Wojciech Ciepłucha, Krzysztof Zima, Kacper Burek
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APPLICATION OF BIM SYSTEMS IN INTELLIGENT DESIGN – PROCESS AND COST

ZASTOSOWANIE SYSTEMÓW BIM W INTELIGENTNYM PROJEKTOWANIU – OPTYMALIZACJA PROCESÓW I KOSZTÓW

Wojciech Ciepłucha*, Krzysztof Zima, Kacper Burek
Cracow University of Technology, Poland

Abstract

The article analyzes the application of BIM (Building Information Modeling) systems in intelligent design, focusing on process and cost optimization in construction. The authors discuss the benefits of implementing BIM throughout the entire life cycle of a building, from the pre-design phase to operation. BIM enables rapid concept analysis, supports interdisciplinary collaboration, streamlines cost estimation, and improves construction management. During the operational phase, BIM supports efficient facility management through real-time data collection and updates. The authors emphasize that the future of construction lies in integrating BIM with technologies such as IoT, artificial intelligence, and augmented reality. Despite the low level of BIM adoption in Polish companies, the trend of digitalization in construction is inevitable, and firms effectively implementing these technologies will gain a competitive advantage.

Keywords: BIM, design, optimization, costs, automation

Streszczenie

Artykuł analizuje zastosowanie systemów BIM (Building Information Modeling) w inteligentnym projektowaniu, koncentrując się na optymalizacji procesów i kosztów w budownictwie. Autorzy omawiają korzyści płynące z wdrożenia BIM w całym cyklu życia obiektu budowlanego, od fazy przedprojektowej po eksploatację. BIM umożliwia szybką analizę koncepcji, wspiera współpracę międzybranżową, usprawnia kosztorysowanie i zarządzanie budową. W fazie eksploatacji BIM wspiera efektywne zarządzanie obiektem poprzez gromadzenie i aktualizację danych w czasie rzeczywistym. Autorzy podkreślają, że przyszłość budownictwa leży w integracji BIM z technologiami takimi jak IoT, sztuczna inteligencja i rozszerzona rzeczywistość. Mimo niskiego stopnia wdrożenia BIM w polskich firmach trend digitalizacji budownictwa jest nieunikniony, a firmy skutecznie implementujące te technologie zyskają przewagę konkurencyjną.

Słowa kluczowe: bim, projektowanie, optymalizacja, koszty, automatyzacja

1. INTRODUCTION

BIM (Building Information Modeling) technology is revolutionizing contemporary architectural design, offering a range of benefits for the entire construction process. From generating comprehensive technical documentation to automatic updates across all project views, BIM is a powerful tool supporting designers' work. In the dynamic world of architecture, where design decisions are subject to constant changes, and every part of the building requires careful consideration in terms of functionality and aesthetics, BIM systems prove invaluable. BIM is a universal tool used in various phases of the investment process, and the BIM concept itself assumes the possibility of using it throughout the entire life cycle of a building. The construction process is schematically shown in Figure 1.

*Cracow University of Technology, Poland, e-mail: wojciech.cieplucha@pk.edu.pl

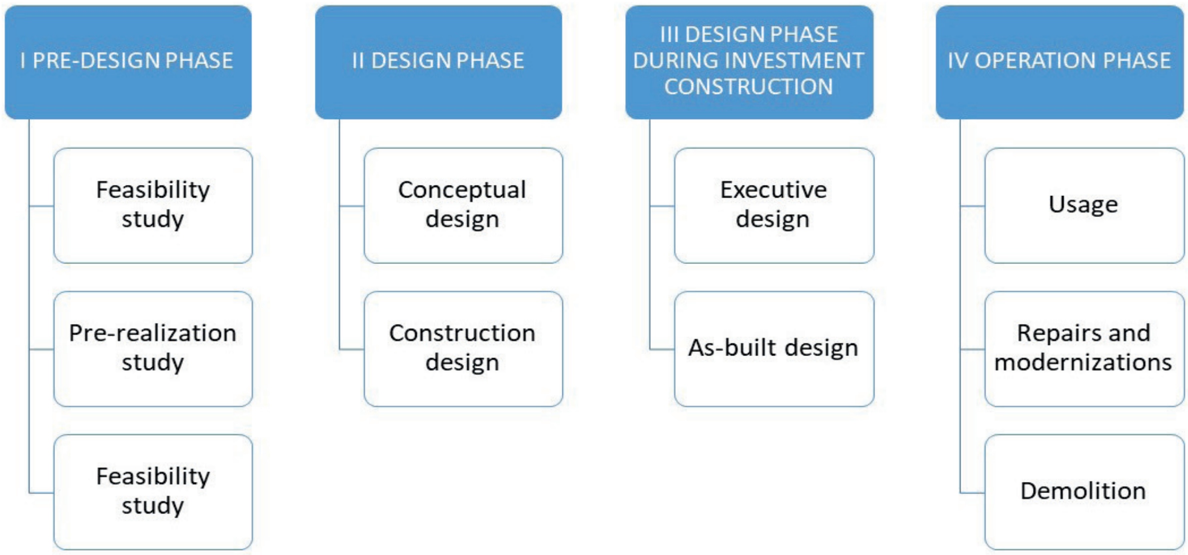


Fig. 1. Phases of the construction investment process with division into individual stages (source: [1])

The purpose of such a division is primarily to optimize the management of the investment process, among others by reducing costs, reducing investment implementation time, as well as minimizing the risk of inefficient use of resources [2]. BIM can be applied for various purposes in each of the distinguished stages, which is shown in the article.

