Andrzej Szymon Borkowski
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HAVE WE ENTERED THE FOURTH ERA OF BIM? FROM THE ERA OF OPEN STANDARDS TO THE ERA OF ARTIFICIAL INTELLIGENCE

CZY WKROCZYLIŚMY W CZWARTĄ ERĘ BIM? OD ERY OTWARTYCH STANDARDÓW DO ERY SZTUCZNEJ INTELIGENCJI

Andrzej Szymon Borkowski*
Warsaw University of Technology, Poland

Abstract

Building Information Modeling (BIM) has been the hottest topic in the construction sector over the last decade. The evolution from CAD to BIM systems has been going on for over 40 years. The current periodization indicates that we are now in the third era of BIM development, the era of open standards, which was initiated by the idea of openBIM in 2012. Earlier evolutionary periods included the model federation (second era) and CAD3D (first era). Since 2022, there has been extremely dynamic development of artificial intelligence (AI), especially generative AI. AI tools automate some of the tasks that were previously performed by humans. Thus, the research question is: are we entering the next, fourth era of BIM development? The era of artificial intelligence? This chapter attempts to answer this reflective question. During an in-depth literature review, the directions of current and future research on BIM development are discussed.

Keywords: building information modeling, BIM, artificial intelligence, AI, development, periodization

Streszczenie

Modelowanie informacji o budynku (BIM) było najgorętszym tematem w branży budowlanej w ciągu ostatniej dekady. Ewolucja od systemów CAD do systemów BIM trwa już ponad 40 lat. Obecna periodizacja wskazuje, że znajdujemy się w trzeciej erze rozwoju BIM, erze otwartych standardów, zapoczątkowanej ideą openBIM w 2012 roku. Wcześniejsze okresy ewolucji obejmowały federację modeli (druga era) oraz CAD3D (pierwsza era). Od 2022 roku obserwuje się niezwykle dynamiczny rozwój sztucznej inteligencji (AI), zwłaszcza generatywnej. Narzędzia AI automatyzują niektóre zadania, które wcześniej były wykonywane przez ludzi. W związku z tym pojawia się pytanie badawcze: czy wkraczamy w kolejną, czwartą erę rozwoju BIM? Erę sztucznej inteligencji? W niniejszym artykule podjęto próbę odpowiedzi na to refleksyjne pytanie. W trakcie dogłębnego przeglądu literatury omówiono kierunki obecnych i przyszłych badań nad rozwojem BIM.

Słowa kluczowe: modelowanie informacji o budynku, BIM, sztuczna inteligencja, AI, rozwój, periodyzacja

1. INTRODUCTION

The current periodization (division into evolutionary periods) of BIM (Building Information Modeling) assumes the existence of three developmental periods in history (Borkowski, 2023). The first era covers the 1980s and 1990s as the time when the idea of BIM was born through the development of innovative applications – Archicad, Sonata, Reflex, Revit (in chronological order). In this era, users employ software (CAD2D, CAD2.5D, CAD3D), usually used closed

*Warsaw University of Technology, Poland, e-mail: andrzej.borkowski@pw.edu.pl

solutions, and modeled individual building objects. The second era saw the maturation of this concept, which began to cover an increasingly wider spectrum of professions and stakeholder groups. The advent of new tools and the spread of computers enabled the federation of models. Thus, more specialized professions were included in the digitization process, communication efficiency increased, and the number of collisions, errors, and antagonisms was minimized. The third era began with the announcement of the openBIM concept (in 2012) and the dynamic development of independent, open standards (Fig. 1). The developed norms and standards allow for the structuring of the BIM process and increase the productivity of companies and organizations. At the beginning of the second decade of the 21st century, it seemed that this era was continuing and that the much-anticipated interoperability was close to being achieved. However, the emergence of widespread generative artificial intelligence (AI) in 2022 changed the course of events. Scientists, practitioners, and innovators are wondering if this is the end of the era of open standards. Have we perhaps entered a new era of heavy machine use in the design, construction, and operation of buildings?

