Automation in Construction 51 (2015) 23–31

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

Quantitative analysis of warnings in building information modeling (BIM)

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ARTICLE INFO

Article history:
Received 4 June 2014
Received in revised form 28 September 2014
Accepted 11 December 2014
Available online 5 January 2015

Keywords:
Building information modeling
Design errors
Decision making
Design management
Pareto analysis

ABSTRACT

Building information modeling (BIM) provides automatic detection of design-related errors by issuing warning messages for potential problems related to model elements. However, if not properly managed, the otherwise useful warning feature of BIM can significantly reduce the speed of model processing and increase the size of models. As the first study of its kind, this study proposes to apply the Pareto analysis to investigate BIM warnings in terms of type and frequency. Based on warning data collected from three California healthcare projects, the analysis revealed that the 15–80 rule applies across the case projects and their design phases—15% of the warning messages are responsible for nearly 80% of the warnings. Two other noteworthy findings include the following: (1) only the schematic design phase indicates a different Pareto rule of 25–80, as well as warning pattern from other design phases due to its unique purpose; and (2) the decisions of individual design teams are a major variable in the pattern of warning types. Lastly, time estimation for warning corrections is proposed based on learning curve theory to support efficient BIM warning management practices. The results and warning classifications presented in this study are expected to contribute to the design management and modeling practices of design teams involved in large, complex projects.

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1. Introduction

With more architecture, engineering, and construction (AEC) companies realizing the benefits of building information modeling (BIM) in their projects, its adoption in North America dramatically increased from 28% in 2007 to 71% in 2012 [1]. The AEC industry appears to increasingly agree that BIM has become the critical part of current design and construction practices. The 3D-based virtual models of BIM integrate a vast amount of design information that supports the efficient delivery of capital projects [2]. In particular, BIM can support the reduction of design-related errors and reworks by allowing for automatic detection of errors related to model elements [3,4]. As a way of error detection, BIM issues real-time *warnings* to inform users of potential problems that can harm the key components of design information, such as the integrity of the model, the design intent, and the reliability of documentation [5].

One unique nature of BIM warnings is that users are allowed to dismiss warning messages when issued. Warnings then are stored and maintained by the BIM system until users revisit them at their convenience. When users wish to make corrective actions, the system allows for a quick retrieval of previously dismissed warnings. In a large, complex project, it is common to see warnings accumulate into the thousands. Because BIM is processor-intensive and requires a high level of computing, such excessive warnings are known to significantly reduce the speed of model processing and increase file sizes [6]. Therefore, users are required to diligently manage the accumulating warnings in order to prevent this useful feature from causing inefficiency during the design and modeling processes.

However, despite the significance of BIM warnings, there has been little to no research aimed at investigating them. In response, the overarching goal of this study is to describe and analyze warning data by applying the Pareto analysis. For the purpose of this study, a total of 15,586 warning messages were collected from three California healthcare projects of varying types and sizes, where Autodesk Revit® was used as their main BIM software.

Based on the extensive literature review, this study is found to be the first of its kind that attempts to classify and analyze BIM warnings. Although we make no attempt to generalize the results of this study to the rest of the BIM community, the rigor of this study can be seen as a step forward in providing insight regarding patterns and classifications

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http://dx.doi.org/10.1016/j.autcon.2014.12.007
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of BIM warnings. The findings and proposed classifications are expected to contribute to the design management and modeling practices of the AEC industry, especially for design teams involved in large, complex projects.

2. Background

This section summarizes the literature review that was performed in the relevant subject areas including BIM, design errors, and the Pareto analysis.

2.1. Building information modeling (BIM)

Information technology (IT) supports the development of projects in an efficient manner while streamlining the different phases of construction [7]. As a recent IT innovation in virtual design and construction (VDC), BIM provides a new approach to design, construction, and facility management by enabling the 3D-based representation of design information, improving project and design coordination accordingly [2]. In recent years, BIM has been widely used for many different activities during the project lifecycle including building design, structural design, equipment management, cost estimation, and property management. A survey about BIM usage [8] showed that BIM is most frequently used during the design stage (55%), followed by the detail design and tender stage (52%), construction stage (35%), feasibility stage (27%), and operation and maintenance stage (9%).

A number of studies have reported benefits from the implementation of BIM in construction projects [9,10]. BIM provides an integrated platform of building design for energy efficiency [11] and supports construction and project managements [12,13]. Overall productivity can be improved because BIM helps to improve the coordination and communication of design information by sharing a centralized model with the other project members [14]. Using BIM enables a greater exchange of information between stakeholders, designers, manufacturers, and contractors. It also improves the quality of the information, which accordingly allows for informed decision making [15].

