FRAMING CONSTRUCTION USES OF VIRTUAL INFORMATION MODELS

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Abstract: Digital models incorporating 3D geometry and information attributes are becoming a standard for industrial facility and commercial building design. Despite the advancements in technologies to develop design models there is an opportunity to better leverage models within facility construction processes. The current work aims to identify the breadth of construction needs for using information models, and develop an approach to improve information accessibility to support construction. With a thorough literature review, the current work identifies the state-of-art workflows in using design content to support construction tasks. The existing gaps of using models for construction uses have also been captured, indicating the opportunities of better leveraging model content throughout construction process. Discussion of how a planning approach and implementation guidelines will be developed to advance model uses in construction will help conclude the paper.

1 INTRODUCTION

Digital models incorporating 3D geometry and information attributes are becoming a standard for industrial facility and commercial building design. Depending on the technology, a variety of model uses have been developed to serve particular purposes for project stakeholders, such as designers and contractors, across project phases. Practitioners have acknowledged the benefits of adopting the data-enriched models in integrating design and construction (Eastman et al., 2011). Regardless, challenges remain in better leveraging models within facility construction processes. Current practices frequently require significant design content remodeling or revision for construction, such as the creation of detailed fabrication models and coordination models adding details required for construction. Moreover, there is a need for a comprehensive understanding of construction information requirements that are not presently available, but could be delivered via a model. This presents an opportunity to create coordinated industry guidelines and a process for leveraging model content through the construction phase.

As an initial step, this paper focuses beyond the implementation of models for commercial building projects, and aims to identify the breadth of construction needs for using information models. A thorough review of recent academic publications has been conducted to capture the state-of-the-art construction modeling. The existing gaps of using models for construction uses have been revealed, indicating the opportunities of better leveraging model content throughout construction process. The need of developing a planning approach and implementation guidelines to advance model uses in construction is discussed as well.
2 BACKGROUND

Information modeling has been adopted in the architectural, engineering, and construction (A/E/C) industry since late 1980's. Focusing on commercial building projects, Kreider and Messner (2013) defined a building information model use as “a method of applying Building Information Modeling (BIM) during a facility’s lifecycle to achieve one or more specific objectives.” There have been many efforts on listing BIM uses, documented in publications (Eastman et al., 2011), industry guides (Department of Veterans Affairs, 2010), and other industry efforts (Computer Integrated Construction Research Program, 2010). None of them are completely comprehensive or generated by a consistent methodology. Regardless, according to the BIM Project Execution Planning Guide (Computer Integrated Construction Research Program, 2010), which is the most widely adopted for BIM uses, there are 9 of 25 defined uses that can be adopted to support the construction. Among them, 3D coordination was reported in an online survey as the most frequently used BIM use and perceived as the highest beneficial use; while the others, digital fabrication, in particular, was considered as very beneficial, yet not used frequently (Kreider et al., 2010).

One of the main reasons to explain the challenges during adoption is managerial (AGC, 2005). There is a need to standardize the process and to define the guidelines for using the models along with the embedded information to facilitate construction process (Azhar et al., 2011). Driven by the managerial challenges, Kreider (2013) applied a methodology and generated a model use taxonomy for BIM implementation, which has also been approved for adoption in the National BIM Standard – US, Version 3 (still awaiting publication). The primary components of a BIM Use are shown in Figure 1, with five different purposes identified as “Gather,” “Generate,” “Analyze,” “Communicate,” and “Realize.” The ontology that applied in this study provides an effective methodology to categorize BIM Uses and also allows for future expansion of BIM Uses.

![Figure 1: The components of a BIM Use (Kreider, 2013)](image)

Therefore, this paper employs the ontology to capture the state-of-the-art model use and identifies the gaps and areas to potentially expand modeling implementation in the future. To avoid the challenges related to the perception of BIM’s application to be specific to a category of facilities, more broad language is used here by John Messner to define the “Model Use” as: “a method or strategy of applying digital modeling during a project lifecycle to achieve one or more specific objectives.”

3 METHODOLOGY

A review of recent academic research on the development and implementation of construction modeling has been applied to capture the leading model use and identify potential construction needs for future modeling implementation. Seven journals and five conferences were targeted as sources (Table 1). “Virtual model” and “construction” were used as key words to search the targeted journal publications and conference proceedings for relevant papers. With a total number of 53, Figure 2 shows the number of relevant papers in each 5-year period of the past two decades.

