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BIM (Building Information Modeling) in civil engineering: Determining building information modeling effectiveness

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Abstract
Building Information Modeling (BIM) is a promising development that can address the inherited inefficiencies in construction. This research aims to develop a framework for assessing BIM effectiveness. Following an extensive literature review and expert opinions, the proposed framework was generated with a total of seven constructs. Structural Equation Modeling (SEM) was used to validate the proposed framework and test the research hypotheses based on 172 responses collected from 107 construction projects. The results revealed that BIM effectiveness is mainly governed by project- and company-based factors; where industry-based factors have indirect influences. Besides, BIM effectiveness drives higher process effectiveness, which in turn generates project- and company-related benefits. This research has developed an interactive framework that could be used to collect and analyze data from other countries to enable comparison of findings. Construction practitioners and policy-makers can benefit from the recommended strategies to enhance BIM effectiveness at project, company, and industry levels.

Highlights
- Effectiveness of BIM implementation is determined mostly by the project-based factors followed by the company-based factors.
- Industry-based factors do not directly impact the effectiveness of BIM implementation, but they indirectly affect it through exerting influences on the project- and company-based factors.
- A strong association exists between the effectiveness of BIM implementation and the effectiveness of the construction process.
- Effectiveness of the construction process directly influences both the project- and company-related benefits, where slightly greater impacts are observed on the project-related benefits.

Keywords: BIM (Building Information Modeling), civil engineering, modeling effectiveness

Introduction
Technological advancement can be measured by means of improvements in the efficiency of production methods or the raw material consumption. Enhanced productivity decreases costs, increases profits, and improves the standard of life by making goods and services affordable. Unfortunately, construction industry has achieved very little technological advancement [1]. The increasing competition in the international construction market puts pressure on construction companies to enhance their performances [2]. In this respect, Building Information Modeling (BIM) is considered a great opportunity for the companies to sustain their competitiveness globally.

BIM is considered a new work method rather than just an improvement in the construction process. BIM ensures that a single model can include and coordinate construction documents, visualization, material quantities, cost estimates, construction sequencing, scheduling, and fabrication [3]. Designers can make iterations, simulations, and tests on many aspects of the construction process before the actual construction starts. Correction of inaccuracies virtually prior to construction provides material and time savings [4]. Similarly, construction managers and supervisors can simulate the construction process before they commit to the labor and materials. Product and process alternatives can be explored, parts can be changed, and the construction procedures can be adapted in advance. Being able to perform all the activities continuously helps them to deal with the unexpected situations before they emerge [5].

BIM is a relatively new concept for the construction industry. Even though the BIM concept goes back to 1970s [6], BIM implementation started in the construction industry in 2000 [7]. Investigation of BIM implementation in construction projects has been a trending research topic. A number of studies have analyzed BIM implementation from various perspectives such as investigation of the success parameters [8, 9, 10], evaluation of the performance [11, 12, 13], and realization of the outcomes [14, 15, 16]. However, there are few studies conducted to analyze BIM implementation by considering these perspectives as a whole.

This research aims to develop a comprehensive BIM effectiveness framework. The framework is mainly composed of the determinants (project-, company-, and industry-based factors), measurements (BIM and process effectiveness criteria), and outcomes (project- and company-related benefits). Structural Equation Modeling (SEM) is the statistical analysis technique used to validate the framework and reveal the interactions between the constructs based on data collected through a questionnaire survey directed to BIM practitioners. The objectives of the research are to (i) develop an extensive BIM effectiveness framework, (ii) unveil the interactions between the constructs, (iii) prioritize the factors under each construct, and (iv) propose a roadmap to promote BIM implementation.

The research proposes a novel conceptual framework to systematically assess the effectiveness of BIM implementation within the context of country characteristics. The main difference and value of the study

lies in the fact that the model incorporates the interrelated nature of the parameters under investigation. Besides, the recommended strategies are distinguished at three different levels (project, company, and industry) as well as different stakeholders (construction companies, government bodies, and non-profit organizations). Findings of the research and the recommendations can help devise mechanisms to diffuse BIM use in the construction projects and improve the effectiveness of BIM-enabled project management practices.

The paper consists of six sections. The second section summarizes previous studies focusing on BIM implementation from various perspectives. The methodology (development of the framework, data collection, SEM analysis, and roadmap development) is presented in the third section. In the fourth section, the results of the analysis (respondent profiles, path coefficients, reliability and validity tests, and factor loadings) are shown and the roadmap is introduced. The fifth section discusses the interactions between the constructs, the most significant factors, and the proposed roadmap. In the conclusion section, major observations are indicated, recommendations are provided, limitations are expressed, and contribution to the body of knowledge is emphasized.

Conclusion

This study proposed a BIM effectiveness framework for construction companies. The framework was composed of the determinants (project-, company-, and industry-based factors), the measurements (BIM effectiveness and process effectiveness criteria), and the outcomes (project- and company-related benefits). A total of 172 samples obtained from 107 different construction projects were analyzed to test the developed hypothesis and validate the framework by using SEM.

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