Currently, artificial intelligence tools can bring significant benefits, such as streamlining decision-making, optimizing processes, and increasing productivity. The construction industry faces various challenges, including low productivity, cost overruns, unskilled labor, and resource waste. Digital manufacturing, smart devices, and automation are seen as potential solutions to these problems. Although the integration of BIM and artificial intelligence is challenging, it could represent a significant paradigm shift in the construction industry (Heidari, Peyvastehgar, Amanzadegan, 2024). Previous research points to six advanced research areas in BIM-AI integration, including automated design and rule checking, 3D as-built reconstruction, event log exploration, building performance analysis, virtual and augmented reality, and digital twins (Pan, Zhang, 2023). A strongly emphasized area of research in the construction sector is prefabrication, a modern construction technique in which some or all of the structural elements are manufactured in a controlled environment and then installed on the construction site. The architecture, engineering, and construction (AEC) industry is gradually implementing prefabrication by integrating BIM with artificial intelligence and Internet of Things (IoT) applications (Rangasamy, Yang, 2024).

BIM is elective and optional. Many countries have opted for a BIM mandate (mandatory use of BIM in

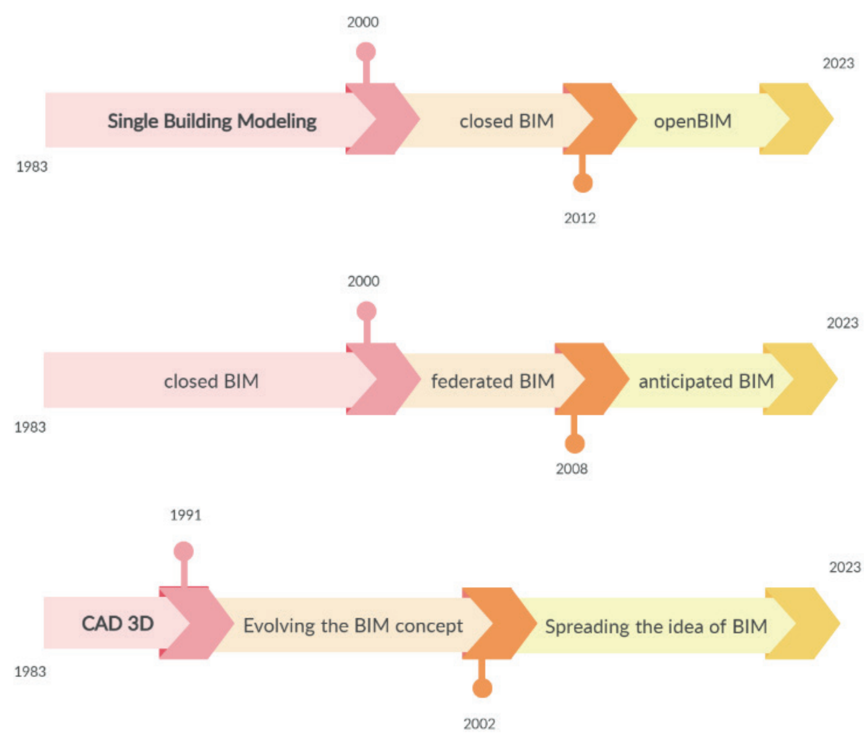

Fig. 1. The current periodization of BIM depending on various factors (from top): approach, organizational culture, idea
Source: Borkowski, 2023

public procurement), other countries encourage its use in a textbook approach, and others do not adopt it at all (Mitera-Kiełbasa, Zima, 2024). The reasons for these decisions vary, but without the digitization, robotization, and automation of the construction sector, which is the most burdensome for the natural environment, it is difficult to imagine achieving the ambitious goals of the circular economy. It therefore seems appropriate to ask a reflective question: has a new, fourth era in the development of BIM begun? The era of artificial intelligence? In order to fill this important research gap, a broad and inclusive literature review was decided upon. As a result of the analysis, synthesis, and evaluation of existing scientific and technical evidence, it was decided to raise the discussion on the future of BIM.