Through the literature review, matrices are used to capture the current model uses and to reveal the opportunities of future model uses to support construction tasks. In the current work, three types of matrices have been plotted:

- Model Use Technology verses Construction Task: to capture the construction tasks that can be supported by model uses leveraging emerging technologies.
Model Use Technology versus Model Use Purpose: to capture the purposes of existing model uses in construction.

Construction Task versus Model Use Purpose: to capture the construction tasks that have modeling supported in different purposes.

In addition to capture the existing model use, the three matrices are expected to reveal the gap of model uses in construction, indicating opportunities of leveraging technologies and model information to facilitate construction operations. The next two sections will discuss the review results, starting with the description of the matrix components.

### Table 1: Publications of major construction journals and conferences for review

<table>
<thead>
<tr>
<th>Source</th>
<th>Name</th>
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<tbody>
<tr>
<td>Journal</td>
<td>ASCE Journal of Computing in Civil Engineering</td>
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<td>ASCE Journal of Construction Engineering and Management</td>
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<td>Elsevier Journal of Automation in Construction</td>
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<td>Journal of Information Technology in Construction</td>
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<td>ASCE Journal of Architectural Engineering</td>
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<td>Canadian Journal of Civil Engineering</td>
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<td></td>
<td>Elsevier Journal of Advanced Engineering Informatics</td>
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<tr>
<td>Conference</td>
<td>International Society for Computing in Civil and Building Engineering (ISCCBE) Conference</td>
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<td></td>
<td>International Symposium on Automation and Robotics in Construction (SARCI)</td>
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<td></td>
<td>International Council for Research and Innovation in Building and Construction (CIB) W78 Conference</td>
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<td></td>
<td>eWork and eBusiness in Architecture, Engineering and Construction: ECPPM</td>
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<td></td>
<td>Annual Conference of the International Group for Lean Construction (IGLC)</td>
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Number of Relevant Publications Reviewed (Total: 53)

![bar chart](Image)

Figure 2: Academic publications reviewed during the period of 1994-2014

### 4 DIMENSIONS OF MODEL USE MATRIX

Three dimensions are used to develop the model use matrix and to capture construction modeling uses: model use technology, construction task, and model use purpose.

#### 4.1 Model Use Technology

The first dimension of model use matrix is “model use technology,” to capture the emerging technologies being leveraged for model use in the construction industry. Anderson and Schaan (2001) categorized the advanced technologies into five high-level groups: communications, on-site plant and equipment, materials and systems, systems, and design. Fenn (2010) mapped out a number of potentially transformative technologies, from augmentation to tablets, depending on the time to and the impacts on the mainstream adoption of each. In the current study, seven different types of models use technologies are categorized and summarized:

- **Simulating technology**: it described as the technology to create a model that behaves or operates like a given system with a set of controlled input (Anderson and Schaan, 2001).
- **Business management tools**: it includes all the systems and applications used by organizations to cope with the planning and management of expenses, process, resources, documents, field administration, and communication (Neelamkavil, 2009). Example tools can be Enterprise Resource Planning (ERP), and document management systems.
- **Geographic information system (GIS)**: GIS is defined as a computer system “capable of storing, editing, processing, and presenting geographical data and information as maps” (Campbell and Shin,
GIS applications allow users to query and analyze spatial information, edit geographical data in maps, and present the results of all these operations.

- **Positioning systems (or tracking systems):** it describes the usage of technology to determine or track the location of an object during construction (Grau et al., 2009). Related technology includes Global Positioning System (GPS), Radio-frequency (RF) Technology, and Ultra-wideband (UWB).
- **Imaging technology:** it indicates the application of technology that is used to capture, process, and preserve images to support construction operations, such as 3D video rage imaging, photogrammetry, laser scanning, and augmented reality (Turkan et al., 2013).
- **Mobile technology:** this technology provides support for small, handheld computing devices with a display screen, such as mobile phones and tablets, to be used by mobile workers to view, input, and transmit information (Kondratova, 2004).
- **Robotics:** it indicates the application of robots to support and even automate construction operations (Neelamkavil, 2009).

