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Analysis of modeling effort and impact of different levels of detail in building information models

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ABSTRACT

The main objectives of this paper are to evaluate the modeling effort associated with generating building information modeling (BIM) at different levels of detail (LoD) and the impact of LoD in a project in supporting mechanical, electrical and plumbing (MEP) design coordination. Results show an increase in total modeling time ranging from doubling the modeling effort to eleven folding it, when going from one LoD to another. When comparing modeling time per object, rates ranged from 0.2 (decreased modeling time) to 1.56 (increased modeling time). Based on the experiments done in MEP design coordination, it was observed that the automatic clash detection process using BIMs, with its consistently higher recall rate, provides a more complete identification of clashes, with the cost of false positives (low precision). This study showed that additional modeling effort can lead to more comprehensive analyses and better decision support during design and construction.

1. Introduction

According to the National Building Information Modeling Standard Committee, a building information model (BIM) is defined as "a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onward" [1]. BIMs have been gaining acceptance in the construction industry for many applications, such as constructability analyses, design checks, commissioning, life-cycle assessment, among others. Moreover, the widespread use of BIM is currently being encouraged by the US General Services Administration (GSA) as well as the US Army Corps of Engineers (USACE). GSA's Office of Government wide Policy [2] is the largest lessee of building assets in the United States, with 169 million sq ft leased. GSA requires utilization of BIM for all major projects receiving design funding from 2007 and on [3]. The USACE is another example of a federal agency implementing BIM organization-wide [4].

Various industry organizations, such as Associated General Contractors (AGC), National Institute for Building Sciences (NIBS) and major government organizations, such as GSA, have specialty groups working on adaptation of BIM within the Architecture, Engineering, Construction, and Facility Management (AEC/FM) industry, and are developing guidelines for generation, utilization and adoption of BIMs [3,5,6]. While potential benefits of utilizing such models are much talked about [7–12], there have not been many research studies investigating the modeling effort associated with generating BIM at different levels of detail (LoD) and the impact of an LoD in a project. Such evaluations are needed in order to take full advantage of the benefits of a semantically-rich building representation.

Based on an existing set of LoDs [13] and on case studies carried out in two construction projects, the main objectives of this paper are: (1) to evaluate the modeling effort associated with generating BIM at different levels of details, ranging from depiction of *approximate geometry*, to *precise geometry* and then to *fabrication* level precision (these LoDs are defined in the Background Research section of this paper); and (2) to evaluate the impact of LoD in a project in supporting clash detection, in terms of precision and recall of identified clashes in mechanical, electrical and plumbing (MEP) design coordination.

2. Background research

There is increasing support from industry professionals and software vendors for the utilization of BIM for improving project performance, interoperability and processes within the AEC/FM industry. This increasing support targets reducing losses of approximately $15.8 billion dollars annually for capital facilities, in the

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United States alone, caused by a lack of complete integrated life-cycle information about facilities [14]. Moreover, the Construction Industry Institute, as stated in Eastman et al. [42], reported that 57% of activities in the construction industry are waste or non-value added activities, as compared to 26% in manufacturing. Waste in the construction industry is estimated in $300–400 billion annually [42]. AEC/FM committees and alliances, such as NIBS and AGC, work for full life-cycle implementation of BIM [3,5]. Software vendors also focus on providing interoperable solutions, such as developing Industry Foundation Classes (IFC) compliant applications, in order to enable integrated project information throughout the life-cycle of construction projects. With these efforts, more AEC/FM companies are utilizing BIM applications. For example, 48% of AEC/FM companies were using BIM in 2009, which is a 75% increase as compared to 2007 [15].

Wide support for BIM is due to its various benefits throughout project design and planning, construction and facilities management. There are many benefits of BIM cited in the previous work in supporting decisions and improving processes throughout the life-cycle of a project [1,16–21]. Related to the preconstruction phase of a project, these benefits include identification of design conflicts prior to construction, enabling the prefabrication of components prior to construction, and accurate geometric representation of all parts of a facility [1,16,18,20]. During construction, these benefits include less rework, reduction in requests for information and change orders, customer satisfaction through visualization, improved productivity in phasing and scheduling, faster and more effective construction management with easier information exchange [1,17,19]. For the whole lifecycle of a project, these benefits will include control of whole life cycle costs, integrated life-cycle data, rapid and accurate updating of changes common through the conceptual development [1,17–20].

