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A review and outlook for a 'Building Information Model' (BIM): A multi-standpoint framework for technological development

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ABSTRACT

This study provides a review of important issues for 'Building Information Modelling' (BIM) tools and standards and comprehensive recommendations for their advancement and development that may improve BIM technologies and provide a basis for inter-operability, integration, model-based communication, and collaboration in building projects.

Based on a critical review of Building Product Modelling, including the development of standards for exchange and the features of over 150 AEC/O (Architecture, Engineering, Construction, and Operation) tools and digital models, a methodological framework is proposed for improvements to both BIM tools and schemata. The features relevant to the framework were studied using a conceptual process model and a 'BIM System-of-Systems' (BIM-SoS) model. The development, implementation, and use of the BIM Schema are analysed from the standpoint of standardisation.

The results embrace the requirements for a BIM research methodology, with an example of methods and procedures, an R&D review with critique, and a multi-standpoint framework for developments with concrete recommendations, supported by BIM metrics, upon which the progress of tools, models, and standards may be measured, evaluated, streamlined, and judged. It is also proposed that any BIM Schema will never be 'completed' but should be developed as evolutionary ontology by 'segmented standpoint models' to better account for evolving tools and AEC/O practices.

1. Introduction

Product-model data exchange in project communication is often one of the most expensive and yet least adequately managed processes [45] in the product lifecycle. Despite the fact that the AEC/O (Architecture, Engineering, Construction, and Operations) industry spends billions each year [41] on inter-operability issues, little added value is obtained. Moreover, the exchange of building product-model data is increasingly demanding as tools for modelling, analysis, visualisation, and simulation evolve.

The key issue in this area has historically been, and remains, how to achieve *inter-operability between multiple models and multiple tools* that are used in the whole product lifecycle. This has led to over *30 years of standardisation* efforts towards a standard *common product model*. Three important inter-operability standards that exist today, ISO 10303, ISO 15531, and ISO 13584, enable engineering enterprises to technologically integrate product-development processes; these are known as STEP, MANDATE, and PLIB, respectively [77].

1.1. The role of standards for BIM

The role of standards can be labelled by the '3C' (competitiveness, conformity, and connectivity) [116]. Furthermore, standardisation is considered a key instrument towards innovation [37]. Unfortunately, applications of the STEP standard for 'Building Information Modelling' (BIM) that enable product-model data exchange, for example, 'Industry Foundation Classes' (IFC), ISO/PAS 16739, do not yet exhibit the *three roles of any standard enabling innovation: (1) inter-operability, (2) trust, and (3) comparability*.

Two essential questions for the future of project communication are, "*Will another 30 years of standardisation be sufficient?*" and "*What is the way forward for BIM technologies?*" The necessarily *broader* context for the AEC/O industry may be adopted from the 'European Inter-operability Framework' (EIF) [38], which provides policies and guidelines for the standardisation of interactions between organisations beyond technological standpoints.

Several studies [4,57,124] have indicated that, until recently, project communication has been little studied from more than a technological standpoint. Some recent research has addressed non-technological issues, e.g., adoption frameworks [88,108], BIM business process re-engineering [8,83], experience with practical use of BIM [53,109], impact of ICT [65] and BIM [109], and the role

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of visual communication in BIM [27]; this research has not, however, addressed the two essential questions stated above.

1.2. Study scope and goals

The goal of this study was to introduce a *framework for the validation and verification of the technological development* of BIM tools and standards that would be relevant for standardisation organisations, researchers, software vendors, and AEC/O software end-users. The essential proposition of this study is that it may be possible to advance and develop BIM tools and standards towards new, harmonised, innovative solutions if a multi-standpoint framework was developed that took into account:

- *Complementary research methodologies:* The research must consider affected groups, primarily building-project stakeholders, AEC/O software developers, and developers of standards for exchange, who all directly or indirectly affect project communication. It is important to be aware that *the technologies can be improved through the study of non-technological issues*.
- *Evolving practices and models:* AEC/O practitioners continually attempt to improve the way they analyse, document, and communicate information about the form, function, and technical parameters of buildings. This leads to continual development of AEC/O software, the development of which follows a pattern common to any engineering domain: *to describe and solve problems with an ever-increasing level of detail, accuracy, and efficiency*. Accordingly, the complexity of models and tools is increasing.
- *Engineering communication channels:* Too much effort is currently expended on the subject of communication rather than on the semiotics of communication (verbal and non-verbal between humans via computer): *"it is a virtue of any system, if the system is aware of other systems*" [122].

