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PROSPECTS FOR ARCHITECTURE AND URBAN PLANNING: INTEGRATION OF BIM AND 4.0 TECHNOLOGY IN THE CONTEXT OF CLIMATE CHANGE

PERSPEKTYWY DLA ARCHITEKTURY I URBANISTYKI: INTEGRACJA BIM I TECHNOLOGII 4.0 W KONTEKŚCIE ZMIAN KLIMATYCZNYCH

Abstract

Progressive climate changes necessitate new strategies and sustainable design. Research highlights the need for the implementation of new technologies. The article discusses the prospects of using BIM and 4.0 technologies in architecture and urban planning. The aim of the work is to draw attention to the efficiency of design processes using modern methods and tools. The main research method adopted is a review and evaluation of cases of BIM and Artificial Intelligence adaptation in projects in Poland and worldwide. The results focus on the latest technological and scientific achievements in the IT field permeating the world of architecture. The conclusions indicate the need to strengthen interdisciplinary integration as well as the digitization and futurization of design practices. The topic of this work aligns with current research trends and its content can be used to increase collective awareness among designers about the benefits offered by information technology.

Keywords: BIM, 4.0 technologies, climate change, climate adaptation, architecture, urban planning

Streszczenie

Postępujące zmiany klimatyczne wymagają nowych strategii oraz zrównoważonego projektowania. Badania wskazują na potrzebę implementacji nowych technologii. Artykuł traktuje o perspektywach wykorzystania BIM i technologii 4.0 w architekturze oraz urbanistyce. Celem pracy jest zwrócenie uwagi na efektywność procesów projektowych z wykorzystaniem nowoczesnych metod i narzędzi. Jako główną metodę badawczą przyjęto wykonanie przeglądu oraz ocenę przypadków adaptacji BIM i sztucznej inteligencji w realizacjach w Polsce i na świecie. Wyniki koncentrują się wokół najnowszych osiągnięć technologicznych i naukowych z obszaru IT przenikających do świata architektury. Wnioski wskazują na potrzebę wzmocnienia integracji międzydyscyplinarnej oraz digitalizacji i futuryzacji praktyk projektowych. Temat niniejszej pracy wpisuje się w obecne trendy badawcze, a jej zawartość może posłużyć do zwiększenia zbiorowej świadomości projektantów na temat korzyści oferowanych przez informatykę.

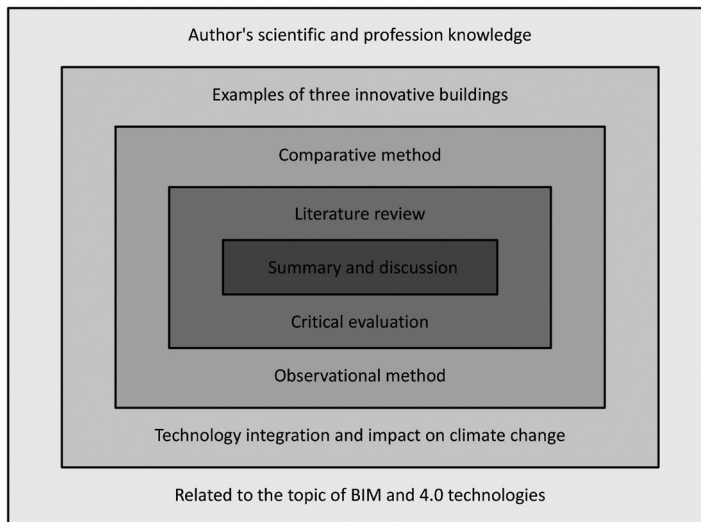
Słowa kluczowe: BIM, technologie 4.0, zmiany klimatu, adaptacja klimatyczna, architektura, urbanistyka

1. INTRODUCTION

The purpose of this article is to examine how the integration of BIM (Building Information Modeling) and 4.0 Technology can contribute to creating more sustainable and climate change resilient solutions in the field of architecture and urban planning. The study aims to understand how these technologies can be used to improve energy efficiency, reduce CO₂ emissions, or adapt to climate change in the design and construction of urban infrastructure. This research is crucial, as climate change represents one of the biggest challenges for the modern world, not only in the engineering and technical field. The integration of BIM and 4.0 Technology offers new opportunities for the construction sector, enabling the creation of more sustainable and resilient solutions. The results of this study may contribute to the development of new strategies and practices in the field that will respond to new challenges. Furthermore, the article encourages reflection and discussion regarding the further development and implementation of these solutions in the construction sector.

