM skills and competence are not assumed to be provided through university education or professional training for architects or engineers, nor certified as an integral part of professional registration requirements, and must therefore be explicitly tested for as part of the pre-conditions for participation in any given construction project. Furthermore, the skill set needed for the new role of BIM Manager is considered to be sufficiently different to that of designers, and formal training for it is not yet available. The research literature supports this view. Succar et al. (2013) introduced a detailed taxonomy of individual BIM skills and proposed a process for evaluation of competence at both individual and organization levels. Sacks and Pikas developed curricula for BIM education based on analysis of the industry's needs for specific skills, organized according to Bloom's taxonomy (Sacks and Pikas, 2013). Both of these reflect the fact that, with a few exceptions, development of competence in BIM is not yet a mainstream part of architectural, engineering or construction education and training.

Another reason for the prevalence of requirements for pre-qualification arises from the understanding that a construction owner's demand for work with BIM is not simply a demand for use of a specific sophisticated design tool, but rather a demand for a deeper change in the working relationships between various project participants and improvement of the information flows among them. Change in business processes cannot be obtained solely through skills training for individuals.

The desire of many of the organizations to promote collaborative working relationships on their projects finds expression in their documents in the form of BEP development requirements, recommendations for IPD, and in specification of big-room co-located design spaces. This need is at the core of the interoperability provisions of the NBIMS.

The documents also reflect the current culture and the cultural differences among project participants. The allocation of responsibility ranges from specification of individual tasks to general collective responsibility for use of BIM and for delivery of the design. Some carefully specify the information handoffs and even the physical environment for designers (e.g. USC's big-room), whereas others (e.g. NBIMS) adopt a laissez-fare approach, placing few if any restrictions on the designers' freedom of action.

National and state governments use BIM documents as instruments for advancing the use of BIM within their construction industries. The Singapore and the UK documents are particularly good examples of these efforts. The UK standard is part of a broader effort that imposes BIM use for public projects through contract terms that require BIM – this has a strong effect in determining commercial and design/engineering behavior across the industry, spreading BIM use to the private sector. The Singapore government's efforts are even more direct, providing direct funding incentives for AEC firms to purchase hardware and software and by supporting BIM training. The documents are an essential part of these efforts because they standardize implementation across companies and design firms. This is critical when transitioning from simple individual use of BIM to collaborative utilization of BIM tools.

5.3 Development

Sorting the table of documents in chronological order of publication reveals that the level of detail of requirements for three of the topics - interoperability, pre-qualification of designers and LOD - has increased over time. This reflects the growing awareness and experience of the authors of the BIM documents of the importance of these topics, as well as the development of techniques and technology. Pre-qualification, for example, requires a means of assessment; Succar's BIM Maturity Matrix and Competency Sets (Succar et al., 2013), for example, were introduced in 2009 and provide a useful framework for such assessment. Interoperability and the use of IFC for 'Open BIM' has been facilitated with the maturation of the IFC standard (Liebich, 2010), and this too is reflected in the later BIM documents.

In some documents, the strong influence of the organization's prior commitment to CAD standards is apparent. The LACCD and COE guides detail the structure, content, layer naming and format for drawings that are required for submission at different project stages, emphasizing the role of BIM as a tool for producing drawings. This stands in sharp contrast with the shift from drawings to models as the primary means of communication with BIM. The UK standard (BS 1192-4 and PAS 1192-2:2013), on the other hand, outlines a strong model-based process despite being an extension of a suite of CAD standards (the BS 1192 series).

Future development of BIM guideline documents might consider applications of BIM that have yet to be fully exploited, such as modular construction (Prefinished Prefabricated Volumetric Construction - PPVC), supply chain management (reference to standard building object naming conventions), e-submission and e-checking of building permit applications, advanced simulations (such as design quality checking for egress, accessibility, sustainability)

6. CONCLUSION

Motivated by the value of BIM documents to public and private sector organizations for systematic implementation of BIM in construction projects, the authors undertook a comprehensive review and analysis of 15 BIM documents. The sample set of 15 documents were selected from a database of 81 guides (BuildingSmart, 2015) and were chosen to represent a range of organization types, sizes and countries of origin. Some of the large-scale construction clients' and university campus BIM guides reflect the influence of earlier CAD standards, with stipulations of 2D drawings to be submitted at various stages of the design and construction process. The national standards are in general free of these influences, reflecting a more holistic view of the procurement process with BIM. Standardization of design processes, simulations, information requirements and deliverables within the BIM documents is complemented by standardization of the structure, format and syntax of model exchanges provided by the IFC standard.