In turn, the authors in [3] write about many dimensions of BIM (4D improved time management, 5D costs, 6D energy analysis, 7D facility management, 8D investment security). The authors emphasize that there is no single BIM application covering all these dimensions, but many different software specializing in various stages of building creation and life.

Collaboration between designers, contractors, investors, and other participants in the construction process is crucial for the success of any construction project and gains a new dimension thanks to BIM. This technology enables effective communication at various stages of the project, from traditional meetings in architectural offices, through multi-disciplinary online meetings, to quick exchange of information via emails, text messages, or phone calls. In this article, the authors will indicate how the application of BIM systems affects the optimization of design processes and cost reduction, opening new possibilities in intelligent design. Research conducted in [4] confirmed that the degree of BIM technology application in Polish construction companies is still not satisfactory, and its pace of development largely depends on the requirements set by public contracting authorities and private investors. Therefore, it is important to indicate the possibilities of using BIM in design and construction companies and the subsequent implementation of these solutions.

Next, the authors will show the possibilities of applying BIM in subsequent phases of the construction investment process.

2. PRE-DESIGN PHASE

Conceptual massing and site context modeling open up a range of possibilities for us. By utilizing tools for creating conceptual masses of the surroundings and the designed building, we can assess the degree of site shading, which allows us to refine the form of our structure. These analyses also enable optimal space utilization, determining the proportions between the built-up area and the building's foreground. Figure 2 shows a compilation of apartment areas for an example building mass along with sunlight and shading analysis.

Preliminary analyses are performed in programs for modeling the general form of the building, such as Formit or SketchUp, with the ability to add a location with specific geographic coordinates. This approach also supports the analysis of the building's total area, usable floor area, and built-up area, allowing for the assessment of building coefficients relative to the plot. Guidelines for proportions are determined by Development Conditions or Local Spatial Development Plans.

When starting the design process, an architect tries to understand the context of the place: existing building heights, building line, the need to create semi-public or semi-private spaces for clients and new users. They consider how the new structure will affect the surroundings and what aspects can enhance the location's prestige. When designing the form and

