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The Influence of Deep Neural Networks (DNNs) on Building Information Modeling (BIM) Methods: A Study on Generative AI Approaches †

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Abstract: The power of the relationship between building information modeling (BIM) systems and advanced artificial intelligence models holds considerable weight for users of BIM. This relationship allows the generation, analysis, and deduction of insights from substantial construction data. This research examines the relationship between generative artificial intelligence (generative AI), deep neural nets, and the BIM system, including its users. This study examines the correlation between generative artificial intelligence and BIM system by conducting a case study. Furthermore, this paper examines the conceptual and practical use of generative AI components (e.g., diffusion models) in BIM systems via bibliometric analysis.

Keywords: BIM designer; text-to-image models; generative adversarial networks (GANs); generative diffusion models; bibliometric analysis

1. Introduction

The implementation of virtual design and construction (VDC) and digital twin (DT) methodologies plays a crucial role in the digital transformation of the construction sector. Besides, the potential applications of building information modeling are extensive [1]. Within the discipline of architecture, several systems are utilized to enhance design processes. These systems encompass computer-aided design data, parametric design processes data, generative design models, and the extensive data derived from building activities. These data sources serve as inputs for artificial intelligence models, enabling the integration of advanced computational techniques in architectural practices. Artificial intelligence (AI) models exhibit a high degree of complexity and find application across various academic disciplines. The utilization and theoretical frameworks surrounding the implementation of deep neural networks (DNNs) in the fields of construction and architecture have experienced a steady growth over time. Numerous research has been conducted to examine the practicality of employing generative AI tools or methodologies within the field of architecture [14,20,21,23,26]. The primary objective of this research is to investigate the amalgamation of building information modeling and state-of-art deep learning models. Furthermore, a case study has been carried out to assess its effectiveness.

Numerous studies have been conducted to examine the correlation between artificial intelligence and BIM [2–4,24]. Additionally, exploring the integration of BIM models into currently developed generative artificial intelligence models is essential. The utilization of generative models in conjunction with the BIM system facilitates the simplification of the designer's tasks. Generative adversarial networks (GANs), text-to-image techniques, diffusion networks, and large-scale language models possess promising prospects for utilization within the domain of the use of BIM design. In overall, this work examines the correlation between generative artificial intelligence and BIM by means of a specific case

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study. In this case study, a comprehensive textual depiction of the architectural component was formulated, and various alternatives were developed at varying levels of specificity. Moreover, the present work employs bibliometric analysis as a method to examine and interpret large-scale scientific datasets.

2. Experiments and Theoretical Framework

The culture surrounding BIM is complex and encompasses several procedures related to the generation of BIM data and the assessment of its outcomes. The inclusion of both geometric and textual data inside BIM holds significant relevance for both designers and field applications. This study examines the relationship between generative AI tools and the BIM designer by means of a case study (Figure 1). The methods are subjected to testing via the design of an architectural component, specifically a window, as well as alternate design options (Figure 1/#0-1-2-3). The Dall-E v2 [16], Stable Diffusion [17,18], and MidJourney [19] tools have undergone testing. The resulting 2D images with varying levels of detail provide insight to the designer or modeler who is developing the BIM model. Ploennigs (2023) [15] employed diffusion models in the generation of architectural plans and presented a prospective workflow diagram for a "semantic BIM-based diffusion model" in the future directions segment of their study. In their research, Jang and Lee (2023, p. 7) [22] examined the process of incorporating pre-trained large language models into BIM authoring tools. The field of generative AI incorporates a wide range of methodologies that are characterized by their multidimensional nature, consisting of various constituent components and models.