Detailed analysis was based on ten categories of topics that encompass the contents and scope of the full set of documents. The results reflect the effectiveness and the clarity of each of the individual documents. Seven of the ten main topics – interoperability, role of the BIM manager, collaboration modes, operation and maintenance requirements, BIM execution plan, and simulation & analysis – are similar across all, but their content, specificity, frequency and level of resolution are different. Other topics are omitted from most of the documents: for example, only two documents call for design fee structure changes along the timeline of a project, and only three call for Integrated Project Delivery. The former is needed in all documents to properly align compensation with the increased early phase workload that is needed for projects designed with BIM, whereas the latter remains an esoteric project procurement pathway that is excellent for some projects but unsuitable for many others.

The need for BIM documents arises from the essence of the use of the technology: in as far as BIM supports technical communication among project participants, standardization is a key enabler. BIM documents facilitate not only the use of the technology, but also deepen the impact of its use by allowing exploitation of the data for the multiple simulations and analyses that enhance the quality of buildings and the efficiency of construction. Industry-wide standards promulgated by governments or developed by non-profit industry associations are important enablers for achieving effective communication with BIM, but they are not sufficient for transition from use of BIM in isolated 'islands' of automation to its use in collaborative design and construction. Adoption of a coherent and mandatory BIM guideline is therefore an essential step for any large construction client organization that wishes to exploit the potential benefits of BIM processes and technology to the full.

Naturally, every major client organization operates within its own specific commercial, legal, technological and professional context. Among other differences, the contents of an industry-wide or national standard ad its degree of prescription, or the absence such a standard, will directly affect the contents of a client organization’s BIM guideline document. Therefore, the content and degree of detail of construction client organizations’ BIM guideline documents will vary widely. The information provided in this paper can be used to ensure that all relevant topics are covered appropriately, and also to identify and locate sections of the documents that may be of use to them. The ten core topics identified and discussed may serve as a checklist for development within an organization as it prepares its own set of BIM guidelines. Integrated Project Delivery (a sub-topic within ‘Modes of collaboration’) is a contractual platform that enables projects to achieve stronger collaboration than can be achieved using competitive contracting arrangements, and thus goes hand in hand with the use of BIM, although clearly IPD and BIM are not mutually dependent.

Finally, the main purpose of organizational BIM guideline documents is to establish working methods for project participants that will be mandated by reference to the guideline documents in design and construction contracts. Thus authors of guidelines must consider carefully whether the working methods and relationships they specify suit the local industrial culture in terms of collaboration, information sharing, etc.

The contribution of this paper lies in the set of recommendations provided for major construction client organizations (commercial companies, public authorities and governments large and small) to support preparation or update of their own BIM guides. The paper contributes a check-list of the essential areas that must be covered, including topics that are not yet covered in the majority of the pioneering BIM documents that were reviewed.

Given the benefits to be obtained through collaboration and data integration, construction client organizations perceive the need to accelerate adoption of BIM; and given the fundamental nature of the change, one of the tools is to establish policy frameworks expressed in the form of national standards, collaboration guides and/or project-level BIM execution plans. Yet with the plethora of such organizations, development of a large set of BIM guides with disparate requirements could lead to confusion among architects, engineers and builders. Generation of harmonized or standard templates for BIM guides for different organization types could reduce the potential for confusion, and this review may contribute to that effort.

7. REFERENCES

ACOE. (2009), "New York District US Army Corp. of Engineers official manual for building information modeling projects", Army Corp. of Engineers, May, available at: http://www.nan.usace.army.mil/Portals/37/docs/EngDiv/CENAN_BIM_SUBMISSION_MANUAL.pdf

Alhava, O., Laine, E. and Kiviniemi, A. (2015), "Intensive big room process for co-creating value in legacy construction projects", *Journal of Information Technology in Construction (ITcon)*, Vol. 20 No. ECPPM 2014 Special Issue, pp. 146–158.