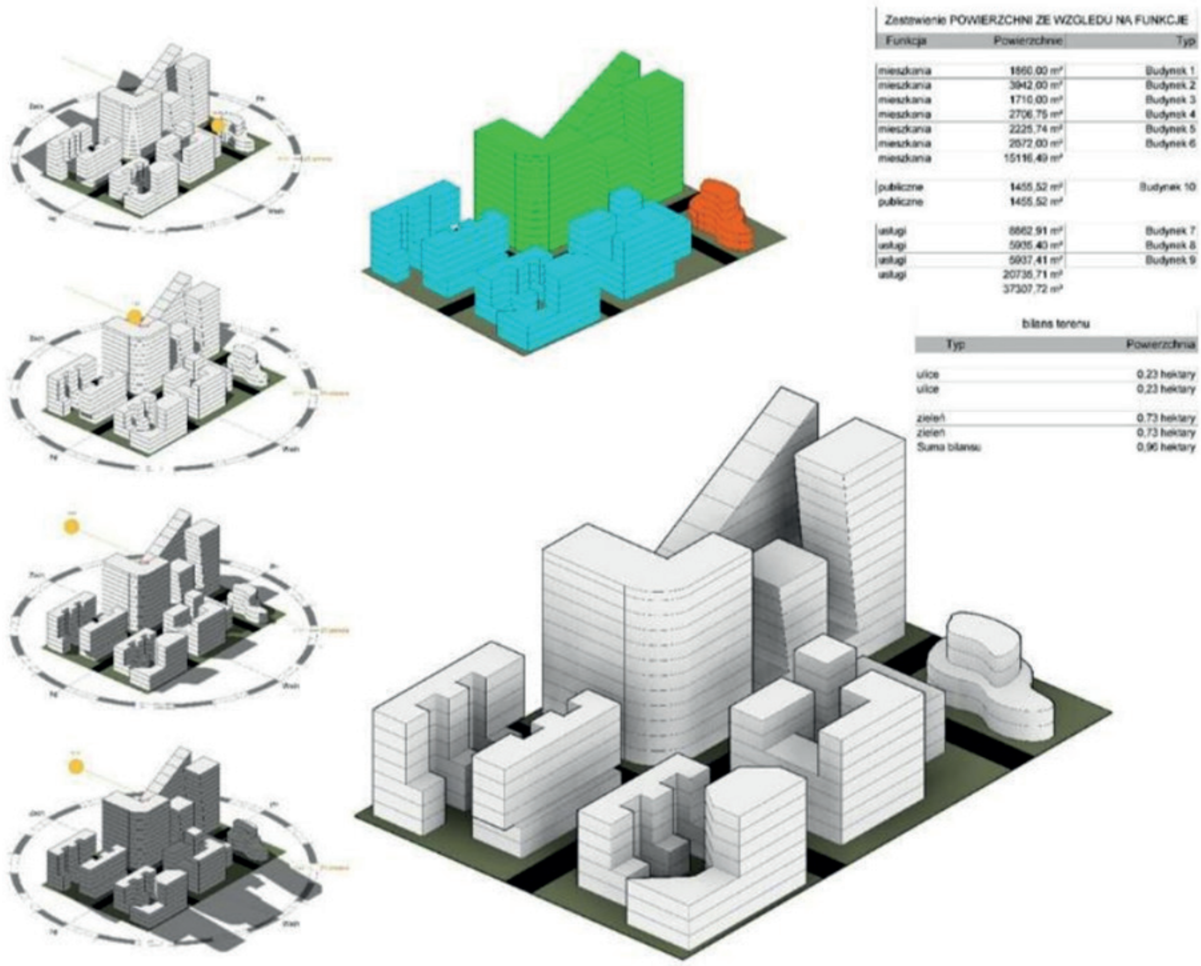


Fig. 2. Compilation of apartment areas for an example building mass with sunlight and shading analysis

layout, it's important to remember that you're not just creating a building with its physical elements, but also a new space that can attract investors.

3D printing is often used in the process of designing the building layout. A previously prepared master model serves to define the context. Then, building masses of various shapes, close to the desired final effect, are printed. Such models can be modeled in 3D programs, exported to .stl files, and printed in appropriate scales for presentation at meetings. Discussions over a physical model accelerate the decision-making process because humans are accustomed to making spatial decisions by directly experiencing space. A monitor and flat screen are only a representation of space, often distorted compared to reality after construction.

The ideal of intelligent design could involve an architect creating cardboard models that are automatically transformed into 3D models and analyzed for ergonomics and finances. Such an approach would combine the intuitiveness of working with physical material with advanced digital analysis.

3. DESIGN PHASE

BIM models in various disciplines serve diverse functions. We distinguish between architectural, structural, MEP (Mechanical, Electrical, and Plumbing) models, and others adapted to the specifics and needs of a given project. These are created by designers in close interdisciplinary collaboration.

Initially, the model is usually created in an architectural office and shared with other disciplines for further collaboration. The aim is to ensure linear progress of changes with the participation of all involved parties. It is crucial to provide a platform for exchanging project information, such as CDE (Common Data Environment) or BCF (BIM Collaboration Format).

Architectural models enable the analysis of key parameters such as the building's usable area, plot coverage ratio, or the number and size of apartments.

Structural models are primarily used for engineering calculations. Consisting of beams, columns, walls, and slabs, they are analyzed in terms of geometry and shape. The results of these analyses allow for optimization and possible redesign of undersized elements, ensuring the optimality of the structure in terms of dimensions at every point.

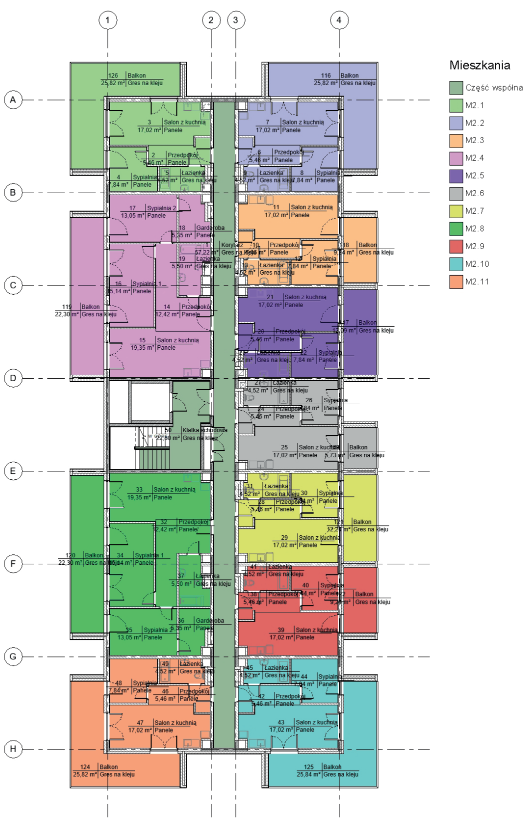
MEP models (ventilation, air conditioning, water and sewage, electrical) inside and outside the building serve two main purposes. Firstly, they enable internal calculations such as pressure drops or selection of profiles and duct sizes. Secondly, they allow for external clash detection between disciplines. It is important that the MEP model is integrated with architectural and structural models, creating a federated, comprehensive building model.