### 4.2 Construction Task

The second dimension of the matrix is “construction tasks,” to capture the construction activities that can be supported by model uses. Preliminary investigation of construction tasks was based on the schedule-based control structure approach (Halpin et al., 1987), also named as work breakdown structure (WBS). As the first level of breakdown structure, those following categories can be subdivided into the level of detail as needed. The planning and management tasks throughout the construction process are considered as a separate category listed as follows:

- **Construction planning & management:** it describes the activities related to planning and management before and throughout construction, including construction scheduling and planning, progress monitoring, resource tracking and management, safety, and coordination activities.
- **Procurement:** it describes the acquisition of resources needed to transform a design to a physical facility, from purchasing to manufacturing/fabrication, and delivery to the construction site.
- **Civil engineering activities:** here it is considered as site development tasks based on hydraulic, environmental and geotechnical engineering, like surveying, drilling, boring, pavement, etc.
- **Excavation & Foundation:** it describes the construction tasks for excavation and foundation construction.
- **Frame Erection:** the erection of structural frame/components is the focus of this category.
- **Assembly & Installation:** it describes the construction assembly and installation tasks at site.
- **Engineering Systems:** it refers to the construction activities related to mechanical, electrical, and plumbing (MEP) systems.
- **Enclosure & Finishes:** it indicates the construction of building envelope and finishing work.
- **Quality Assurance/Quality Control (QA/QC):** activities that help to inspect and control the quality of construction belong to this category.

### 4.3 Model Use Purpose

Another dimension that used to plot the matrix is model uses purposes. According to Kreider (2013), there are five categories and eighteen subcategories of model uses purposes in the industry (Figure 3):

- **Gather:** to collect or organize facility information, covering the sub-purposes such as “Qualify,” “Monitor,” “Capture,” and “Quantify.”
- **Generate:** to create or author information about the facility, covering the sub-purposes such as “Prescribe,” “Size,” and “Arrange.”
- **Analyze:** to examine elements of the facility to gain a better understanding of the elements, covering the sub-purposes such as “Coordinate,” “Forecast,” and “Validate.”
- **Communicate:** to present information about a facility in a method in which it can be shared or exchanged, covering the sub-purposes such as “Visualize,” “Draw,” “Transform,” and “Document.”
- **Realize:** to make or control a physical element using facility information, covering the sub-purposes such as “Fabricate,” “Assemble,” “Control,” and “Regulate.”
5 RESULTS

Plotted between the three dimensions, three matrices are developed and explained in the following.

5.1 Model Use Technologies Supporting Different Construction Tasks

Figure 4 illustrates the matrix of model use technologies broken down by construction tasks. The data indicates the number of publications that employed the particular model use and technology to support construction operations. It should be noted that one case may use multiple technologies; and on the other hand, one type of technology use can be applied for multiple construction tasks. For the modeling effort that supports construction planning and management, it is also interested to capture the phases, from procurement to quality inspection, when the application emphasized and occurred.

![Model Use Technologies for Construction Tasks](image)

As illustrated, construction planning and management is considered as the primary task that needs the support from construction modeling with advanced technologies. More specifically, progress monitoring and resource management become the focus, considering the technological impacts on the improvement of craft productivity (Grau et al., 2009). They are widely tested in the procurement, erection, assembly, and installation of structural components such as beams and columns (Figure 4). Simulation technology, imaging technology, and positioning systems are mostly applied to support the activities. Compared with structural components, monitoring and tracking the work of engineering systems is found to be challenging. However, leveraging model uses and technologies for construction tasks regarding engineering systems is largely needed (Figure 4), since they constitute a large portion of construction costs and asset value (Bosché et al., 2013).

Robots have also been studied in order to support various construction operations, such as excavation and foundation work (Ha et al., 2002), frame erection (Kang and Miranda 2006), assembly and installation (Chu et al., 2013), finishes (Bai, 2007), and QA/QC (Shen, Lu, and Chen, 2010) (Figure 4). Regardless,
they are not implemented on a wide scale for many reasons, such as dynamic nature of construction sites, culture, human skills, and cost of applying robotics technology (Caldas and Goodrum, 2010).