2. METHODOLOGY

A detailed literature review was conducted on the integration of BIM and 4.0 Technology in the context of climate change. Scientific articles, industry reports, and case studies from various regions of the world were analyzed. Databases such as Scopus, Web of Science, ResearchGate, and Google Scholar were used to identify the latest research and publications on this topic. The literature indicates the growing importance of digital technologies in the construction sector and their potential in the context of sustainable development.



Ill. 1. Scheme of methods, source: M. Donderewicz, author's material.

Material concerning examples of three buildings was used to identify good practices and challenges associated with the implementation of BIM and 4.0 Technology in architectural

and urban planning projects. For the purpose of this work, projects are compared. Each case was analyzed in terms of the technologies used, benefits achieved, and problems encountered. The selection is justified by a selective and innovative choice of solutions applied in the realization of these construction investments. The authors' practical knowledge about using BIM tools was applied. Based on the intuitive assessment method, an attempt was made to synthesize conclusions in the context of simulating technological benefits in the face of climate change and their impact on buildings and urban infrastructure.

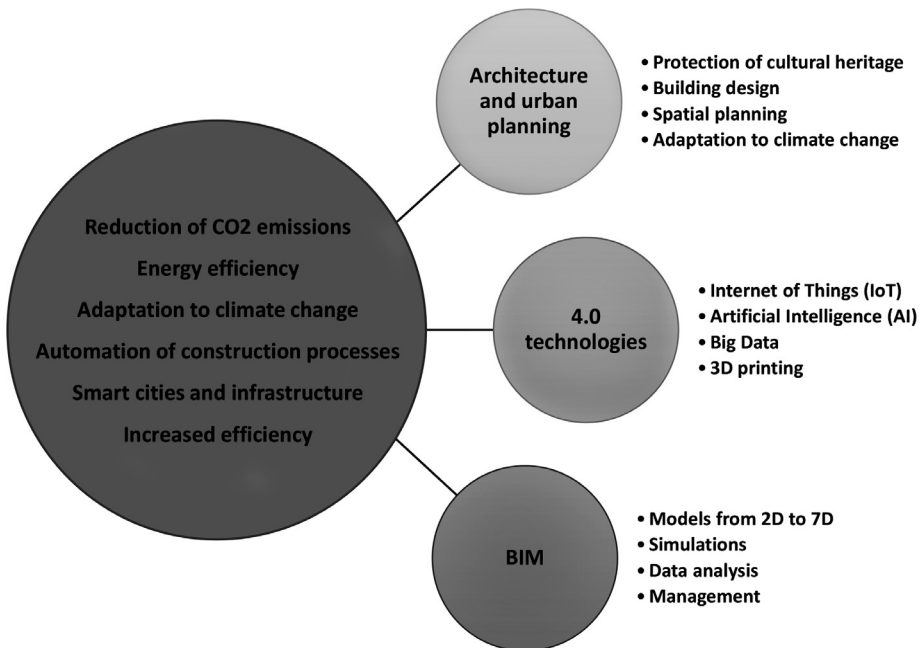
3. BIM & 4.0 TECHNOLOGY IN ARCHITECTURE AND URBAN PLANNING