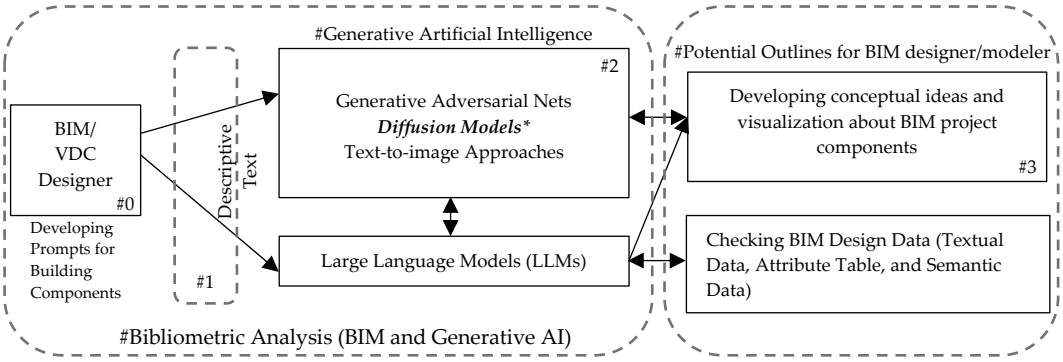

Figure 1. Developed roadmap for this study's work packages

In the contemporary construction sector, the impact of digitization has prompted efforts to transition from conventional digital approaches to artificial intelligence-aided design processes and the use of generative BIM practices. This study examines the effects of deep neural network and generative artificial intelligence techniques on the development and understanding of BIM design data. The present study employed bibliometric analysis via VOSViewer program and Scopus database. The data was loaded into VOSViewer software [5] and afterwards subjected to co-occurrence analysis. The chosen approach for analysis was the full counting method, with the unit of analysis being author keywords.

In their study, Heidari et al. (2023) [6] using VOSViewer, CiteSpace, and Gephi tools to conduct a bibliometric analysis on the terms "AI" and "BIM". Deep learning algorithms have many kinds of applications in the construction industry [7–12,25]. Furthermore, Zabin et al. (2022) [13] conducted a systematic literature study to examine the correlation between machine learning methods and building information modeling systems. Generative artificial intelligence (generative AI) encompasses various cutting-edge methodologies, including generative adversarial neural networks (GANs), diffusion models, variational autoencoder (VAE), and transformer architecture. The influence of generative artificial intelligence has been extensive in various academic disciplines, with particular attention given to its implications for the design industry. The integration of generative

models has the potential to greatly enhance various design processes, spanning from the idea to visual representation.

3. Results and Discussion

The findings of this study are comprised of two distinct components. The initial section of this study entails the detailed explanation of the findings obtained from the bibliometric analysis. The subsequent section focuses on the exploration of different 2D options for the design of BIM component (form-finding strategies), namely the architectural element known as the `window`. This exploration is conducted through the utilization of generative artificial intelligence techniques. A thorough investigation was carried out in the Scopus database by inputting the keywords "BIM" and "deep neural network" [(Query: ((ALL ("BIM") AND ALL ("deep neural network")))]. A comprehensive analysis was conducted on a total of 1092 papers. There was an observed increase in the quantity of publications from 2015 to 2023. Most of the publications originate from the disciplines of engineering and computer science (Figure 2).

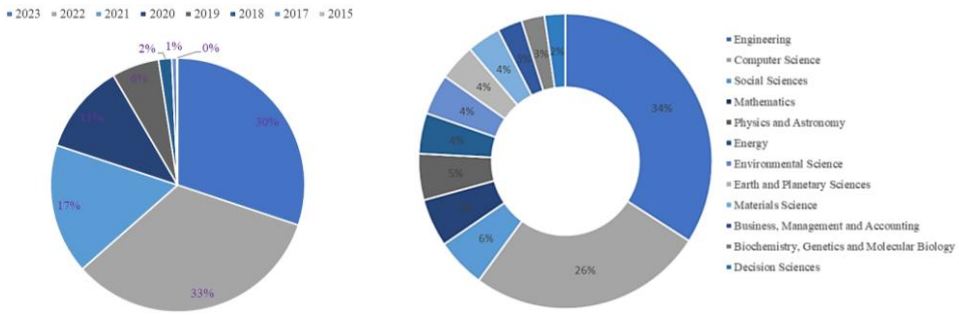

Figure 2. Publication Year (**left**) and Source Analysis (**right**).

Subsequently, an analysis was conducted on publications that encompassed the concepts of "Building Information Modeling" and "Generative Adversarial Networks" based on the specified query: ((ALL ("Building Information Modeling") OR ALL ("Building Information Modelling")) AND ALL ("Generative Adversarial Network")). A cumulative count of 146 scholarly articles was identified. Since the year 2019, there has been an observed increase in the quantity of published works (Figure 3). Based on the findings of the examination, a total of 11 clusters were identified. Elements of the clusters include terms such as architecture, generative design, smart building, 3D reconstruction, building layout, and data analytics (Figure 3).

