Czech Journal of Civil Engineering
2024
Volume 10
Issue 01

Enhancing BIM for more efficient energy performance calculations of buildings

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ORIGINAL SCIENTIFIC ARTICLE

ABSTRACT

Building Information Modelling (BIM) has the potential to revolutionize energy management by enabling stakeholders to analyse and optimize energy efficiency throughout the entire life cycle of a building—from initial design, through construction, to operation and maintenance (facility management). A BIM model serves as a foundational tool for decision-making processes, encompassing not only geometric data but also non-graphic information about the building's properties, systems, and environment. This rich data set facilitates various simulations and design optimizations, including those related to energy efficiency. For designers, BIM provides a powerful resource that aids in assessing measures by considering the characteristics of construction in relation to the future operation of the building. A significant advancement is the ability to conduct initial evaluations during the early stages of the project cycle, allowing for better-informed decisions and more effective planning right from the outset. Overall, the integration of BIM into energy management processes underscores its critical role in promoting sustainability and operational efficiency in building projects.

Keywords: *BIM; BEM; Energy performance; Energy efficiency.*

1 INTRODUCTION

The urgency for energy efficiency in the built environment has reached unprecedented levels, as nations across the globe strive to reduce carbon footprints and promote sustainable development. Among the leading tools facilitating this transformation is Building Information Modelling (BIM), a sophisticated digital representation that encompasses the physical and functional characteristics of a facility. BIM has emerged as a crucial technology for addressing the persistent challenge of the performance gap—the discrepancy between a building's predicted energy performance and its actual energy consumption.

This chapter explores the strategic application of BIM to bridge the performance gap by integrating advanced energy efficiency measures. By leveraging BIM, project stakeholders can simulate, analyse, and optimize energy performance from the design phase through to the operational phase, thereby ensuring that buildings consistently meet their energy targets.

Effective implementation of energy efficiency measures through BIM hinges on the involvement of skilled professionals. This chapter aims to highlight the essential role of energy proficiency in this context, delving into how professional expertise and training enhance the efficacy of BIM applications. This ensures that energy-saving strategies are accurately executed and maintained throughout a building's lifecycle. Not only does this integration help minimize the performance gap, but it also emphasizes the importance of investing in energy skills. By cultivating a workforce adept in both BIM and energy efficiency principles, the construction industry can accelerate the agenda for sustainable development and resource optimization.

Reducing energy consumption is closely linked and dependent on the readiness of workers who participate in individual construction activities, but also those who participate in the preparation of project documentation, including all professions. The link between energy skills and quality of construction will is represented by conducting case studies for measuring reduction of performance gap when using skilled engineers.

If an engineer or architect has the right knowledge and skills, he can achieve a significant energy reduction in the future, especially if he uses digital tools such as BIM. These savings can be evaluated already in the initial stages of the project, but also during construction planning, or during the operation and maintenance of the existing building. This gives the engineer a tool that allows him to make better decisions based on accurate information and data derived from a BIM model. The intersection of BIM and energy efficiency expertise represents a powerful opportunity to advance sustainable practices within the construction industry, ultimately contributing to a more energy-conscious future.

1.1 Obligation and motivation

According to Article VI of Directive 2012/27/EU on energy efficiency, EU member countries must ensure that central state administration bodies procure only products, services, and buildings with high energy efficiency. This obligation must align with cost-effectiveness, economic feasibility, broader sustainability considerations, technical suitability, and sufficient competition, as outlined in Annex III of the Directive [1].

Building Information Modelling (BIM) can significantly contribute to achieving these goals by enabling state administration bodies to procure energy-efficient products and services, thus advancing the broader objectives of cost-effectiveness, sustainability, and technical suitability.

While the installation of equipment utilizing renewable energy sources is not a direct condition for receiving financial support for a project, it represents a crucial step toward achieving ultra-low energy standards and is essential for attaining buildings with nearly zero energy demand. In this regard, BIM serves as a valuable tool for engineers.

BIM can also be applied in the energy evaluation and assessment of buildings, as indicated in the handbook for applicants seeking non-refundable financial contributions. An energy assessment must be included in the project documentation to evaluate the eligibility criteria. BIM facilitates the rapid collection of necessary data, significantly reducing the time required to produce this assessment.