Barison, M.B. and Santos, E.T. (2011), "The Competencies of BIM Specialists: A Comparative Analysis of the Literature Review and Job Ad Descriptions", presented at the International Workshop on Computing in Civil Engineering, American Society of Civil Engineers.

BCA. (2014), "Case Study on Economic Benefits of SS CP 83 Enabling e-Submission in the Construction Sector", Building and Construction Authority, Singapore.

Belsky, M., Sacks, R. and Brilakis, I. (2015), "Semantic Enrichment for Building Information Modeling", *Computer-Aided Civil and Infrastructure Engineering*, p. n/a–n/a.

BSI. (2007), "BS 1192 Collaborative production of architectural, engineering and construction information. Code of practice", British Standards Institution, available at: http://shop.bsigroup.com/ProductDetail/?pid=000000000030163398 (accessed 20 October 2015).

BSI. (2013), "PAS 1192-2:2013", The British Standards Institution.

Building and Construction Authority. (2013), "Singapore BIM Guide version 2", Building and Construction Authority, August, available at: https://www.corenet.gov.sg/integrated_submission/bim/BIM/Singapore%20BIM%20Guide_V2.pdf (accessed 27 April 2015).

BuildingSmart. (2015), "BIM Guide Project", BuildingSmart, available at: http://bimguides.vtreem.com/bin/view/BIMGuides/Guidelines (accessed 17 August 2015).

BuildingSmart. (2016), "BIM Guide Project", available at: http://bimguides.vtreem.com/bin/view/BIMGuides/Guidelines (accessed 27 May 2016).

BuildLACCD. (2009), "LACCD Building Information Modeling Standards (LACCD BIMS) Interim Version", BuildLACCD, 18 June, available at: https://www.google.co.il/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0CB0QFjAAahUKEwiG0ei27-HHAhVCORQKHSRnDgQ&url=http%3A%2F%2Fprojects.buildingsmartalliance.org%2Ffiles%2F%3Fartifact_id%3D3350&usg=AFQjCNEDjsL046mtRqZTOZEXn7M9jcpjsg&sig2=QbHAH6WQdhqGQi-r7skLzA.

CanBIM. (2012), "AEC (CAN) BIM Protocol", CanBIM AEC (CAN) Designers Committee, October, available at: http://s3.amazonaws.com/canbim-production/vol/www/apps/canbim_production/releases/20121021065404/en/public/documents/documents/original_63.pdf?1352735902.

Chae, L.S. and Kang, J. (2015), "Understanding of Essential BIM Skills through BIM Guidelines", in Tulio, Sulbaran (Ed.), *51st ASC Annual International Conference Proceedings, The Associated Schools Construction, April 22-25, 2015. p.8*, Texas A&M University.

Cheng, J.C. and Lu, Q. (2015), "A review of the efforts and roles of the public sector for BIM adoption worldwide", *Journal of Information Technology in Construction*, Vol. 20, pp. 442–478.

East, E.W. (2007), *Construction Operations Building Information Exchange (Cobie): Requirements Definition and Pilot Implementation Standard*, No. ADA491932, Engineering Research and Development Center, Champaign IL Construction Engineering Research Lab, p. 195.

Eastman, C.M., Jeong, Y.S., Sacks, R. and Kaner, I. (2010), "Exchange Model and Exchange Object Concepts for Implementation of National BIM Standards", *Journal of Computing in Civil Engineering*, Vol. 24, pp. 25–34.

Eastman, C.M., Teicholz, P., Sacks, R. and Liston, K. (2011), *BIM Handbook: A Guide to Building Information Modeling of Owners, Managers, Designers, Engineers and Contractors*, Second Edition., John Wiley and Sons, Hoboken, NJ.

Eckblad, S., Ashcraft, H., Audsley, P., Blieman, D., Bedrick, J., Brewis, C., Hartung, R.J., et al. (2007), *Integrated Project Delivery - A Working Definition*, available at: http://ipd-ca.net/images/Integrated%20Project%20Delivery%20Definition.pdf.