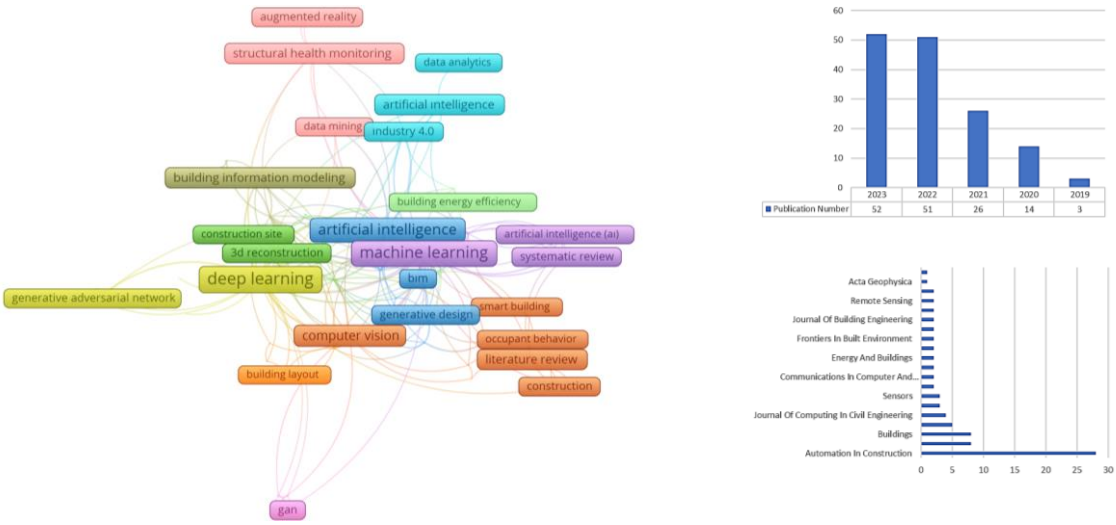

Figure 3. Publication Year and Source Analysis (**right**) and Co-occurrence Analysis (**left**) Results.

The database was queried using the search terms "Building Information Modeling" and "Transformer" [(Query: TITLE-ABS-KEY ("Building Information Modeling") OR TITLE-ABS-KEY ("Building Information Modelling") OR TITLE-ABS-KEY ("BIM") AND TITLE-ABS-KEY ("Transformer"))]. The quantity of scholarly articles published throughout the time frame of 2010 to 2023 amounts to 32. A total of 25 publications were recorded over the time frame of 2017 to 2023. Publications encompass the fields of engineering and computer sciences. Large language model, prompt engineering, natural language processing, construction management, automated code checking, generative pre-trained transformer, and ICT are some of the cluster keywords (Figure 4). Furthermore, a search was conducted in the Scopus database using the terms "Building Information Modeling" and "Diffusion model" (ALL ("Building Information Modeling") AND ALL ("diffusion network") OR ALL ("diffusion model") AND ALL ("Artificial Intelligence")). A total of 30 publications were identified. There has been an increase in the number of publications since the year 2015. Eight clusters were constructed. Computational design, deep learning, generative design, digital twin, 5D BIM, blockchain, design process, GNN, and conceptual model are some of the cluster keywords (Figure 5).

Figure 4. Publication Year and Source Analysis (**right**) and Co-occurrence Analysis (**left**) Results.

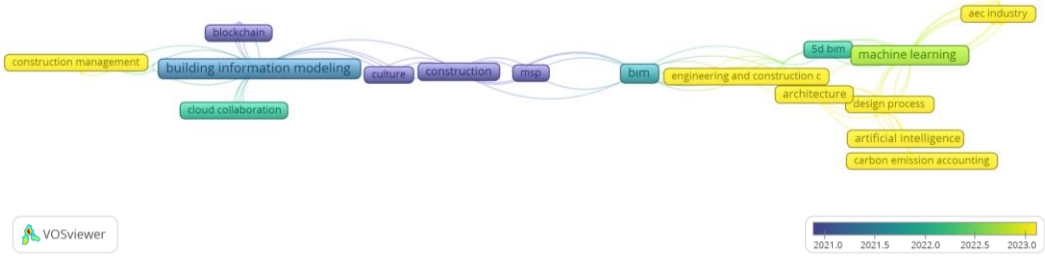

Figure 5. Co-occurrence Analysis Results: "Building Information Modeling" and "Diffusion model" terms.

Finally, the database was searched using the keywords "building information modeling" and "variational autoencoder" with the query: TITLE-ABS-KEY ("Building Information Modeling") OR TITLE-ABS-KEY ("Building Information Modelling") AND TITLE-ABS-KEY ("Variational Autoencoder"). Simultaneously, the database was queried [(Query: (ALL("Building Information Modeling") AND ALL("Large Language Model"))] using the phrases "Building Information Modeling" and "Large Language Model," resulting in the identification of six publications.