Starting in 2030, all new buildings must achieve zero-emission status, with new buildings owned or used by public bodies required to meet this standard beginning in 2028. Member States will consider the global warming potential of a building over its entire lifecycle, including the production and disposal of construction materials. For residential buildings, Member States must implement measures to reduce the average primary energy consumption by at least 16% by 2030 and by 20-22% by 2035. Under the new directive, member countries will also need to progressively renovate non-residential buildings to meet minimum energy efficiency standards. By 2030, they must have renovated 16% of the non-residential buildings with the worst economic performance; this share will increase to 26% by 2033, with the ultimate goal of achieving climate neutrality by 2050 [1, 2].

doi.org/10.51704/cjce.2024.vol10.iss1.pp22-33
ISSN (online) 2336-7148

The EU strategy aims to reduce the overall costs associated with building utilization. In 2021, heating costs for public buildings reached nearly 500 million euros, with realistic energy prices suggesting that costs in 2022 could approach one billion euros. A significant contributing factor is that approximately 75% of public buildings are energy inefficient and in urgent need of renovation. Comprehensive renovations can lead to energy consumption reductions of over 70% in these facilities [3].

2 BUILDING INFORMATION MODELING

Building Information Modelling (BIM) has the potential to revolutionize energy management by enabling stakeholders to analyse and optimize energy efficiency throughout the entire lifecycle of any building—from initial design, through construction, to operation and maintenance (facility management) [4, 5]. A BIM model serves as a foundation for decision-making processes, containing not only geometric data but also non-graphical information about its properties, systems, and environment. This allows for various simulations and design optimizations, including those focused on energy efficiency. Designers are equipped with a powerful tool that helps them evaluate measures while considering the future operational characteristics of the structures. A significant advancement is the ability to conduct initial assessments during the early stages of the project cycle [6].

BIM introduces the digital age to the construction industry. Although the concept of information modeling is not new in Slovakia, it opens up numerous unexplored topics closely related to project creation, particularly the parametric model. However, this change—often compared to the shift from hand drawing to computer-aided design (CAD)—is considerably more complex. This approach transforms how processes and standards are perceived. The organized structure of data—known as asset information—is a valuable resource that many in the industry have yet to fully appreciate. This leads to a low or nonexistent demand for a structured data model for the transmitted information [4, 7].

The integration of BIM into the building lifecycle, like other systematic approaches, evolves gradually and penetrates various areas of a project over time. However, for BIM to be widely adopted, a certain level of expertise based on experience with data exchange and the ability to share information models among different professions must be achieved. We are witnessing a global increase in BIM usage, particularly in project design activities, and to some extent in pre-project preparation, construction, and facility management. The level of BIM adoption and its penetration into the construction sector is crucial for evaluating the market's readiness for energy modelling of buildings within a BIM environment [8, 9]. Therefore, it is not feasible to integrate Building Energy Modelling (BEM) without high-quality information models. In addition to the necessary skills for designers creating models, it is also essential to focus on non-graphical information—often referred to as parameters or attributes.

Correctly integrating and involving experts in a timely manner is also crucial. BIM allows for the earlier inclusion of various experts than traditional methods typically permit. Experience from more developed countries indicates that facility managers can add value as early as the project preparation phase. Early involvement of such professionals can lead to a significant reduction in operational costs, as they can influence up to 80% of future operating expenses. Active cooperation among the design team, contractor personnel, and facility management consultants is therefore essential [10].

2.1 Data exchange

From the perspective of the current European standard, EN ISO 19650-1, an information model is defined as a set of structured and unstructured information containers. The term "information container" (a permanent group of information) is relatively new to the construction field [11]. Essentially, it comprises information that can be repeatedly retrieved from files, systems, or other storage, such as drawings, budgets, schedules, model geometries, or images. BIM is defined by this set of standards as the use of a shared digital representation of a built asset to facilitate design, construction, and operation processes, forming a reliable basis for decision-making. Thus, the goal of BIM is not merely to create a model; rather, the BIM model serves as a gateway to the digital transformation of the industry.

Exchange formats are fundamental to collaboration and inter-professional cooperation. Open formats, as opposed to proprietary ones, promote cooperative openness and enhance information accessibility, as they do not require purchasing licenses from specific software vendors [12].