BIM supports a holistic approach to design, where the building is treated as a whole rather than a collection of separate systems. It helps solve design problems that extend beyond individual disciplines.

The vision of intelligent design assumes a system where the designer inputs data, which is then automatically analyzed by advanced algorithms, generating conclusions and calculations. The designer's role evolves towards verification and acceptance of these results and further refining of parameters for generating results, leading to a more efficient and precise design process. An example of such actions can be the automation of apartment schedules (Fig. 3).

Algorithmization, which can be performed using the Dynamo application, helps in many such activities. There are many programming languages that allow for creating applications. Dynamo is one of the programs supporting modeling and creating various schedules in Revit. It can be described as an environment for designing new tools within Revit using block diagrams. Importantly, using Dynamo doesn't require advanced programming skills, although basic knowledge in this area is helpful. With such tools, you can create block diagrams that interact with each other, and the only limitation is the user's imagination. Using a few input data, we can control extensive urban planning assumptions or modify the layout of rooms in a building.

One of the interesting examples of Dynamo application is the creation of parametric building objects. The article shows the general principle of operation using the example of designing a cubic building. Initially, you need to enter a few key values such as: number of floors, floor height, degree of mass rotation, or total building height. By modifying these data, we can generate different variants of the building. We can then analyze each version in terms of total area, usable area (PUM), and estimated implementation costs, and even the attractiveness



Zestawienie pomieszczeń

Mieszkanie	Numer	Nazwa	Powierzchnia
Część wspólna	1	Korytarz	57 m²
Część wspólna	50	Klatka schodowa	23 m²
			80 m²
M2.1	2	Przedpokój	5 m²
M2.1	3	Salon z kuchnią	17 m²
M2.1	4	Sypialnia	8 m²
M2.1	5	Łazienka	5 m²
M2.1	126	Balkon	26 m²
			61 m²
M2.2	6	Przedpokój	5 m²
M2.2	7	Salon z kuchnią	17 m²
M2.2	8	Sypialnia	8 m²
M2.2	9	Łazienka	5 m²
M2.2	116	Balkon	26 m²
			61 m²
M2.3	10	Przedpokój	5 m²
M2.3	11	Salon z kuchnią	17 m²
M2.3	12	Sypialnia	8 m²
M2.3	13	Łazienka	5 m²
M2.3	118	Balkon	9 m²
			44 m²
M2.4	14	Przedpokój	12 m²
M2.4	15	Salon z kuchnią	19 m²
M2.4	16	Sypialnia 1	15 m²
M2.4	17	Sypialnia 2	13 m²
M2.4	18	Garderoba	5 m²
M2.4	19	Łazienka	5 m²
M2.4	119	Balkon	22 m²
			93 m²
M2.5	20	Przedpokój	5 m²
M2.5	21	Salon z kuchnią	17 m²
M2.5	22	Sypialnia	8 m²
M2.5	23	Łazienka	5 m²
M2.5	117	Balkon	12 m²
			47 m²
M2.6	24	Przedpokój	5 m²
M2.6	25	Salon z kuchnią	17 m²
M2.6	26	Sypialnia	8 m²
M2.6	27	Łazienka	5 m²
M2.6	123	Balkon	6 m²
			41 m²
M2.7	28	Przedpokój	5 m²
M2.7	29	Salon z kuchnią	17 m²
M2.7	30	Sypialnia	8 m²
M2.7	31	Łazienka	5 m²
M2.7	121	Balkon	12 m²
			47 m²
M2.8	32	Przedpokój	12 m²
M2.8	33	Salon z kuchnią	19 m²
M2.8	34	Sypialnia 1	15 m²
M2.8	35	Sypialnia 2	13 m²
M2.8	36	Garderoba	5 m²
M2.8	37	Łazienka	5 m²
M2.8	120	Balkon	22 m²
			93 m²
M2.9	38	Przedpokój	5 m²
M2.9	39	Salon z kuchnią	17 m²
M2.9	40	Sypialnia	8 m²
M2.9	41	Łazienka	5 m²
M2.9	122	Balkon	9 m²
			44 m²
M2.10	42	Przedpokój	5 m²
M2.10	43	Salon z kuchnią	17 m²
M2.10	44	Sypialnia	8 m²
M2.10	45	Łazienka	5 m²
M2.10	125	Balkon	26 m²
			61 m²
M2.11	46	Przedpokój	5 m²
M2.11	47	Salon z kuchnią	17 m²
M2.11	48	Sypialnia	8 m²
M2.11	49	Łazienka	5 m²
M2.11	124	Balkon	26 m²
			61 m²