When utilizing BIM data, the BIM designer has the opportunity to utilize machine learning technologies such as natural language processing, computer vision, and generative artificial intelligence. This study utilizes generative artificial intelligence technologies to generate diverse design ideas for BIM components (Figure 6). For illustrative purposes,

a specific window design is delineated, and its intricacies are articulated in written form. The basic concepts were generated via diffusion models. Several bases were decommissioned and reconstructed in accordance with BIM guideline (Figure 6).

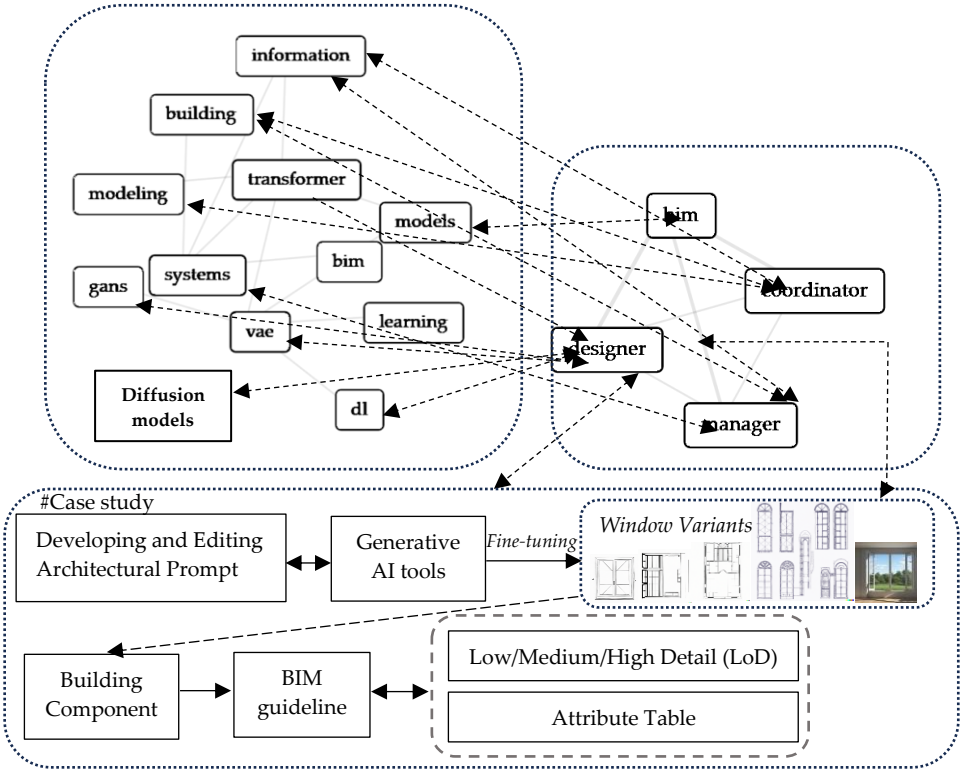

Figure 6. Creating a pipeline for the case study (**lower**) and the BIM-generative AI ecosystem (**upper**).

The BIM ecosystem encompasses various actors, including BIM designers and BIM managers, each of whom possesses distinct areas of jurisdiction. For instance, the generation of the BIM model or the formulation of BIM implementation plans (BEP) are carried out by distinct users. Gaining insight into the necessary criteria for the implementation of sophisticated deep learning (DL) models (e.g., CNNs, RNNs, LLMs, VAE, GANs, diffusion models, and transformer models) within the context of building information modeling systems is essential for BIM designer (Figure 6).

4. Conclusions

The establishment of a culture centered around BIM possesses the capacity to furnish a digital framework that effectively caters to the needs of users throughout various stages of the design process (ranging from initial concept design to the final stage) as well as throughout implementation (including fabrication processes and field applications). Furthermore, the BIM system encompasses various players, including the each of these actors assumes significant tasks as delineated by the workflow charts. This study investigates the correlation between generative artificial intelligence (AI), deep neural networks, and building information modeling through case study and bibliometric analysis. Besides, generative AI models have demonstrated notable efficacy within the domain of deep learning models, specifically in the areas of generating novel design alternatives and accommodating a diverse array of variations. This approach can allow for the development of numerous design problems and corresponding solutions. In sub-sequent research endeavors, the field of BIM big data will undergo further development, accompanied by the design of a comprehensive case study with LLMs.

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