2. MATERIALS AND METHODS

This study adopted a deep literature study approach, which differs from systematic literature reviews conducted previously in this field (Ceccon, Villa, 2021; Bassir et al., 2023; Saleh et al., 2024; Du et al., 2024; Shamreeva, Doroschkin, 2021). The rationale for this methodological choice was twofold: first, comprehensive systematic reviews on BIM-AI integration already exist (Table 1), making another quantitative synthesis redundant; second, the rapid pace of AI development required a flexible, exploratory approach capable of capturing emerging phenomena not yet consolidated in the literature.

The literature search was conducted between September and November 2024 across three databases: Scopus, Web of Science, and Google Scholar. The search employed combinations of the following keywords: “BIM”, “Building Information Modeling”, “HBIM”, “Heritage BIM”, “artificial intelligence”, “AI”, “machine learning”, “ML”, “generative AI”, “deep learning”, and “IFC”. The selection criteria included: (1) publication date between 2020 and 2024 to capture recent developments; (2) thematic focus on the intersection of BIM with either AI technologies or open standards; (3) English language publications. From an initial pool of over 300 identified records, publications were screened based on relevance to the research question. Priority was given to empirical studies demonstrating practical BIM-AI applications, while purely conceptual works without implementation evidence were excluded. The final analysis encompassed both normative literature (peer-reviewed articles, monographs, conference papers) and gray literature (preprints, doctoral theses, industry reports) to ensure coverage of cutting-edge developments. It has already been established that the integration of artificial intelligence with BIM accelerates and improves decision-making processes (Zima, Wieczorek, 2024). Therefore, this study focused on qualitative analysis of how AI is transforming BIM practices across different phases of the building lifecycle.

3. LITERATURE REVIEW

Using BIM in AEC, construction project participants create digital models of buildings (buildings, infrastructure, public spaces, or entire cities) and generate vast amounts of information throughout the entire life cycle of a building. This generated

Table 1. Related works

No.	Authors	Title	Year of publication	Differences
1.	Bassir D., Lodge H., Chang H., Majak J., & Chen G.	Application of artificial intelligence and machine learning for BIM	2023	Overview of applications for quality monitoring
2.	Saleh F., Elhendawi A., Darwish A.S., & Farrell P.	A Framework for Leveraging the Incorporation of AI, BIM, and IoT to Achieve Smart Sustainable Cities	2024	Literature review on smart and sustainable cities
3.	Ceccon L., & Villa D.	AI-BIM interdisciplinary spill-overs: prospected interplay of AI and BIM development paradigms	2021	Analysis of approaches to BIM-AI integration
4.	Du S., Hou L., Zhang G., Tan Y., & Mao P.	BIM and IFC Data Readiness for AI Integration in the Construction Industry: A Review Approach	2024	Systematic literature review according to PRISMA
5.	Shamreeva A., & Doroschkin A.	Analysis of the influencing factors for the practical application of BIM in combination with AI in Germany	2021	Domestic market analysis – Germany
6.	Zima K., & Wieczorek D.	Overview of the possibilities of using artificial intelligence in BIM modeling	2024	Study of trends in the use of AI in BIM

digital data can be used for further evaluation, risk mitigation, analysis, and simulation using machines. Many specialized professions and a number of different stakeholder groups are involved in the investment and construction process. Often, their goals differ, and the lack of relational agreements and the use of contractual provisions alone results in the investment being staged. During these stages, stakeholders exchange databases or models, often losing some of the data in the process. The idea of open standards – openBIM – seeks to address the lack of seamless interoperability. It involves the use of independent standards such as IFC (Industry Foundation Classes) and BCF (BIM Collaboration Format), which have been developed over many years by the buildingSMART organization, as well as the ISO 19650 series providing international standards for information management using BIM (ISO, 2018). However, the experience of companies to date shows that despite the use of open standards, data is still lost or re-entered, which involves additional effort or loss of time, money, or energy.