Fig. 3. Automation of apartment area schedules in Revit (source: own elaboration)

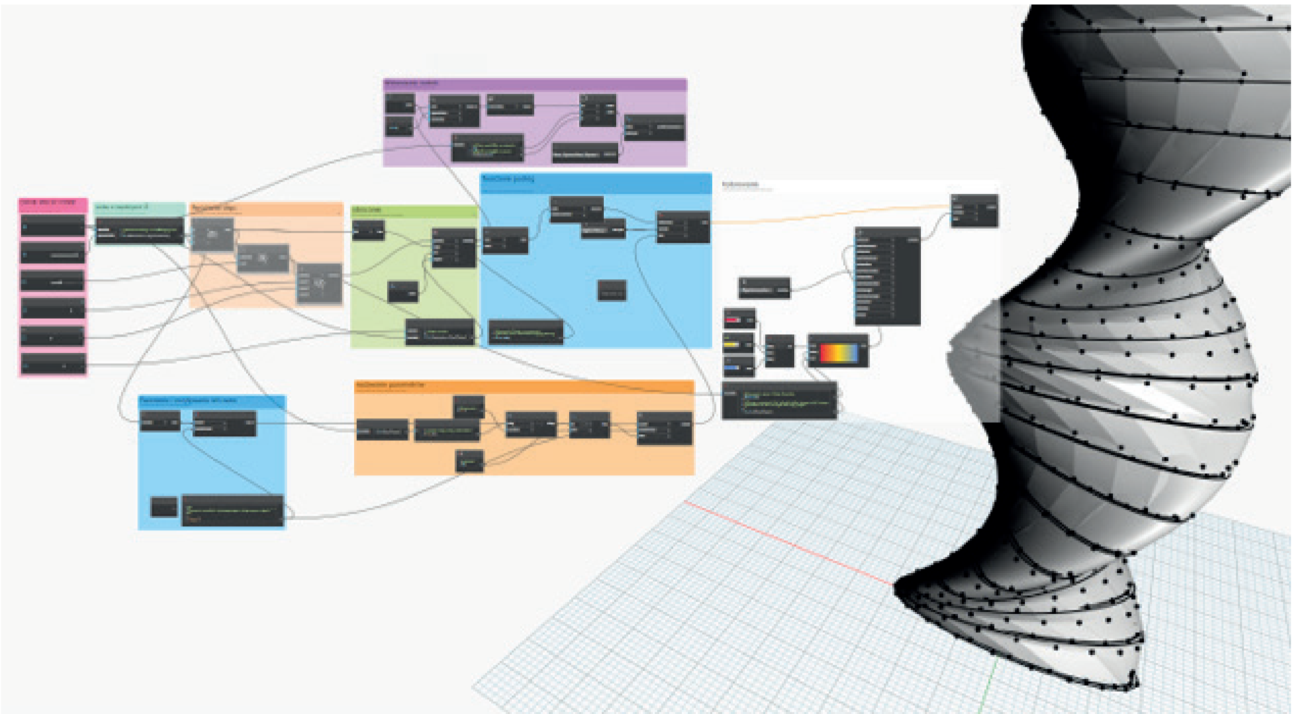


Fig. 4. Using algorithms in the Dynamo application to create a building mass

of the resulting building mass (Fig. 4). On the automatically generated mesh of the mass, you can add more elements, e.g., structural components or equipment elements. Thanks to the fact that all these elements go into schedules, you can also continuously control the form and shape of the building, while having a precise insight into, for example, costs – everything is automatically updated in the schedules.

This approach to design allows for quick creation and analysis of many variants, which significantly streamlines the decision-making process and project optimization both functionally and economically. The possibilities of interpreting and compiling data in BIM modeling are diverse and advanced. The geometry introduced in the model is always three-dimensional, which allows for accurate analysis of the structure, dimensions, and size of individual elements. These detailed data form the basis for drawing conclusions and making design decisions. By sorting elements by floor, we can easily determine the number of components at a given level. This information is crucial for estimating the time needed to build individual parts of the object. Additionally, this data enables logistics optimization, allowing precise planning of the transport of elements to the construction site. One of the biggest advantages of BIM modeling is the interactive connection between geometry and schedules. This means that any changes made to the project automatically update related schedules. When a designer modifies the geometry, the system immediately recalculates and updates all dependent data.

This dynamic relationship between the model and schedules allows for ongoing control over the project budget. Every change in geometry, materials, or specifications is immediately reflected in cost schedules. Thanks to this, designers and investors can continuously track the impact of design decisions on costs, which significantly facilitates the process of optimization and decision-making. This approach to design not only increases the accuracy of cost estimation but also allows for quick analysis of various scenarios and design variants. This enables making more informed decisions based on current and precise data, which in effect leads to a more efficient design and implementation process.