Edirisinghe, R. and London, K. (2015), “Comparative analysis of international and national level BIM standardization efforts and BIM adoption”, *32nd International Conference of CIB W78,Oct 27-29, 2015*, CIB, Eindhoven, The Netherlands, pp. 149–158.

Erdener, E. and Gruenwald, H. (2001), “CAD standards and the institutions of higher education”, *Facilities*, Vol. 19 No. 7/8, pp. 287–295.

Gallaugher, J.M. and Wang, Y.-M. (2002), “Understanding network effects in software markets: evidence from web server pricing”, *Mis Quarterly*, Vol. 26 No. 4, pp. 303–327.

Georgia Institute of Technology. (2011), “Georgia Tech BIM Requirements & Guidelines for Architects, Engineers and Contractors”, Georgia Institute of Technology, September, available at: http://www.facilities.gatech.edu/dc/standards/2011_0815_GT_BIM_Requirements_v1.0.pdf (accessed 27 April 2015).

Hemenway, D. (1975), *Industrywide Voluntary Product Standards*, Ballinger Publishing Company.

Howard, H., Levitt, R., Paulson, B., Pohl, J. and Tatum, C. (1989), “Computer Integration: Reducing Fragmentation in AEC Industry”, *Journal of Computing in Civil Engineering*, Vol. 3 No. 1, pp. 18–32.

Howard, R. and Björk, B.-C. (2007), “Use of standards for CAD layers in building”, *Automation in Construction*, Vol. 16 No. 3, pp. 290–297.

Hsieh, H.-F. and Shannon, S.E. (2005), “Three Approaches to Qualitative Content Analysis”, *Qualitative Health Research*, Vol. 15 No. 9, pp. 1277–1288.

IFMA. (2013), *BIM for Facility Managers*, edited by Teicholz, P., Wiley, Hoboken NJ, available at: https://books.google.co.il/books?id=wHQDghScf2YC.

Indiana University Architect’s Office. (2012), “Indiana University Building Information Modeling (BIM) Guidelines and Standards for Architects, Engineers, and Contractors”, Indiana University, 2 July, available at: http://www.indiana.edu/~uao/iubim.html (accessed 27 April 2015).

Indiana university Architect’s office. (2012), “Indiana University BIM proficiency matrix”, Indiana University, 2 July, available at: http://www.indiana.edu/~uao/docs/standards/IU%20BIM%20Proficiency%20Matrix.xls.

ISO. (1994), “ISO 10303-1: Industrial automation systems and integration -- Product data representation and exchange -- Part 1: Overview and fundamental principles”, International Standards Organisation, available at: http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=20579 (accessed 20 October 2015).

ISO. (1998), “ISO 13567-2:1998 - Technical product documentation -- Organization and naming of layers for CAD. Part 2: Concepts, format and codes used in construction documentation”, International Standards Organisation, available at: http://www.iso.org/iso/home/store/catalogue_ics/catalogue_detail_ics.htm?ics1=01&ics2=110&ics3=&csnumber=22281 (accessed 20 October 2015).

ISO. (2013), “ISO 16739 Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries”, International Standards Organisation, available at: http://www.iso.org/iso/catalogue_detail.htm?csnumber=51622 (accessed 27 August 2015).

Kassem, M., Succar, B. and Dawood, N. (2015), “Building Information Modeling: Analyzing Noteworthy Publications of Eight Countries Using a Knowledge Content Taxonomy”, *Building Information Modeling*, American Society of Civil Engineers, pp. 329–371.

Keenliside, S. (2015), “Comparative analysis of existing building information modelling (BIM) guides”, in Froese, T.M., Newton, L., Sadeghpour, F. and Vanier, D.J. (Eds.), *Proceedings of ICSC15: The Canadian Society for Civil Engineering 5th International/11th Construction Specialty Conference*, University of British Columbia, Vancouver, Canada, pp. 293-1-293–9.

Kohlbacher, F. (2006), “The Use of Qualitative Content Analysis in Case Study Research”, *Forum Qualitative Sozialforschung / Forum: Qualitative Social Research*, Vol. 7 No. 1, available at: http://www.qualitative-research.net/index.php/fqs/article/view/75.