Artificial intelligence methods, on the other hand, are used in various areas of application, such as building design, industrial prefabrication, construction site planning, and project management. The convergence of AI algorithms and BIM enables the creation of virtual environments where stakeholders can explore and evaluate different design options. This significantly reduces the time and manual effort required to design a layout. An example is the Particle Swarm Optimization (PSO) algorithm, which generates optimized 2D layouts, which in turn are seamlessly converted into 3D BIM models through visual programming performed in Dynamo (Alavi et al., 2024). This conversion allows stakeholders to visualize, analyze, and comprehensively monitor projects, facilitating informed decision-making. Another innovative approach to generating BIM models based on artificial intelligence algorithms involves analyzing architectural and structural drawings (Urbieta et al., 2023). A trained structure called "Mask R-CNN" automatically generates a BIM model corresponding to one of the multi-story buildings using the Industry Foundation Classes (IFC) format.

Generative artificial intelligence enhances the creative input of architects and engineers by generating innovative design alternatives rooted in BIM data. The collaborative ethos of BIM is extended through natural language interfaces such as ChatGPT, supporting seamless communication and idea exchange among project stakeholders (Rane, Choudhary, Rane, 2023). The synergy between BIM and generative AI is also leveraged in simulations and analyses, enabling predictions related to structural performance, energy efficiency, and environmental impact. The research introduces an innovative framework that seamlessly integrates BIM and generative AI, prioritizing interoperability, data consistency, and user-friendly interfaces. Another study integrated AI methods into Heritage BIM (HBIM) models. Currently, heritage reconstruction or historical building information modeling (HBIM) based on laser scanning or photogrammetric surveys is a manual, time-consuming, and overly subjective process, but the emergence of artificial intelligence techniques applied to existing architectural heritage offers new ways of interpreting, processing, and developing raw digital geodetic data such as point clouds (Croce et al., 2023).

Generative artificial intelligence systems can be very effective for BIM designers and modelers, especially during the conceptual design and project development stages. When text-image models are trained using architectural vocabulary and BIM terminology, they can be effective in generating innovative ideas for designers. In this context, it is crucial to create prompts that use BIM vocabulary and relevant datasets. Therefore, it may be necessary to formulate prompts that are based on BIM-specific terminology and reinforced with architectural, structural, and mechanical elements (Yönder, 2023). AI applications (e.g., Stable Diffusion) are already being used in visualization (Cao, Abdul Aziz, Mohd Arshard, 2024), thus replacing "offline" and "real-time rendering" engines (Borkowski, Nowakowski, 2023). Image generators are currently useful mainly in the initial stages of design (the ability to create a spectrum of directions) and in the later stages of variant creation (Gil, 2024). AI image generators based on diffusion models have recently attracted attention due to their ability to create images based on simple prompts. However, for practical application in AEC, they must be able to create specific construction plans for given requirements. One study tested the potential of current AI generators to address such challenges, specifically in the creation of simple floor plans. Several experiments showed that the accuracy of generated floor plans could be improved from 6% to 90% (Ploennigs, Berger, 2024).

During the construction phase, BIM-AI integration improves real-time decision-making by on-site personnel by providing AI-generated insights based on BIM data. This ensures higher project productivity, cost efficiency, and risk management. For example, civil engineers optimize the construction site for logistics, while IT specialists improve the performance of pathfinding algorithms on reference maps. In one such study, logistical information from the BIM model, such as unloading and loading points, was used to find paths for multiple machines to improve the productivity of the entire construction fleet. Such an algorithm can quickly replan a path to resolve an emergency situation on a construction site (Xiang et al., 2021). IoT sensors, such as RFID, are also used on construction sites to track components or access to different areas of the site (Borkowski, Brożyna, Lesiuk, 2024). This ensures a higher degree of safety and faster project completion.