Building Information Modeling (BIM) is a process that involves generating and managing data about a building throughout its life cycle – from concept to demolition. BIM utilizes three-dimensional, spatiotemporal, dynamic models of construction objects, which are integrated with a database. This allows architects, engineers, and other professionals to accurately analyze and simulate various aspects of a building even before its physical existence. 4.0 Technology, also known as Industry 4.0, represents a new era in industry characterized by the digitization and automation of processes. In the context of architecture and urban planning, 4.0 Technology includes tools such as artificial intelligence (AI), the Internet of Things (IoT), Big Data, robotics, 3D printing, and others. The integration of BIM and 4.0 Technology in architecture and urban planning opens up new possibilities for the construction sector. This makes it possible to create more sustainable and climate change resilient solutions. It is worth noting the benefits that come with the use of artificial intelligence for the AEC industry. AI has enormous potential to transform sustainable design in an ecological context. Certain interesting benefits and possibilities for implementing these techniques are highlighted:¹

- [1] **Energy efficiency** – assistance in creating buildings with high energy efficiency. For example, using BIM one can model and simulate a building's energy consumption, which allows for the optimization of its design in terms of energy efficiency. Meanwhile, IoT can be used to monitor and manage energy consumption in real-time.
- [2] **Reduction of CO₂ emissions** – reducing CO₂ emissions in the construction sector. For example, using BIM, the impact of various building materials and techniques on CO₂ emissions is modeled and simulated. In turn, AI and Big Data can be used to analyze and optimize construction processes for CO₂ reduction.
- [3] **Adaptation to climate change** – creating buildings and urban infrastructure that are resistant to climate changes. For example, using BIM one can model and simulate the impact of various climate scenarios on a building or city. Meanwhile, IoT and AI can be used to monitor and respond to climate changes in real-time.
- [4] **Smart cities and infrastructure** – AI can contribute to the creation of smart cities and infrastructure that are more sustainable and resistant to climate changes.

¹ K. Zawada et al., *Digitization of AEC Industries Based on BIM and 4.0 Technologies*, "Buildings" 2024, no. 14(5), art. no. 1350. DOI: 10.3390/buildings14051350; Y. Zhang, *Application of ecological architecture in architectural design based on information technology integration*, "Applied Mathematics and Nonlinear Sciences", 9(1), pp. 1–12. DOI: 10.2478/amns.2023.1.00327.

- [5] **Analysis and optimization of energy consumption** – analyzing data on energy consumption in buildings and urban infrastructure, identifying areas where savings can be achieved. AI can also optimize energy management systems to minimize energy consumption and reduce CO₂ emissions.
- [6] **Eco-oriented design** – AI can assist architects and urban planners in creating designs that are more in harmony with nature and local ecosystems. This may include using AI to model and simulate the impact of projects on local ecosystems, allowing for a better understanding and minimization of potential negative effects.
- [7] **Adaptation to climate change** – the possibility of using it in predicting and adapting to climate changes. This may include the use of AI to analyze climate data and forecast future conditions, allowing architects and urban planners to better adapt their designs to future climate conditions.
- [8] **Automation and efficiency of construction processes** – automation of many construction processes, which can lead to greater efficiency and less environmental impact. This may include the use of robotics and other 4.0 technologies to automate processes such as construction, assembly, and disassembly.



III. 2. Diagram of the symbiosis of architecture and urban planning with BIM and 4.0 technologies, source: K. Zawada, M. Donderevicz, author's material.

It can be concluded that the use of BIM and 4.0 technologies may have potential in the context of their use in projects, analyses, and legislation related to the architectural world. The integration of these technologies can contribute to the creation of more sustainable and climate change-resistant solutions, which is extremely important in the face of global environmental challenges. However, it is worth paying attention to certain risks and

challenges associated with their implementation. Firstly, the high initial costs associated with the implementation of new technologies can pose a significant barrier for many companies, especially those with limited financial resources. Secondly, the lack of uniform standards and regulations regarding the use of BIM and 4.0 technologies can lead to inconsistencies in practices and difficulties in integrating different systems. Thirdly, resistance from traditional construction and design firms to the adoption of new technologies is another challenge that may slow down the industry's transformation process. In light of the above, it is worth considering taking additional actions aimed at educating and raising awareness among potential users about the benefits of using BIM and 4.0 technologies. It may be advisable to develop and implement consistent standards and regulations that will facilitate the implementation process and ensure uniformity in practices. The potential of these technologies in architecture and construction is high, and it is believed that the next stage of development should be their popularization and facilitation of access.²