A separate issue is the costs of construction and subsequent operation. The topic of incorrect cost estimates or discrepancies has already been addressed multiple times in the literature, e.g., in [5, 6]. The article [7] presents examples of large discrepancies in the calculation of investment costs by the client and bidders, and the fundamental causes of the most common risk in practice of exceeding the parameters of an investment project. The possibilities of eliminating such significant differences through

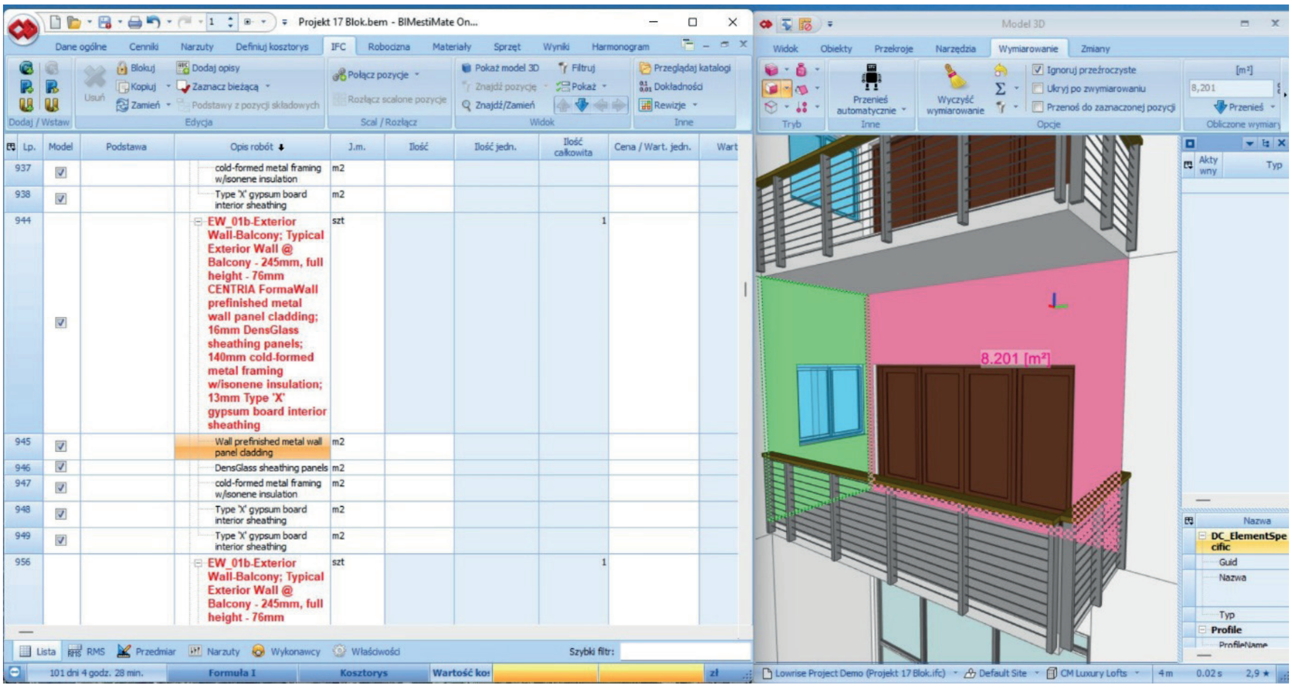


Fig. 5. Automatic creation of the scope of work in the BIMestiMate program along with quick quantity calculations "by indication" of the element and selection of the unit of measure (source: own elaboration)

the use of BIM technology and the use of uniform and consistent data by participants in the investment project were indicated.

And here BIM has two great advantages. Firstly, it significantly accelerates calculations due to the automation of the scope of work and quantity calculations, which is impossible in the case of 2D projects. The lack of the third dimension precludes automation of quantity calculations. An example of such automation is shown in Figure 5. It's enough to indicate an element, choose a unit of measure, and we get, for example, the wall area already without openings (if they were correctly modeled).

Significant acceleration of calculations has a very beneficial effect on the time devoted to cost estimate optimization. This, in turn, translates into the second benefit: precision and correctness of cost estimates. By saving time on performing the bill of quantities, the cost estimator can focus on cost optimization and the correctness of selecting prices of production factors.

4. DESIGN PHASE DURING INVESTMENT CONSTRUCTION

Cost adjustments are generally made similarly to work schedules, both in the design phase and the implementation phase. Linking activities in the schedule with 3D model elements allows for creating visualizations showing successive stages of investment implementation. This approach leads to, among others:

- better understanding of individual stages and the entire process of object creation (virtual construction before real construction),
- visual comparison of the actual state of construction progress with the planned state,
- monitoring construction progress even using augmented reality techniques,
- illustrating how the object should look at a chosen date.