Interoperability is a basic requirement of BIM systems and refers to the ability of two separate systems or programs to communicate and exchange data. The exchange of models and other data across different software platforms remains one of the industry's primary challenges on the path toward fully integrated project team collaboration.

2.2 Building Energy Modelling (BEM)

The primary goal of energy management is to ensure compliance with applicable legal regulations while maintaining reasonable costs. From the designer's perspective, optimizing energy consumption during a building's operational phase is essential. Given that buildings have been in operation for decades, effective optimization can significantly impact overall operating costs [13].

A large portion of the work involved in preparing energy assessments and analyses consists of manual operations linked to gathering technical data, specifications, and parameters of individual elements and structures. Evaluating the necessary qualifications for such tasks reveals that much of this work can be classified as unproductive. Studies from abroad indicate that, in some cases, up to 90% of the time is spent studying project documents and searching for relevant information, with only 10% dedicated to the preparation of the assessments themselves.

With the advent of Building Information Modelling (BIM), it is now possible to eliminate much of this manual work. BIM can enhance the efficiency of the entire process and facilitate the acquisition of more accurate data for informed professional decisions. It is essential to consider the use of BIM as a foundational element for Building Energy Modelling (BEM) from the outset of a project. Properly modelled structures allow for effective analysis of factors such as shape, glare, primary energy usage, and the examination of thermal and technical properties using specialized software [14, 15].

Currently, many contractors—both public and private—lack sufficient experience in defining projects that should be implemented using BIM. These contractors could play a crucial role in increasing the share of contracts executed with information modelling. One of the main challenges is accurately articulating the client's requirements into a clear assignment that can be monitored for compliance. This includes defining necessary details such as geometry, parameters, documents, and the requirements for information delivery at specified project stages.

Although much information about the building is found in project documentation, the limitations of currently used CAD technologies persist. These traditional systems often have limited capabilities for leveraging electronic tools, and the information is typically not well connected to the actual building, hindering its further use. In contrast, a Building Information Model enables a comprehensive view of all parts of the building, including the characteristics of its structures and systems. Furthermore, data can be derived in semi-automated or automated ways. Consequently, we can utilize a BIM model as a

doi.org/10.51704/cjce.2024.vol10.iss1.pp22-33
ISSN (online) 2336-7148
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valuable source of information for extensive analyses and assessments of alternative solutions in earlier phases than is currently common [16, 17].

3 LIFECYCLE APPROACH FOR ENERGY REDUCTION

As previously discussed, Building Information Modelling (BIM) has revolutionized the construction industry by introducing a digitized process that enhances the quality of preparation and execution at every stage of a building's lifecycle. BIM directly influences project preparation quality and contributes to potential energy savings across several lifecycle phases, which we can categorize into three main areas:

1. Design,
2. Construction,
3. Facility management.

During the design phase, BIM provides a comprehensive platform for integrating all aspects of a building's energy performance. Designers can utilize BIM to create detailed 3D models incorporating energy-efficient elements, which allows for in-depth simulations. These simulations cover various factors, including thermal performance, daylight analysis, and HVAC efficiency, thus providing crucial insights into the expected energy consumption of the proposed design.

In the construction phase, BIM plays a critical role in maintaining the integrity of the design while achieving energy efficiency goals. The transition from design to construction is streamlined through BIM’s detailed documentation and clash detection features, ensuring that all elements are properly coordinated and potential issues are identified early.

In the facility management phase, BIM provides a robust foundation for ongoing energy management and optimization. The data-rich BIM model serves as a valuable repository of information that can be utilized for the building's operational and maintenance needs, enabling more efficient energy management strategies.

3.1 Energy simulations of the dynamic model

Understanding the importance of using BIM tools for energy simulations is key to helping engineers reduce energy consumption through various case studies. Selecting the right project for a case study on using BIM for energy evaluation and simulations involves considering several important factors that demonstrate BIM’s capabilities and benefits. These factors include manageable complexity, stakeholder commitment, data availability, software compatibility, support for innovation, replicability, and adequate resources.