4. CLIMATE CHANGE, ARCHITECTURE AND URBAN DESIGN

Climate change represents one of the greatest challenges of the modern world, and its impact on architecture and urban planning is inevitable and comprehensive. This requires designers to adopt a new approach and propose solutions more resistant to extreme conditions. The creation and co-creation of cities with crisis and infrastructure management systems is becoming a fundamental need and form of response. Key factors for this field include changes in temperature and precipitation, which affect local conditions, resulting in the need to adapt buildings and their surroundings to new building physics parameters. In regions where temperatures are rising, effective cooling and insulation of buildings become crucial. In places with more intense rainfall, it is necessary to use appropriate drainage systems and moisture-resistant materials. Water shortages are equally important, so proper retention of rainwater and creating opportunities for its storage for conservation and reuse is important. Another factor is changes in land use, which can lead to the shifting of agricultural areas, changes in collective living zones, and the need to integrate green spaces into modern cities. This will require some flexibility in spatial planning. Extreme weather conditions are associated with the need for response and implementation of infrastructure management solutions. Rising sea levels pose a particular threat to coastal areas, requiring adaptation through building on elevated platforms, creating flood barriers, and designing water drainage systems. Modern solutions such as BIM and other tools related to 4.0 Technology open up new possibilities for adaptation and counteracting the negative effects of climate change. BIM allows for precise modeling and simulation of various climate scenarios, which enables more careful preparation of buildings and infrastructure for extreme weather conditions. Additionally, in terms of adaptation to these problems, BIM enables energy analysis and efficiency, risk management, and resource optimization. In terms of legal aspects and certification, new regulations are being introduced, such as stricter energy efficiency standards for new buildings and requirements for reducing CO₂ emissions

² Z. Liu et al., *Immersive Technology and Building Information Modeling (BIM) for Sustainable Smart Cities*, "Buildings" 2024, no. 14(6), art. no. 1765. DOI: 10.3390/buildings14061765; A. Starzyk et al., *The Evolution of Multi-Family Housing Development Standards in the Climate Crisis: A Comparative Analysis of Selected Issues*, "Buildings" 2023, no. 13(8), art. no. 1985. DOI: 10.3390/buildings13081985.

or environmental footprint, including carbon footprint. There is also increasing pressure on constructions resistant to extreme weather conditions and improving energy efficiency both in design and construction as well as in building operations. The BREEAM environmental certification updates its assessment requirements to better reflect the carbon performance of assets. In the context of architecture and urban planning, new technologies offer management and continuous monitoring of environmental conditions and the state of buildings, enabling a quick response to changing climate conditions. Smart energy and water management systems can automatically adjust to current needs, optimizing resource consumption. Adaptive design is supported by AI and Big Data, which analyze large sets of climate and environmental data, allowing for the creation of buildings and infrastructure better adapted to future environmental conditions. Drones and 3D printing enable rapid response to natural disasters by immediately conducting damage inspections and building temporary structures and barriers. 4.0 technologies also support sustainable and green construction through the development of construction technologies, such as the use of renewable and recyclable materials, as well as the integration of green roofs and facades, which are valuable modifiers of temperature and air, allow for the retention and storage of rainwater, improve insulation, reduce urban heat islands, and increase biodiversity in cities.³

5. EXAMPLES OF USING NEW TECHNOLOGIES

5.1. ONE CENTRAL PARK, SYDNEY

One Central Park in Sydney is a residential-commercial complex that is considered an example of sustainable construction thanks to its innovative approach to design and energy management. This building, designed by Ateliers Jean Nouvel, utilizes advanced technologies such as BIM and IoT to optimize energy and resource consumption. BIM was used to design energy management systems and analyze air flow and natural lighting, which allowed for better preparation of the building for changing climatic conditions. IoT enabled monitoring of energy and water consumption and optimization of building operation and maintenance. The sustainable nature of the solutions in the project was highlighted by the use of photovoltaic panels, water recycling systems, and vertical gardens, which reduce CO₂ emissions and energy consumption. Thanks to these solutions, One Central Park has achieved a 25% reduction in energy consumption and a significant reduction in the building's carbon footprint. This implementation is a good example of how modern technologies can support sustainable construction and contribute to the fight against climate change.⁴