It should be noted that the 3D model, although useful for visualizing the planned construction object, is static and does not allow for a clear understanding of the construction process implementation and its dynamics that characterize successive sequences of construction works. To make work sequences dynamic, it is necessary to integrate the fourth dimension, which is time. In practice, this corresponds to linking 3D elements of the BIM model with the construction project schedule. The effect of applying 4D modeling can therefore be different:

1. Static visualization: Static visualization allows for combining the three-dimensional model with the work schedule, i.e., creating an image of the works being performed or the state of the object at a specific given date. The view of the schedule itself in the form of the familiar Gantt chart or in the form of a network

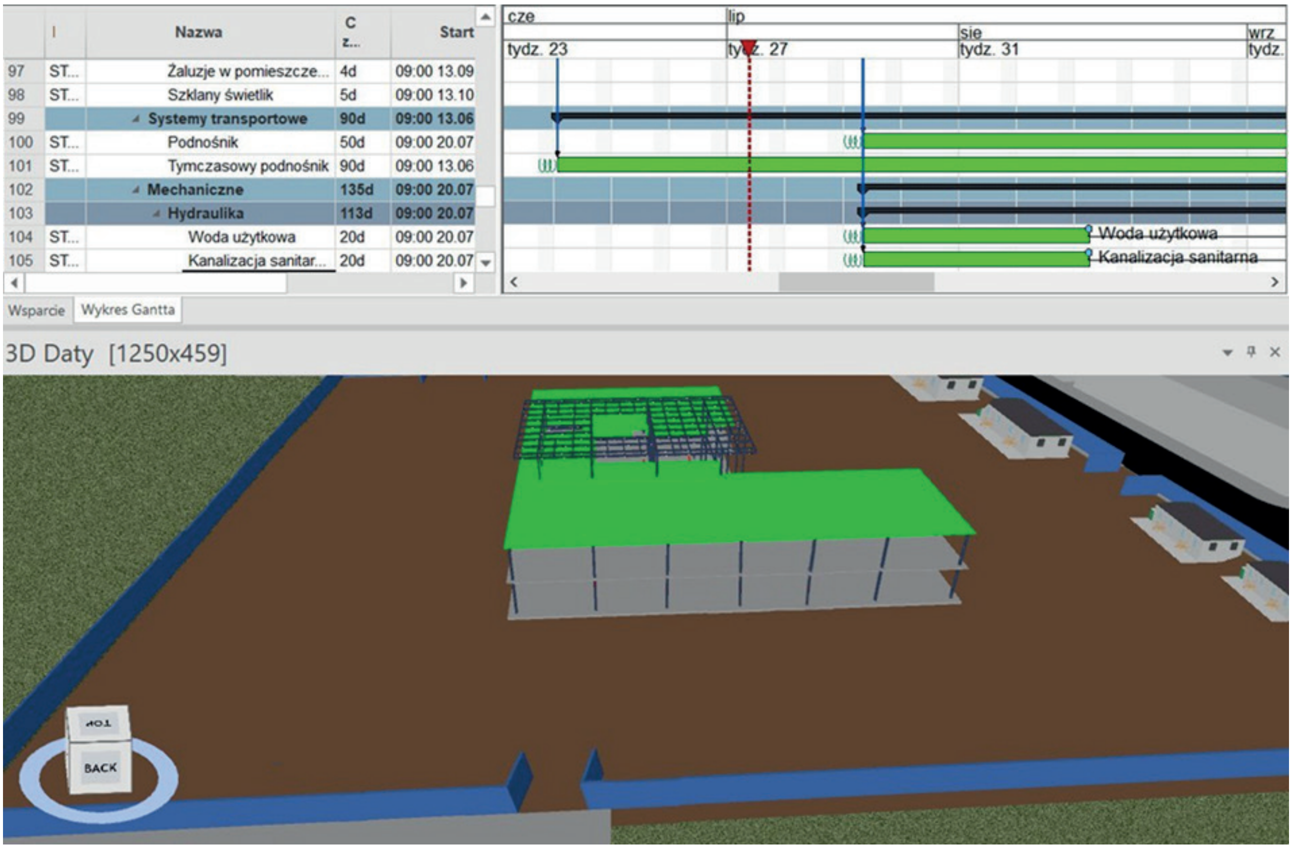


Fig. 6. BIM 4D – static image of work execution at a selected date referenced to the Gantt chart (source: own elaboration)

model or in the form of LOB (Line of Balance), often does not allow for appropriate interpretation in terms of technological and organizational sequence of construction works, and constitutes a static image at a given date (Fig. 6).