Several tools are available today that help engineers leverage information from the BIM model to achieve energy savings; however, experience in using these tools remains limited. To improve this situation, engineers must focus on developing the following:

- knowledge (theoretical and factual)
- skills (cognitive and practical)

doi.org/10.51704/cjce.2024.vol10.iss1.pp22-33
ISSN (online) 2336-7148

3.2 Creation of an analytical model for BEM

Integrating Building Energy Modelling (BEM) with BIM offers a potent approach to optimizing energy performance from the earliest design stages. This chapter discusses standardized methodologies for developing a BEM analytical model using BIM during the design phase. Highlighting best practices for preparing BIM data into a robust analytical model ensures accuracy and consistency. Establishing a standardized process aids in demonstrating how early-stage energy simulations lead to better-informed decision-making at the design phase, enhancing collaboration among project stakeholders and establishing a foundation for high-performance, energy-efficient buildings.

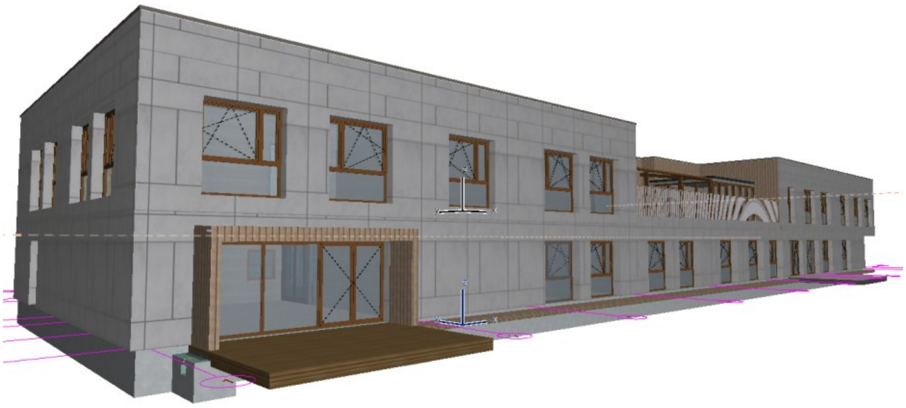

Fig. 1 BIM model of selected project

As mentioned, energy assessments can be initiated during early design phases, necessitating a mindful approach to using BIM for this purpose while adhering to specific model creation rules. The BIM model must be prepared correctly to enable effective energy evaluation. For optimal outcomes, all systems must be removed, and the model should undergo post-processing, including simplification routines.