³ L.J. Ramirez Lopez et al., *Sustainability and Resilience in Smart City Planning: A Review*, "Sustainability" 2020, no. 13(1), art. no. 181. DOI: 10.3390/su13010181; C.C. Duarte et al., *The Adaptability of Residential Planning and Design to World-Changing Events*, "Buildings" 2023, no. 14(1), art. no. 9. DOI: 10.3390/buildings14010009; J. Kobylarczyk, J. Marchwinski, *Pluralism of goals of proecological architecture*, "Budownictwo i Architektura" 2020, no. 19(1), pp. 5–4; N. Dunbar, *BREEAM Version 7 set to embrace new Biodiversity Net Gain legislation* [in:] Bregroup, 31.01.2024, <https://bregroup.com/insights/breeam-version-7-set-to-embrace-new-biodiversity-net-gain-legislation/> (access: 15.06.2024).

⁴ J. Nouvel, *One Central Park*, "ARQ (Santiago)" 2019, no. 102, pp. 134–145. DOI: 10.4067/S0717-69962019000200134.



Ill. 3. One Central Park in Sydney, Australia – first example, source: ArchDaily, 25.09.2014, <https://www.archdaily.com/551329/one-central-park-jean-nouvel-patrick-blanc> (access: 15.06.2024).

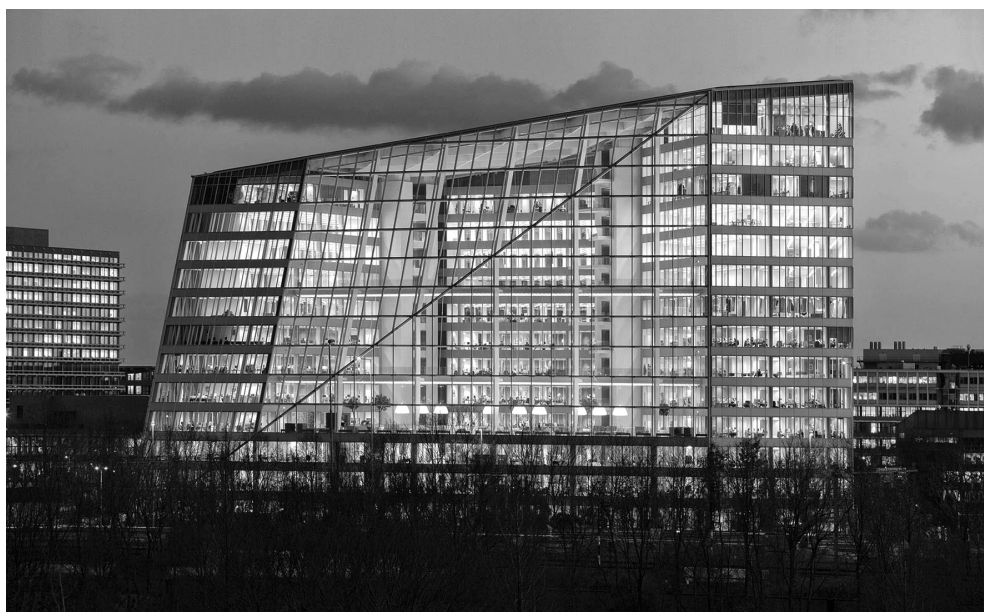
5.2. BOSCO VERTICALE, MILAN

Bosco Verticale in Milan is a complex of two residential towers that integrate vertical gardens, promoting sustainable living in the city. The building, designed by Boeri Studio, used BIM for structural and environmental modeling, air flow analysis, and resource consumption optimization. IoT enabled the monitoring of plant health and environmental conditions, optimizing irrigation systems. This is important for maintaining vegetation on the building, given its quite characteristic and challenging placement. The vegetation on Bosco Verticale absorbs CO₂ and produces oxygen, which improves air quality and reduces the urban heat island effect. This project also contributes to increasing biodiversity in the urban environment by offering green spaces in a densely built-up area. Bosco Verticale is an example of how the integration of greenery in architecture can improve the quality of life in cities and support sustainable development.⁵

⁵ G. Kalogeropoulos, J. Tzorti, A. Dimoudi, *Remote Sensing and Field Measurements for the Analysis of the Thermal Environment in the “Bosco Verticale” Area in Milan City*, “Land” 2024, no. 13(2), art. no. 182. DOI: 10.3390/land13020182.