Though BIM is becoming widely-used in the AEC/FM industry, there is still a need for understanding the value added by BIM for construction projects and for companies operating in the AEC/FM industry. The usage of BIM for all stages of a project is not yet a common practice. Nonetheless, there have been numerous case studies identifying the benefits, and testing the capabilities and limitations of BIM [22–31]. In order to quantify the value added by BIM, several researchers have used different evaluation metrics depending on the purpose for which BIM was utilized. Savings in man-hours during design, ability to quantify rooms and spaces within a facility, improvements in time and accuracy of cost estimates and design coordination, reduction in the number of requests for information (RFI) and change orders are examples of the metrics used in previous studies to quantify the value added by BIM usage. Table 1 provides a synopsis of the previous case studies conducted to quantify the benefits of using BIM. Given that structured metrics are difficult to obtain in industry, Table 1 summarizes quantified benefits reported in each publication.

While benefits of BIM are important to quantify, it is equally important to identify what to include in a BIM to achieve the expected value added by BIM usage in construction projects. The LoD to be included is a critical criterion to consider while developing a BIM of a project. Many researchers state that the use of a BIM (e.g., cost estimating, energy simulation, creating fabrication drawings) will dictate the LoD that a model should have [18,26,37,38]. Some researchers state that depending on the use of the BIM, different versions of the BIM need to be created (e.g., cost model, equipment inventory model, sequencing model, coordination model, fabrication model) [39]. Though various researchers stated the importance of defining LoDs, there is a scarcity in defining what these LoDs should be for each use of BIM. An initial effort to define LoD in BIM has been the one developed by Vico Software Inc. In that definition, LoD is defined based on components and defined as the progression of a component from the lowest level of approximation (i.e., conceptual representation) to the highest level of representation (i.e., as-built) based on the component's use. These LoDs are defined as conceptual, approximate geometry, precise geometry, fabrication and as-built [13]. Approximate geometry LoD represents components as generic elements (e.g., modeling a wall component as a generic wall without specifying it as an interior or exterior wall components) without defining their specific properties as it will appear in the confirmed final drawings. Precise geometry LoD represents components as they appear in confirmed final drawings, and shows detailed material and component properties. Fabrication LoD represents details of assemblies as they appear in shop drawings. By using these definitions, levels of details of components that appear in a building information model can be defined. Within this research study, the research team used these definitions as a point of departure, and defined the semantics that should be represented for those levels of details. In addition, using a subset of these LoDs, the research team analyzed the modeling effort (i.e., time and number of objects) needed to generate such LoDs and impact of these LoDs in supporting various construction management tasks (such as coordination). The next section details the research method utilized to perform these analyses.

3. Research method

In order to evaluate the modeling effort and the impact of LoD, two construction projects were selected, where different LoDs were required to be modeled. An overview of the selected projects and how they apply to this research is shown in Table 2, including project description, BIM usage, as well as the studies carried out for the purpose of this paper. The projects are described in detail subsequently, followed by detailed descriptions of how each of the two types of studies was carried out for each project.

Table 1
A synopsis of a set of case studies that quantify benefits of using BIM through project phases.

Purpose to use BIM	Project type	Quantified benefits	References
Cost estimating	Restaurant building	44% faster estimates	[32]
	Various projects	3% cost estimation accuracy, 80% faster estimates	[33]
Space calculations	Medical research lab	20% saving in man-hrs, corresponding to 62% cost savings	[20]
Design and planning	Residential complex, commercial center, public shelter	2.6% to 47.4% reduction in work hours	[34]
	Various projects	40% reduction in unbudgeted change	[33]
	Medical office building	20–30% labor cost saving in MEP contractors	
		25–30% improvement in mechanical component installation	
		6 months of schedule reduction in overall project	
		$9 million saving in cost	[35]
	Aquarium project	$200,000 savings	[36]
	Arts center	$10 million savings	[25]
	Pilot plant facility	60% reduction in RFIs	[18]
	Various projects	10% savings from the contract value	[33]