Liebich, T. (2010), “Unveiling IFC2x4-The next generation of OPENBIM”, *Proceedings of the 2010 CIB W78 Conference*, Virginia Institute of Technology, Cairo, Egypt, p. 8.

Lu, W., Fung, A., Peng, Y., Liang, C. and Rowlinson, S. (2015), “Demystifying Construction Project Time–Effort Distribution Curves: BIM and Non-BIM Comparison”, *Journal of Management in Engineering*, Vol. 31 No. 6, p. 4015010.

MacLeamy, P. (2004), *Collaboration, Integrated Information and the Project Lifecycle in Building Design, Construction and Operation*, available at: http://code bim.com/wp-content/uploads/2013/06/CurtCollaboration.pdf (accessed 20 October 2015).

Matta, C., Kam, K. and Graves, T. (2007), "GSA BIM Guide Series 01", The National 3D-4D-BIM Program, Office of the Chief Architect, Public Buildings Service, available at: http://www.gsa.gov/graphics/pbs/GSA_BIM_Guide_v0_60_Series01_Overview_05_14_07.pdf (accessed 27 April 2015).

Mitropoulos, P. and Tatum, C.B. (1999), "Technology Adoption Decisions in Construction Organizations", *Journal of Construction Engineering and Management*, Vol. 125 No. 5, pp. 330–338.

NATSPEC. (2011), "NATSPEC National BIM Guide", NATSPEC, September, available at: https://vdcscorecard.stanford.edu/sites/default/files/NATSPEC_National_BIM_Guide_v1.0.pdf.

NBIMS-US. (2014), "The National BIM Standard-United States™ (NBIMS-US™)", available at: http://www.nationalbimstandard.org/.

Reinhardt, J. and Bedrick, J. (2015), "Level of Development Specification", American Institute of Architects and Association of General Contractors, available at: www.bimforum.org/lod (accessed 26 October 2015).

Sacks, R., Koskela, L., Dave, B.A. and Owen, R. (2010), "Interaction of Lean and Building Information Modeling in Construction", *Journal of Construction Engineering and Management*, Vol. 136, pp. 968–980.

Sacks, R. and Pikas, E. (2013), "Building Information Modeling Education for Construction Engineering and Management. I: Industry Requirements, State of the Art, and Gap Analysis", *Journal of Construction Engineering and Management*, p. 4013016.

Senate Properties. (2012), "Common BIM Requirements Series", Senate Properties, available at: http://www.en.buildingsmart.kotisivukone.com/3.

State Architect's Office. (n.d.). "State of Ohio Building Information Modelling Protocol", General Services Division State Architect's Office, available at: http://das.ohio.gov/Portals/0/DASDivisions/GeneralServices/SAO/pdf/SAO-BIMProtocol.pdf.

Statsbygg. (2013), "Statsbygg BIM Manual 1.2.1", 17 December, available at: www.statsbygg.no/bim.

Succar, B., Sher, W. and Williams, A. (2013), "An integrated approach to BIM competency assessment, acquisition and application", *Automation in Construction*, Vol. 35, pp. 174–189.

Tietjen, R. (2010), "The VA BIM guide", Dept. of Veterans affairs, April, available at: http://www.cfm.va.gov/til/bim/BIMguide/downloads/VA-BIM-Guide.pdf.

USC. (2012), "University of Southern California Building Information Modeling (BIM) Guidelines version 1.6 For Design Bid Build Contracts", USC Capital Construction Development and Facilities Management Services, 18 April, available at: http://facilities.usc.edu/uploads/documents/cas/BIMGuidelines_VS1_6_2012.pdf.

West, J. (2003), "The role of standards in the creation and use of information systems", in King, J.L. and Lyytiinen, K. (Eds.), *Workshop on Standard Making: A Critical Research Frontier for Information Systems*, MIS Quarterly, Seattel, Washington, pp. 314–326.

West, J. and Dedrick, J. (2000), "Innovation and control in standards architectures: the rise and fall of Japan's PC-98", *Information Systems Research, Informs*, Vol. 11 No. 2, pp. 197–216.

Wong, A.K., Wong, F.K. and Nadeem, A. (2010), "Attributes of building information modelling implementations in various countries", *Architectural Engineering and Design Management*, Vol. 6 No. 4, pp. 288–302.