Fig. 2 BIM model of the project

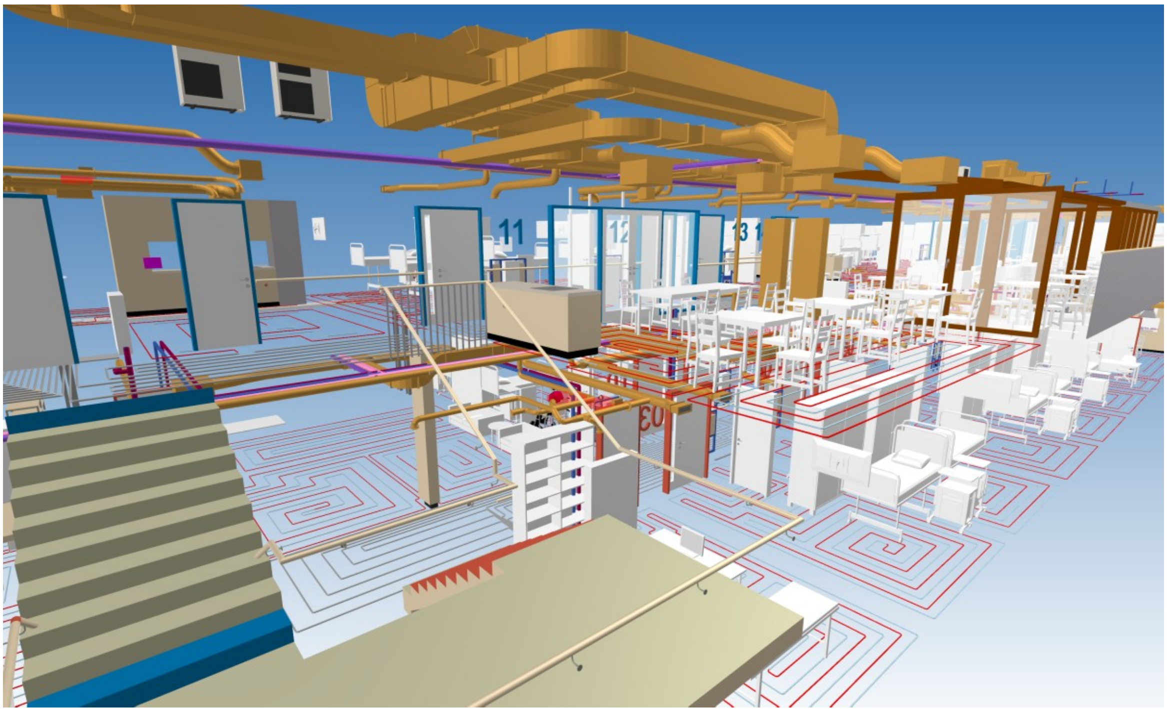

Fig. 3 Building systems

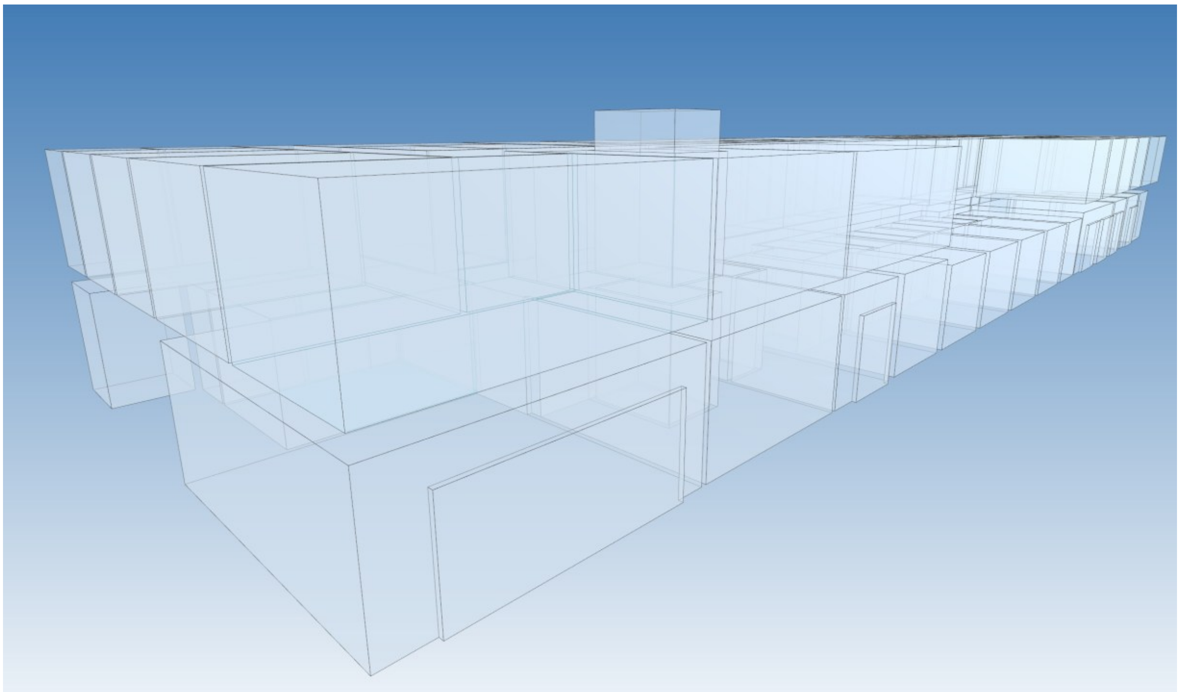

Fig. 4 Spaces in the building

Properly modelling the zones (IfcSpace) in the building is crucial [18]. Compliance with the rules outlined in documents provided by buildingSMART is recommended. Zones should be created automatically using the internal contour method, and boundaries must be specified for cases where multiple zones exist within one space (e.g., a waiting room in a corridor). A space must be associated with a building storey—or a site in the case of exterior spaces—and can span several connected spaces. Space groups categorize spaces included within a storey, while spaces may also be subdivided into parts

doi.org/10.51704/cjce.2024.vol10.iss1.pp22-33
ISSN (online) 2336-7148

that define partial spaces. The entire model should be meticulously examined to ensure all spaces are properly connected and terminated; otherwise, analysis will be compromised. Faulty connections can be identified automatically. It is also important to establish this requirement in the implementation project for BIM through the BIM Execution Plan (BEP). Clients must define this necessity in the Exchange Information Requirements (EIR) prior to selecting the construction designer.

