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Review

# Mapping the knowledge domains of Building Information Modeling (BIM): A bibliometric approach

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ABSTRACT

Building Information Modeling (BIM) has been recognized as an emerging technological innovation which can help transform the construction industry and it has been adopted broadly in the field of built environment. Due to the rapid development of BIM research, various stakeholders require a state-of-the-art review of the BIM research and implementation. The purpose of this paper is to provide an objective and accurate summary of BIM knowledge using 1874 published BIM-related papers. The results show that 60 key research areas, such as information systems, 3D modeling, design and sustainability and 10 key research clusters, such as architecture design studio, building information and lean construction, are extremely important for the development of BIM knowledge. The results are useful for the identification of research clusters and topics in the BIM community. More importantly, these results can help highlight how BIM-related research evolves over time, thus greatly contributing to understanding the underlying structure of BIM. This study offers useful and new insights to summarize the status quo of BIM knowledge and can be used as a dynamic platform to integrate future BIM developments.

## 1. Introduction

The core function of Building Information Modeling (BIM) is to provide users with the ability to integrate, analyze, simulate and visualize the geometric or non-geometric information of a facility. The concept was first raised by Eastman in 1975 [1]. The terms: 'Building Information Model' and 'Building Information Modeling' (which refer to modeling building information, such as ontology development), were first used in Van Nederveen and Tolman [2] and Tolman [3]. However, much attention was paid to BIM in 2002 when it was commercially promoted by Autodesk as the process for generating and managing a facility with physical and functional information. Due to its potential benefits to enhance the information visualization, integration, interaction, sharing and communication, BIM has been widely adopted in many multi-disciplinary fields, including social (e.g. education, management and economics), natural (e.g. environmental science, ecology and energy) and computer science (e.g. information and communication technology, semantics and interoperability). Although a widespread adoption of BIM can demonstrate the usefulness of this technological innovation in multi-disciplinary fields, it can also indicate that the development and adoption of BIM may be fragmented.

The development and application of BIM in multi-disciplinary research can also be reflected in scientific literature. For example, Volk et al. [4] found that previous studies on the use of BIM in existing buildings can be categorized into four groups: functional issues, informational and interoperability issues, technical issues, as well as organization and legal issues. In order to uncover possible connections with scientific literature, many studies have been conducted to review past developments and propose new research trends for BIM. For example, Jung and Joo [5] reviewed the concepts of computer-integrated construction and BIM to provide a BIM framework for practical implementation. Cerovsek [6] examined the development of building product modeling and provided a methodological framework to improve BIM tools and schemata. Similarly, Tang et al. [7] used a critical review to identify the techniques that can be adopted to achieve automatic reconstruction of as-built building information models from laser scanning. Although many studies have been initiated, it should be noted that these reviews are typically qualitative, subjective, and based on a manual review, which can be biased and limited in terms of the number of articles that can be reviewed [8].

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In order to address the issues brought about by manual review, various structured analysis tools have been developed in recent years. These studies aim to reveal the hidden connections of various knowledge domains, which is critically important to the development of BIM, by addressing gaps in the literature and proposing new studies which are distinct enough from existing work to make a viable contribution [9]. For example, Yalcinkaya and Singh [8] used the latent semantic analysis to reorganize the unstructured data objects in the BIM literature to identify patterns for the discovery of knowledge. However, it should be noted that the latent semantic analysis relies on interrelations between different groups and the results may not be easily interpreted by readers. Many other visual tools have therefore been developed to create informative conceptualizations. These tools include Bibexcel, Sci2, VantagePoint, and CiteSpace [10], which are all supported by bibliometric techniques, such as document co-citation analysis and keyword co-occurrence analysis [11]. These techniques are based on the bibliographic records of each scientific document and can be applied to explore the unheeded linkages. As BIM can be considered interdisciplinary, an analysis of its scientific literature and associated bibliographic connections remains difficult. For example, Yalcinkaya and Singh [8] reviewed the trends in BIM by retrieving numerous thematic words from the literature using latent semantic analysis. This does not outline the connections, evolution, and growth of BIM topics in scientific literature. Similarly, He et al. [12] used CiteSpace to map the managerial areas of BIM and eight clusters, including collaboration, innovation, stakeholder, visualization, implementation, culture, framework, as well as operation and maintenance, have been identified. However, it only covers the managerial studies of BIM and only includes a limited number of studies. It should be noted that the bibliometric approach is not designed to replace a manual review. Instead, the approach can help reveal unbiased, quantitative and accurate connections between various studies. Manual reviews and insights produced by experts are still valuable for discussing, interpreting and understanding the complex subject.