5.2 Implementing Model Use Technologies with Different Model Use Purposes

Similarly, Figure 5 illustrates the matrix of model use technologies broken down by model use purposes. The numbers indicate the quantity of publications that leveraged the particular technology for certain model use purpose(s). One case may have multiple technologies applied together to serve a primary model use purpose. Thus, for each case, only the primary model use purposes of the study was plotted into the matrix. For example, Hammad et al. (2007) employed simulation technology and GIS to perform an equipment workspace analysis for infrastructure projects. The representation of the workspace (i.e. “Communicate”) through capturing the existing site information (i.e. “Gather”) can be two model use purposes. But considering that the goal of the study is to detect and resolve the potential equipment workspace conflicts, the primary model use purpose was identified as “Analyze” instead.

![Model Use Technologies with Model Use Purposes](image)

Figure 5: Categorizing model uses and technologies by model use purposes

As shown, “Gather” is the most popular model use purpose, majorly by implementing technologies such as positioning systems and imaging technology to track materials and monitor construction progress (Figure 5). This result is consistent with the high demand of technology uses for construction planning and management indicated in Figure 4. On the contrary, the least amount of studies on construction modeling are found to be driven by “Generate” and “Communicate” purposes. The reason could be that the benefits of implementing 3D modeling and mobile technology to generate, access, and transfer facility information has been widely demonstrated in practice. With the increasing experience of model use, the needs of model use gradually progress beyond the initial intent of visualization and coordination, and to sophisticated analysis (Taylor and Bernstein, 2009). Those analysis employed simulation technology (“Analyze” in Figure 5), to simulate and optimize construction planning, such as planning for site layout (Astour and Franz, 2014), logistics (Saied and El-Rayes, 2014), and equipment workspace (Hammad et al., 2007). Moving beyond “Analyze,” the ultimate model use of robots, combined with other technologies, to automate the realization process of a facility product also attracted a fair amount of attention in academia (“Realize” in Figure 5).

5.3 Construction Tasks Supported with Different Model Use Purposes

The third matrix (Figure 6) illustrates the construction tasks that can be supported by model uses on different purposes. Consistent with previous results, Figure 6 captures the primary need of implementing modeling for planning and management. The majority of model uses were applied to collect information about a facility at various phase, from procurement to quality inspection, for progress tracking and
resource management ("Gather" in Figure 6). Figure 6 also indicates the construction needs of more sophisticated model use, as the number of studies increases from category of "Generate" to "Realize." Even with "Generate" purpose, the modeling application shifted from creating or authoring information about the facility product to generating the plan of temporary structure such as scaffolding for frame erection (Kim and Teizer, 2014). The considerable number of studies with "Realize" model use purpose (Figure 6) reflects the interests of automated construction tasks such as fabrication. Regardless, in overall, there is still lacking model support for construction tasks such as excavation, engineering systems, and envelope and finishes (Figure 6).

![Construction Tasks Supported by Model Use Purposes](image)

Figure 6: Supporting construction tasks with different model use purposes

6 DISCUSSION AND CONCLUSION

To summarize, this paper captures the state-of-the-art model uses for construction tasks. These efforts have been mostly applied in progress monitoring, as well as resource tracking and management. Driven by the “Gather” purpose, technologies such as positioning systems and imaging technology have been used to support these activities. Moreover, this paper identifies the breadth of construction needs of model use, and indicates that the current model uses need to be broadened with sophisticated analysis to support construction operations, such as excavation and engineering systems. The lag of current adoption also calls for developing implementation guidelines, which are expected to address the model use purposes, process, and technology and information requirements, to better support construction needs. It is also important to note that multiple model uses can be combined to achieve an overall goal on a project. Examples of goals which require the integration of multiple model uses include a series of model uses to develop, visualize and analyze a site logistics plan, or the development, visualization and analysis of the material management information for a project. These overall goals require a defined series of activities which build the model content through a progression of model uses, and model information. This paper provides the ground of building such a model progression based on the breadth of construction needs and the paradigm of model use purposes.

Thus, future work will focus on defining an approach to organize the model uses that can be applied together to achieve an overall project goal. The information needs will be identified, along with the interactions between the model uses. Potential near-term future model uses will be explored and defined.

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