Another study on BIM-AI integration developed a system for detecting defects in railway infrastructure, using submerged joints and subsidence as examples of combined defects in railway infrastructure. Artificial intelligence techniques were used to detect defects. Deep neural networks and convolutional neural networks are used to develop predictive models for detecting defects in railway infrastructure and rolling stock. The results of the study show that the developed models have the potential to detect defects with 99% accuracy and are beneficial for railway system asset management in terms of risk management, passenger comfort, and cost-effectiveness (Sresakoolchai, Kaewunruen, 2021). A technical framework has already been developed that integrates BIM-AI for digital defect detection. The framework has been verified in a case study and has proven effective in twin defects regarding their position, geometry, and dimensions (Chen et al., 2022). This research opens up new possibilities for twin defects of objects at the street block level and even cities to support urban renewal.

During the operational phase, public (institutional) and private clients sometimes use open standards to manage a building. For example, resources that are relevant to the maintenance and repair phase are exported. Sometimes IFC models are used for retrofits, i.e., various types of modernization, renovation, or revitalization (Elagiry et al., 2020). However, when attempting to use IFC models from practice for automatic analysis, certain problems arise as a result of inconsistencies between what is recommended or available in the standard and the data sets that are created in practice (Noardo et al., 2021). It is noticeable that the overall quality of the models requires special additional care on the part of modelers before they can be used for automatic analysis, and there is a high level of variability in the storage of some important information (such as georeferences). This issue has direct implications for AI integration in BIM. The quality of training data fundamentally determines the reliability of AI models a principle commonly known as “garbage in, garbage out”. If AI systems are trained on inconsistent, incomplete, or poorly structured IFC models, they will inevitably produce unreliable outputs. This challenge is particularly acute in the AEC industry, where no unified standards for AI training datasets currently exist. Unlike other domains where large, curated datasets are available (e.g., ImageNet for computer vision), the construction sector lacks comparable benchmark datasets for BIM-AI applications. Du et al. (2024) systematically examined IFC data readiness for AI integration, concluding that current BIM models frequently lack the semantic richness, geometric consistency, and attribute completeness required for effective machine learning applications. Their findings underscore that ensuring data quality is a prerequisite for successful AI deployment in BIM workflows. Establishing industry-wide standards for AI-ready BIM data – including minimum requirements for geometric accuracy, semantic richness, and attribute completeness – represents a critical research gap that must be addressed before AI can be reliably integrated into construction practice. On the other hand, BIM models, even native ones, can be managed by machines from the management application level. Fast, remote, real-time, and reliable structural health monitoring (SHM) techniques have already been developed. These intelligent SHM technologies often generate large amounts of data that require advanced data management, visualization, diagnostics, and predictive techniques (Fawad et al., 2023). Over the past few years, researchers have developed numerous methods for diagnosing and predicting damage based on machine learning and artificial intelligence. The development of artificial intelligence is faster than predicted, with new startups presenting interesting, innovative solutions and researchers developing new methods for automating everyday activities, e.g., those of designers.