In order to facilitate the development and implementation of BIM, this study aims to: 1) explore the knowledge base (e.g. unstructured key research topics) and knowledge domains (structured key research areas) associated with BIM using co-citation, co-occurrence and visualization tools based on studies from 2004 to 2015; 2) identify the evolution (e.g. the thematic flow) of BIM knowledge using citation burst detection; and 3) propose a BIM knowledge map based on the knowledge base, knowledge domains and evolution of BIM knowledge. Although this study is not an exhaustive analysis of all BIM-related literature, given its sample size, it offers a quantitative summary of the status quo of the BIM knowledge and illustrates the use of bibliometric techniques for exploring knowledge domains and hidden connections within the BIM discipline. In this study, BIM is considered as the process of generating and managing a facility with physical and functional information.

## 2. Background

Knowledge development is a dynamic process that often encourages particular research fields. Construction informatics is an example of the interdisciplinary field derived from both construction and computer science, shaped by a hierarchy of core knowledge and support themes [13]. BIM, as an area in construction informatics, has a similar hierarchical structure, including core areas (e.g. technical structure and information management process) and support areas (e.g. knowledge transfer, training, and education) [14]. In the field of BIM, many subareas have formed in the past few years, ranging from policy to process and technology [15]. Since its inception in 1975, most scholars tend to concentrate on one or two specific themes under a BIM sub-area that can eventually contribute to the whole body of knowledge. For example, there are studies focusing on the themes of BIM-related policy. Cheng and Lu [16] reviewed the BIM standards and policies that are available in the public sector. Howard and Björk [17] also reviewed the standards of BIM deployment and found that standards are generally supported although not applied rigorously. Dossick and Neff [18] examined BIM from an organizational point of view and concluded that although BIM fosters collaboration among project members, it does not strengthen collaboration between different organizations. In addition, Fan [19] examined intellectual property rights in BIM and concluded that ownership of the copyright of the final BIM model and model elements are both valuable.

Similarly, in the area of BIM-related processes, there are many separate studies which cover the use of BIM in various construction or project processes. For example, Lee et al. [20] proposed an ontological inference procedure to automate the method for searching work items in the tiling process. Park et al. [21] adopted a BIM approach for construction defect management, which is related to the quality control of construction processes. Kim et al. [22] relied on 3D data obtained from remote-sensing technology and developed a 4D BIM platform for automatic construction progress measurement. Similarly, Irizarry et al. [23] used BIM and Geographic information system (GIS) to track supply chain and provided necessary warnings related to the delivery of materials. It seems that BIM is a digital and capable platform to host the development and testing of various innovative theories related to construction and project processes.

As BIM is considered as an information technology enabled platform which can integrate inter-disciplinary collaboration, a few major developments have been conducted on the improvement of the platform, including information retrieval, visualization, data exchange, interaction, and interoperability. For example, Yeh et al. [24] focused on the transformation of the information from BIM models to on-site devices to ensure that correct information can be retrieved with minimal effort. Yan et al. [25] improved the design process in a BIM environment to enhance architectural design and visualization. Jeong et al. [26] investigated data exchange between various BIM models and confirmed that much work is still needed to achieve full interoperability between various BIM platforms. This is in accordance with Grilo and Jardim-Goncalves [27] who found that interoperability remains challenging and an investigation of interoperability at the business level, along with the technical level, is also needed.

It should be noted that although some studies are the fundamental building blocks, others may simply be practical applications or implementations of BIM, which add limited value to the growth of BIM knowledge. In order to identify the fundamental building blocks of BIM knowledge and their connections, there are many reviews which have been conducted. However, the collection of BIM knowledge in literature is extensive, and the ability to investigate connections and relationships among authors, articles, journals, publication dates, or geographic regions remains difficult. As such, many previous reviews only use a manual review method and may have a high level of bias. For example, Wong and Zhou [28] reviewed the use of BIM in enhancing sustainability and found that the current fundamental barriers against green BIM are during its implementation in the design and construction stages. Similarly, Bradley et al. [29] used a critical review to investigate the use of BIM for infrastructure and found that ICT system development and the modeling of infrastructure projects are the fundamental pillars in the research area. Tang et al. [7] conducted reviews to survey the adoption of laser-scanned point clouds for BIM's creation and found that filling the gaps among existing promising techniques and algorithms could become a fundamental burst for automated as-built BIM creation. Despite the importance of identifying fundamental building blocks of BIM knowledge, few studies have been conducted on BIM in a broader context.

Scientific literature contains both persistent and transient elements [30]. The persistent aspect of science literature can be characterized as knowledge domains which are the structured representation of unstructured data and can be identified through clustering analysis. In addition, the transient aspect of scientific literature can be