To begin energy evaluation, Heat Blocks must be created, grouping zones—rooms—with similar temperature and ventilation requirements, as well as operational characteristics and orientations. Operational profiles that include factors such as operational hours, occupancy (including heat gains from people), luminaire types, and necessary temperature profiles to establish boundary conditions for heating and cooling must be added to the zones.

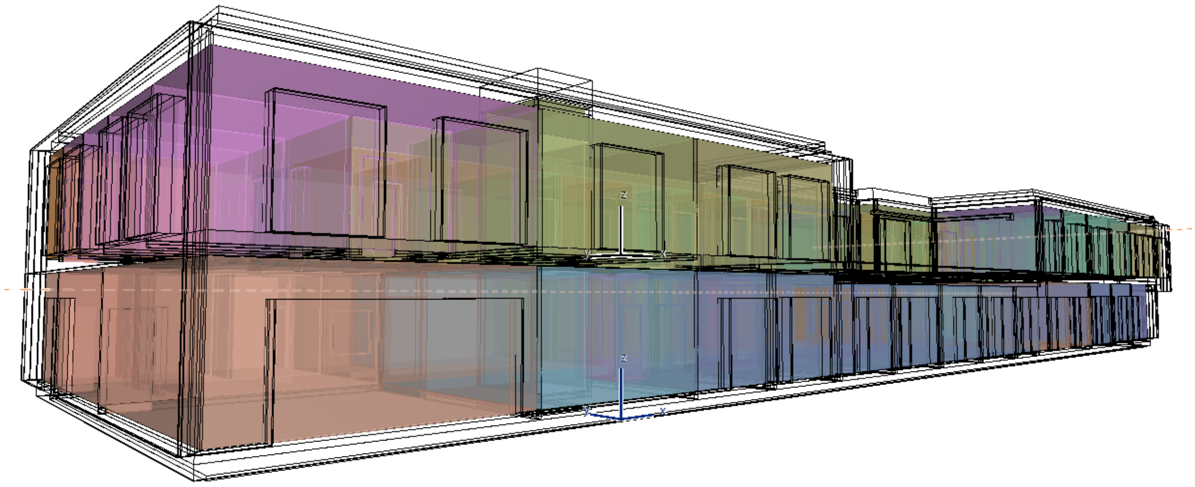

Fig. 5 Thermal blocks visualization

Envelope constructions (walls, slabs) of thermal blocks are assigned automatically, based on recognition from the BIM model structure, with the assignment of windows and doors to existing heat blocks. All surface areas are derived directly from the model. Key values impacting energy calculations, such as Ug-values (W/m²K) and Uf-values for the frame, can be adjusted based on manufacturer specifications, including the Uw value for the entire window. These coefficients are critical in energy calculations as they dictate the heat transfer characteristics of the building envelope.

Mechanical, Electrical, and Plumbing (MEP) and HVAC systems are then defined manually by engineers using this tool. Some software solutions even allow the automatic derivation of this data directly from the relevant BIM model. The next step involves selecting or adjusting daily profiles, which define temperature settings and operational hours for both weekdays and weekends.

Energy sources are identified, and information about energy costs for each type of source can also be incorporated, allowing for a more comprehensive evaluation of financial aspects. By accurately placing the building within its specific geographical context, we can assess geological conditions and the surrounding environment (e.g., proximity to high-rise buildings, forested areas, ponds, etc.). This integration enables simulations of temperature, humidity, wind, and solar exposure.

The necessary environmental data is sourced from databases but can be edited as needed. By correctly situating the building in its environment and acquiring detailed information about the proposed structure, various software tools can recalculate essential balances, such as the delivered versus released energy on a weekly basis.

doi.org/10.51704/cjce.2024.vol10.iss1.pp22-33
ISSN (online) 2336-7148
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3.3 Outputs from the energy assessment

The analysis of the energy performance of the proposed building becomes increasingly complex and provides detailed information about the current state of its structures and systems. These analyses are typically generated at later project stages and require substantial time to complete. This often leaves little opportunity for optimizations, potentially resulting in increased energy demands during the building's operation. If the BIM model is meticulously filled with accurate information and adheres to the specified creation rules, the outputs will include energy balances, temperature trends, solar analysis, thermal bridge assessments, energy consumption according to predefined targets, and an overall evaluation of the building's energy performance.