III. 4. Bosco Verticale in Milan, Italy – second example, source: Karolina, Marta, *Bosco Verticale – las wybudowany na mediolańskich wieżowcach* [in:] Green Design Blog – Architektura Krajo-
brazu, 11.09.2019, <https://www.green-design-blog.com.pl/bosco-verticale/> (access: 14.06.2024).



III. 5. Edge in Amsterdam, the Netherlands – third example, source: PLP Architecture. <https://plparchitecture.com/the-edge/> (access: 13.06.2024).

5.3. THE EDGE, AMSTERDAM

The Edge in Amsterdam is one of the most sustainable office buildings in the world, utilizing advanced technologies for energy and resource management. This facility, designed by PLP Architecture, used BIM for building modeling to optimize energy consumption, lifecycle management, and performance analysis. IoT was used to monitor energy consumption, environmental conditions, and also manage lighting and air conditioning, allowing for automatic adjustments to current needs. AI and Big Data analyze sensory data, predicting and optimizing energy use. Thanks to these technologies, The Edge consumes 70% less energy than a standard office building, significantly reducing CO₂ emissions. This project is another example of how advanced technologies can support sustainable construction and contribute to the fight against climate change while improving energy efficiency and user comfort.⁶

6. SUMMARY AND DISCUSSION

Climate change poses new challenges for architecture and urban planning, requiring innovative and adaptive solutions. The integration of BIM and Industry 4.0 technologies offers powerful tools that can significantly support the design, construction, and management of urban space, enabling better preparation for future changes and minimizing their negative effects. The future of architecture and urban planning depends on the ability to adapt and use modern technologies for sustainable development and environmental protection. Cases like One Central Park, Bosco Verticale, and The Edge show the significant impact of these technologies on reducing energy consumption, improving resource efficiency, and reducing greenhouse gas emissions. Further development and implementation of these technologies will be key to achieving sustainable development of cities and buildings worldwide. BIM's energy modeling allows for the assessment of building energy performance, identification of improvement opportunities, and simulation of the impact of various climate scenarios on energy consumption. Robotics and other Industry 4.0 technologies lead to process automation such as construction, assembly, and disassembly, increasing efficiency and reducing environmental impact. AI can contribute to creating smart cities and infrastructure that are more sustainable and resilient to climate change. However, high initial costs associated with implementing BIM and Industry 4.0 technologies can be a barrier for many companies. The lack of uniform standards and regulations hinders their widespread adoption. Traditional construction and design firms may resist adopting new technologies, slowing down their implementation in design. Overall, closer collaboration between various fields such as architecture, urban planning, engineering, computer science, and environmental sciences is necessary to fully exploit the potential of BIM and Industry 4.0 technologies. Promoting digitization and modern design methods like BIM and AI should become a priority in the training and professional practice of architects and urban planners. Education is also crucial – increasing awareness and skills regarding new

⁶ I. Vardopoulos, A. Demesthenous, R. Mitoula, A paradigm shift in real estate dynamics: Unravelling the blueprint for urban well-being [in:] R. Mitoula (ed.), *1st Open-Air Cities International Conference "Local & Regional Sustainable Development and Urban Reconstruction" – Book of abstracts*, Open-Air Cities Institute, Athens 2024, p. 98.

technologies among designers, engineers, and other construction industry professionals is key to their effective implementation. An important element is also the development of uniform standards and regulations regarding the use of BIM and 4.0 Technology in architecture and urban planning, which will facilitate their implementation and ensure consistency of processes.⁷

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