2. Methodology

The requirements for the research methodology were established in three steps. First, based on the initial literature and software review, a list of problem-methodology pairs was created. Second, problems were separated from methodologies and grouped into clusters by related research results. Third, conflicts and synergies between methodologies were analysed against 'problem-methodology' pairs and clusters and finally synthesised into '*seven requirements for the methodology of BIM research*'. Based on these requirements, the methodology should do the following:

1. Discover groups of related problems, rather than tackle very specific and isolated technical problems
2. Assess and evaluate BIM practices in building projects and the development of BIM tools/schema
3. Capture and correlate irreversible and limiting processes to growth and innovation in BIM solutions
4. Streamline R&D toward new innovative solutions to support BIM-based collaboration and services
5. Assess BIM solutions in the project life cycle (pre-construction, construction, and post-construction)
6. Analyse BIM communication channels between machines, software, and humans that are using ICT
7. Streamline those processes that foster advancement in existing use and new adoption of BIM solutions

These seven requirements translate into a need to analyse BIM from a broader, more holistic perspective, within which a clear distinction between observational and experimental research activities must be made. The traditional literature review was extended using two complementary research methods, a process method and a systems method.

2.1. Literature and software review

A detailed literature and software review is given in the individual sub-sections, along with the introduced concepts. Briefly outlined, the initial literature survey covered the following:

- *Theoretical foundations – theories*: Systems theory [122], information theory [103], observational theory [18]
- *Studies on the use of ICT in construction:* ICT use within the construction organisation [102] and between organisations [1], industry preparedness [4] and project communication [124]
- *BIM reviews and case studies:* Reviews of BIM developments [57], and capabilities [70], case studies [35,90], BIM implementation frameworks [83,88,108] and industry perception [53,109]

The software review covered AEC/O software as follows:

- *Lessons learned from early prototypes:* The focus was on interfaces, automation of modelling, capturing of intent, and documentation, e.g., SketchPad [110], a consistent database for integrated design by Yaski [14], integrated design models [5,34,65], and early CAD/BIM software
- *Development of the AEC software library:* The library was started 10 years ago [115] and later contained 4000 tools [6], from which 150 tools with BIM exchange features were selected
- *Personal participation in BIM practices* on large-scale projects, including a representative case study of a hospital building of over 28,000 sq meters with several digital domain models

2.2. The process centred and systems-thinking approach

In this approach, knowledge is used to refer to knowledge about processes and its results [23]. The knowledge of relevant processes was documented and studied through a series of IDEFØ diagrams, which were used as meta-descriptions of modelling workflows for the development of integrated models (see Fig. 1) and of workflows for the standardisation of model-data exchange (see Section 4). Fig. 1 shows the development of a 5D model (3D – geometry, 4D – costs, and 5D – time) in an integrated environment.

Based on an awareness of the limitations of conceptual process modelling, an additional approach was introduced. The inability of IDEFØ to model cycles and causal dependencies was compensated for by systems-thinking, where systems represents a view of problems [55,122]. The systems-thinking approach has also been adopted in the 'General AEC reference model' (GARM) [44] and applied in frameworks such as knowledge management [101].

Several systems-thinking methods including causal modelling, system-archetypes, structural dynamics, and 'System-of-Systems' (SoS) [105] were used in this work to identify synergies of related systems. A detailed discussion of the development and use of BIM-SoS is beyond the scope of this paper, and only the outcome is presented. The systems were divided into three categories: directed, collaborative and virtual [80] and were studied from multiple standpoints (i.e., organisational, technological and personal [63]).

2.3. Structure of the paper

In Section 3, a set of relevant basic definitions for standpoints are provided to assure common understanding of the terminology. In Section 4, a conceptual IDEFØ model is used to identify relevant