The energy balance output details aspects such as lighting and equipment loads, latent heat gains from occupants, domestic hot water heating, solar gains, heating needs, energy transfer, heat losses, and ventilation requirements. Each room undergoes a detailed analysis, leading to output documents that may exceed 50 pages.

Analysing energy consumption by individual categories—such as heating, cooling, and lighting—during the design phase is crucial for targeted optimizations and tailored solutions. This approach enables performance monitoring, regulatory compliance, and certifications, ultimately resulting in significant cost savings over time through the implementation of more efficient systems and technologies. The end result is energy-efficient buildings that not only reduce environmental impacts but also lower operational expenses and enhance occupant comfort.

3.4 BIM as a source for energy certification

The construction industry is increasingly recognizing the significance of energy-efficient buildings driven by economic benefits, regulatory requirements, and sustainability goals. This awareness has raised the demand for professionals who can ensure compliance across all aspects of building performance.

Energy certification systems such as LEED, BREEAM, and others have become essential methodologies for assessing and promoting the energy performance of buildings, particularly in the retail and office sectors. However, the overall utilization of BIM remains somewhat limited, contributing only minimally to the evaluated aspects within these frameworks.

When discussing Energy Performance Certificates (EPCs)—a mandate for every building—BIM plays a pivotal role as a comprehensive source for energy certification. This chapter will explore how BIM can streamline the certification process, ensure accuracy in energy performance data, and facilitate compliance with stringent energy standards. Energy Performance Certificates are vital instruments for enhancing the energy performance of buildings, with a central role in the Energy Performance of Buildings Directive (2010/31/EU). These certificates provide essential information to consumers regarding buildings they intend to purchase or rent.

Key input values for evaluating energy performance certificates include gross floor area, total floor area, and the area of the building envelope. Additionally, information about the ventilated volume of the building can be automatically extracted from the BIM model. Parameters obtained from individual building components within the BIM model also allow for the determination of heat transfer coefficients for the envelope, floors, and openings.

All this information is critical for creating an energy certificate. By utilizing BIM, we can significantly simplify the calculation process, positioning the BIM model as an essential informational resource for this aspect of building assessment. Unfortunately, these methods are not yet standard practice in the industry. Therefore, this methodology holds great potential for unlocking increased precision and swift processing in future energy evaluations and certifications.

4 CONCLUSIONS

Building Information Modelling (BIM) plays a pivotal role in achieving energy savings and reducing the performance gap in buildings, especially when utilized by skilled professionals with expertise in energy efficiency. The integration of BIM allows for precise evaluation, analysis, and optimization of energy performance throughout a building's lifecycle, leading to informed decision-making and reliable energy savings. Skilled professionals are essential for effectively implementing and maintaining energy-saving strategies, which contribute to significant cost savings and improved project outcomes.

By enhancing accuracy and efficiency, BIM helps prevent costly delays and rework, ensuring that energy performance targets are met during construction. Additionally, in the facility management phase, BIM provides a robust foundation for ongoing energy management and optimization, acting as a comprehensive repository of operational and maintenance information.

Integrating Building Energy Modelling (BEM) with BIM from the early design stages offers a powerful approach to optimizing energy performance. By adhering to established standards and incorporating energy assessments into the BIM Execution Plan (BEP) and Employer's Information Requirements (EIR), accurate early energy analysis enables necessary optimizations and ensures efficient building operation. Properly implemented BIM models deliver detailed energy assessments, including energy balances, temperature trends, solar analysis, and thermal bridge evaluations, ultimately leading to a comprehensive understanding of a building's energy performance.

It is crucial that engineers possess the appropriate skills to leverage BIM effectively for energy evaluation and optimization. By developing these skills, engineers can fully utilize BIM to achieve significant energy savings, reduce the performance gap, and enhance the overall quality and sustainability of building projects.

Funding

„This work was supported by the Slovak Research and Development Agency under the Contract no. APVV-18-0247“.

„This publication was created with the support of the Scientific Grant Agency of the Ministry of Education, science, research and sport of the Slovak Republic and the Slovak Academy of Sciences for the project VEGA-1/0272/22“.

„This research was funded by the project 101033743—SEEtheSkills—H2020-LC-SC3-2018-2019-2020/H2020-LC-SC3-EE-2020-2“.

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