2. Dynamic visualization/simulation: Simulations and animations can be used to better illustrate the construction process. Simulations allow for eliminating, among others, organizational errors, unnecessary works, conflicts related to the wrong technological sequence of construction works. Often, simulations allow for noticing organizational problems such as, for example, collisions of equipment during construction works, for instance collisions of tower cranes, which are perfectly visible in the 3D environment, and sometimes difficult to catch on flat drawings due to differences in the heights of the cranes themselves. A similar problem is collisions with the existing surroundings, e.g., trees or existing objects. Often only during simulation can one notice difficulties in maneuvering equipment related to the small free space on the construction site, especially when the constructed building is already above ground level.
3. BIM washing: BIM 4D in the construction industry today is often just for show. On construction sites, engineers still quite rarely implement 4D in a way that can improve and facilitate communication and efficiency on site. This can be described as “BIM-washing”. “BIMwashing” refers to a situation where a product or service is sold or shown as fully compliant with prevailing standards, in this case, building information modeling principles, but in reality does not meet these standards and does not provide the expected level of interoperability and collaboration. In short, BIMwashing may include exaggerated claims about the level of its implementation, interoperability, capabilities offered by the construction contractor or designer in relation to actual capabilities or actual use.

5. OPERATION PHASE AND DEMOLITION

The operation phase is not only the longest stage in the project lifecycle but also the moment when people gather the most information about the project. Due to the secular nature and complexity of property management during the operation period, as well as the loss of a large amount of information in several periods preceding operation, it is very difficult to manage [8]. To fully utilize the advantages of BIM also in the operation and renovation phase, BIM models must provide a reliable data foundation regarding the as-built state and, accordingly, the current state. However, until now, many properties were neither planned nor built using BIM, and sometimes digital planning information is not even available [9].

Data management therefore requires having reliable information contained in the BIM model, originating from the design and implementation stages of the construction investment, but also requires updating information during the long period of operation. Data from technical inspections of building elements, current and general repairs, etc., should be recorded in the BIM model. We should strive for the so-called Digital BIM (Digital Twin), in which data in the model would be collected on an ongoing basis thanks to sensors distributed throughout the building. Data from such monitoring will create a Big Data database, which may cause problems with information storage, but is useful for monitoring the building's condition, ensuring the safety of the facility.

On the other hand, the BIM model can control devices installed in the building, analyzing data from sensors and controlling, for example, temperature, humidity, opening of blinds automatically. Connecting BIM with other technologies, e.g., IoT (Internet of Things), seems to be a necessity in the development of construction digitalization. The potential results of implementing BIM with one or several technologies are much higher than in the case of a single BIM implementation, especially in the O&M (Operation & Maintenance) phase of the project. In this case, if only BIM is implemented, an important step towards intelligent management will begin, but it seems that this will not be enough. Storing a large amount of related information and updating it in real-time is complex and requires a large amount of resources to maintain the BIM model [10].

The BIM methodology can also significantly enhance the final phase of a building's lifecycle - demolition. BIM models provide valuable information for planning and executing demolition works, including structural details, material specifications, and building components that can be potentially recycled or reused. By leveraging BIM technology during demolition planning, project teams can optimize the deconstruction sequence, minimize waste generation, and identify opportunities for material recovery. This approach supports sustainable demolition practices by enabling detailed analysis of materials that can be salvaged, recycled, or must be disposed of as waste. Furthermore, BIM can assist in planning safe demolition procedures by identifying potential hazards and structural dependencies, ultimately contributing to more efficient and environmentally conscious end-of-life building management.

6. CONCLUSION

The application of BIM systems in intelligent design opens new possibilities for optimizing processes and costs in construction. The analysis presented in the article indicates a number of benefits from implementing BIM throughout the entire lifecycle of a building. In the pre-design phase, BIM enables rapid concept creation and analysis, optimizing design decisions at an early stage. In the design phase, BIM supports effective inter-disciplinary collaboration, automates processes, and enables quick analysis of various project variants. BIM significantly streamlines the cost estimation process, increasing the precision of estimates and allowing for quick updates when project changes occur. In the implementation phase, BIM allows for better planning and control of the construction process, minimizing the risk of errors and delays. In the operation phase, BIM supports efficient facility management, enabling real-time collection and updating of building data.

The future of construction digitalization is based on the full integration of BIM technology with other advanced solutions. The development of building "digital twins", combining BIM models with IoT systems, will enable more effective facility management and optimization of their functioning. The integration of BIM with artificial intelligence and machine learning technologies will open new possibilities in design automation and optimization of construction processes. The development of augmented reality (AR) technology in conjunction with BIM will enable more intuitive project visualization and support for work on the construction site. Standardization and interoperability of BIM systems will be crucial for fully utilizing the potential of this technology across the entire construction industry. Further education and development of digital competencies among construction industry specialists is necessary to fully exploit the potential of BIM and related technologies.

Although the level of BIM implementation in Polish construction companies is still not satisfactory, the trend of construction digitalization is inevitable.

structure

Companies that successfully implement BIM and related technologies will gain a significant competitive advantage in the market. The future of the construction industry lies in an intelligent, integrated approach to designing, implementing, and managing facilities, with BIM forming the foundation of this transformation. Further development and adaptation of BIM technology in combination with innovations in artificial intelligence, IoT, and augmented reality will shape the future of construction, leading to more efficient, sustainable, and intelligent solutions throughout the entire lifecycle of building structures.

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