4. DISCUSSION

BIM is both teleological and parateleological. People working in BIM are focused on achieving a specific goal and at the same time motivated to act by the result, not by the process itself. Other people involved in the BIM process derive pleasure from the process itself, not from the final goal. These people are often motivated by the moment rather than future benefits. Artificial intelligence only reinforces both processes. According to the law of least effort, we as humanity strive to automate our work using machines (Zipf, 2016). A significant barrier to the widespread adoption of AI in BIM is the unresolved question of legal liability. When AI systems make errors in structural calculations, fire safety assessments, or building code compliance, the allocation of responsibility remains unclear. Traditional professional liability frameworks assume human decision-making, where licensed architects and engineers bear responsibility for their designs. However, AI-assisted or AI-generated designs introduce multiple potential liable parties: the design professional who relies on AI outputs, the software vendor providing the AI tool, and the developers who trained the AI model. Currently, professional liability insurance policies typically do not cover AI-generated designs, creating a significant risk exposure for practitioners. Moreover, building codes and regulations worldwide are predicated on human professional judgment and do not yet accommodate AI-driven decision-making processes. The European Union's AI Act (Regulation 2024/1689) represents an initial regulatory response, classifying AI systems used in critical infrastructure-including construction-as high-risk applications requiring conformity assessments and human oversight. However, comprehensive legal frameworks specifically addressing AI liability in construction remain undeveloped. This legal vacuum constitutes a substantial impediment to mass AI adoption in the AEC industry and requires urgent attention from policymakers, professional organizations, and insurers. Nevertheless, one can venture to put forward a hypothesis: the era of open standards may be drawing to a close, and we may be entering the era of artificial intelligence in BIM development (Fig. 2). It should be acknowledged that most current BIM-AI applications remain at the proof-of-concept or early implementation stage, and the AEC industry's historically slow adoption of innovations often requiring several to over a dozen years suggests that full transition to an AI-driven paradigm will be gradual rather than immediate. With the advent of the first widespread generative artificial intelligence (ChatGPT – November 30, 2022), the perception of challenges in BIM has changed.

Closely related to liability is the challenge of validation and verification of AI-generated designs. Current regulatory frameworks require that construction documents be reviewed and stamped by licensed professionals who take personal responsibility for code compliance. However, the verification of AI-generated outputs poses unique challenges. Unlike traditional design processes, where the reasoning behind decisions can be traced and explained, many AI systems particularly deep learning models operate as "black boxes", making it difficult to understand how specific design decisions were reached. This opacity complicates the verification process: how can a licensed professional certify compliance when the underlying logic is not fully transparent? Emerging approaches to address this challenge include explainable AI (XAI) methods that provide interpretable justifications for AI recommendations, automated code compliance checking systems that can validate designs against regulatory requirements, and hybrid workflows where AI generates design options while humans retain final decision-making authority. Nevertheless, the fundamental question of professional responsibility remains regardless of AI involvement, licensed architects and engineers must currently stamp and take legal responsibility for construction documents, effectively positioning AI as a tool rather than a decision-maker in the regulatory sense.

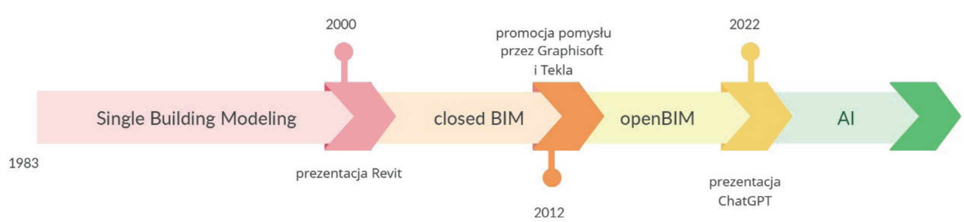

Fig. 2. Periodization of BIM based on approach. A new era in BIM development – the growing use of artificial intelligence
Source: own work

5. CONCLUSION

The observation that we may be entering a new, fourth era in BIM development the era of artificial intelligence appears justified based on current technological trajectories. This does not mean that the problems of digitization in the AEC industry are disappearing. Quite the contrary. In many cases, we are still in the phase of basic research into the processes surrounding BIM. Application research on BIM is extremely time-consuming and costly, and its results are slowly being adapted in national economies in the construction sector. Introducing innovations into organizations in the construction industry sometimes takes several to over a dozen years. Hence, artificial intelligence appears poised to become the decisive factor for broader BIM implementation in the construction sector by automating the enormous amount of manual work involved in modeling and information management. However, the transition from current proof-of-concept applications to mass adoption will require overcoming significant barriers including data quality standards, legal liability frameworks, and workforce adaptation. Without the support of machines, people will continue to make mistakes, which in turn will result in inefficiency, cost overruns, and conflicts. The relationship between BIM and AI seems congruent – full of compatibility.

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