Due to its collaborative nature, BIM requires an enhanced collaboration among project parties, which leads to unique challenges in terms of standards [16], interoperability [17], systems integration [18], collaboration [19], and change management [20]. Also, how to define the responsibility of project parties is a concern because BIM allows various project members to simultaneously participate in modeling [21]. Hence, the collaborative nature of BIM modeling requires enhanced design coordination amongst design team members. In particular, warning management must be part of design coordination practices, because BIM warnings intend to alert users of errors and issues in modeling. Through real-time warning messages, BIM allows for automatic detection of design errors, supplementing the human cognition process in error detection.

2.2. Design errors and error classifications

Human error can be divided into two levels of human cognitive performance based on whether mistakes occur either in a previously experienced situation or in a new one [22,23]. Regarding the level of human cognitive performance, Rasmussen [22] classified those errors into one of three categories: skill-based slips (or lapses) that occur unintentionally during familiar routine, rule-based mistakes that occur in previously experienced situations, and knowledge-based mistakes that occur in new situations when using similar experiences from a similar situation. Because mistakes are the consequence of inappropriate planning and decision making, it is more difficult to detect mistakes in advance than it is to detect slips (or lapses) [24].

In that regard, architectural design errors occur in two representative situations: miscommunications between various parties in a project and cognitive limitation when considering too much data and information simultaneously [24]. Errors made during the design process (such as modeling errors in BIM) can either be slips of unintentional occurrences because of cognitive limitations in regular routines such as drawing plans and writing documents, or mistakes from inappropriate planning and decision making when solving spatial problems or choosing systems.

While slips are more noticeable, architectural design mistakes are hardly detected as errors unless they become noticeable errors at a certain stage of designing. Because the architectural process continues to progress, unless the design mistakes are implemented, they will not be realized as errors in the final product/model [25]. However, architectural design slips may be noticeable at the beginning because they can easily be identified as different or inappropriate in common routines. Assigning different groups to multiple checkpoints where they utilized their field experience and theoretical backgrounds during the design process appeared to reduce design error in architectural projects [24]. Although errors occur at both design and production phases of architectural design, errors at the latter stage cost more in terms of effort to recover [25].

Similarly, Lopez et al.'s [26] error taxonomy that was based on human cognitive performance illustrates that design errors were divided into three categories: skill- or performance-based errors, which were associated with slips of incautious performance in accustomed routines; rule- or knowledge-based errors, which were associated with mistakes; and intentional violations or noncompliance, which were a refusal of appropriate actions. Based on the error taxonomy, design errors were classified with the levels of design errors, which are personal, organizational, and project levels [26]. Similarly, Busby [27] divided the cases of errors in design process into five elements: participants, designs, tools, organization, and environment. Among the 75 cases of error, participants turned out to be the largest source of error, which caused 27 cases (36%), followed by design (25%) and organization (25%), tools (7%), and environment (7%).

Although a number of studies investigated design errors and their classifications during design process, there have been few studies aimed at investigating BIM errors. To fill the gap, the present study seeks to apply the Pareto analysis in order to investigate BIM warnings.

2.3. Pareto analysis in software engineering

The Pareto principle, also known as the 20–80 rule, was introduced by the Italian economist Vilfred Pareto when he found that 20% of people owned 80% of wealth in Italy. The principle is universally applied to a number of different domains—including economics, business, engineering, and quality control—in order to signify "vital few and trivial many" [28].

In particular, a number of studies in software engineering applied the Pareto principle in order to categorize and quantify the frequencies of different types of errors, faults, and failures during software development. Most studies aimed at validating a common belief that most issues result from a small number of causes. For example, Fenton and Ohlsson [29] found strong evidence that 20% of the modules contained nearly 60% of the faults (20–60) and 10% of the modules lead to 100% of the failures (10–100). Similarly, later studies confirmed the Pareto principle in software engineering—that 80% of all errors were caused by either 20% of all bugs detected [30] or 20% of codes [31].

3. Research objectives and methods

This study has three objectives: (1) to empirically test a hypothesis that a small number of warning messages contain most warnings (the Pareto principle); (2) to identify meaningful warning patterns across projects and design phases; and (3) to develop time estimation for correcting warnings. The following shows the research process as implemented in the study, in order to achieve the intended objectives:

1. Collect BIM warning data from case projects.
2. Determine the classifications of warnings based on feedback from project designers.

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