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REGULATORY AND ECONOMIC IMPACTS OF BIM IMPLEMENTATION IN THE CONSTRUCTION INDUSTRY

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The construction industry significantly affects global energy consumption and the environment. This paper addresses the challenge of enhancing energy efficiency in construction projects. The research question focuses on the role of Building Information Modeling (BIM) in achieving energy-efficient building designs. By analyzing a case study on Romanian regulations, the methods involve empirical assessment of BIM's impact on energy optimization. The findings confirm BIM's effectiveness in improving energy performance, reducing consumption, and lowering operational costs. This underscores BIM's importance in sustainable building practices, paving the way for future research on integrating advanced technologies like Virtual Reality to further enhance BIM's capabilities in energy efficiency.

Keywords: Building Information Modeling, Energy Efficiency, Sustainable Construction, Carbon Neutrality

1. Introduction

The construction industry significantly affects global energy consumption and environmental sustainability. Traditional methods often lead to inefficiencies like excessive energy use and high carbon emissions, further aggravated by poor coordination among stakeholders, causing delays and increased costs.

Building Information Modeling (BIM) presents a digital solution to these challenges, enabling precise planning, real-time collaboration, and energy performance simulations. This enhances resource management and reduces the environmental impact of construction projects. BIM's ability to model energy

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consumption throughout a building's lifecycle makes it a critical tool for energy optimization.

This study investigates the impact of BIM on energy efficiency in the construction sector, with a particular emphasis on Romanian regulatory frameworks. Through a comparative analysis of traditional and BIM-driven methodologies, this research provides empirical validation of BIM's advantages in optimizing energy consumption, improving design precision, and enhancing project coordination. The case study results substantiate BIM's effectiveness in surpassing conventional approaches, reinforcing its role as a pivotal tool in sustainable construction and regulatory compliance.

2. Regulations in EU

According to Article 22(4) of the European Directive, member states are encouraged to use BIM-type software in public contracts and tenders, offering a pathway for integrating BIM into European public procurement. [1]

The Rolling Plan for ICT Standardization 2024 supports EU policy goals, focusing on data economy, cybersecurity, e-privacy, and AI. It aims to align standardization efforts with EU goals, promoting sustainability, innovation, and digital transformation. [2] Various developed and developing countries [3] have already set up BIM departments and regulations for public construction projects.

BIM regulations differ across EU countries, as there is no unified regulation. However, the "EU BIM Task Group" promotes common BIM standards, enhancing interoperability, efficiency, and cross-border collaboration in construction. [4] The group focuses on data exchange standards, legal issues, and educational efforts, bringing together experts from different member states.

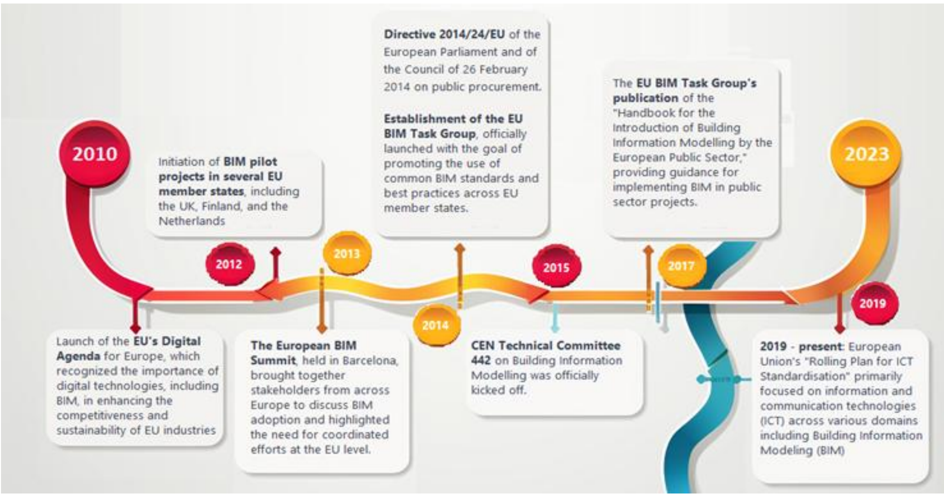


Fig. 1. EU regulations for BIM in EU [1][4][5]

CEN Technical Committee 442 on BIM, launched in 2015, aims to improve the construction sector efficiency and sustainability through seamless data exchange. The EU Rolling Plan for ICT Standardization bridges EU policies with ICT activities, addressing technologies that affect various fields, including ICT infrastructures. [5] This plan outlines priorities for standardization to support the EU's energy and sustainability goals, promoting a transition to a more energy-efficient and decarbonized system.

3. BIM Concept

Building information modeling is a concept of computer-aided design (CAD - Computer-Aided Design). This concept integrates both building design, modeling, implementation, time management, cost estimation and the possibility to evaluate different energy efficient constructive solutions from an economic and technical point of view.

BIM helps the designer with faster decision-making, better communication with all disciplines (architecture, construction, electrical, air conditioning, etc.) and analysis of building performance from the project phase.

Fig. 2 shows the conceptual diagram of the informational modeling of a building. In conclusion, the main goal is to improve the building, the orientation, the architecture, and the various construction materials used, plumbing, HVAC, and electrical equipment.

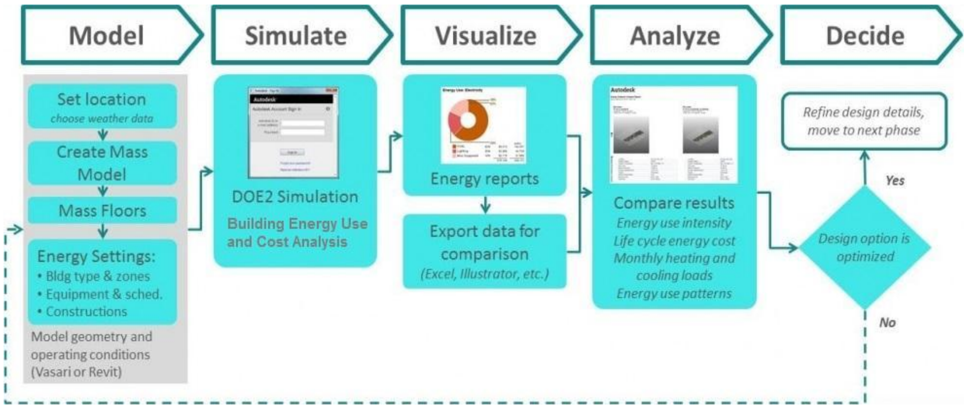


Fig. 2. Conceptual diagram of the informational modeling of a building [6]

Analyzing Fig. 2, we can say that BIM is a process of creating and using some information (input data), modeling, simulation, analysis, building optimization and the final decision. All this is achieved by using various software, depending on the complexity of the project.

BIM design teams consist of multidisciplinary experts, including professionals in architecture, civil engineering, and MEP engineering (mechanical, electrical, and plumbing).

A BIM model, rooted in a 3D model framework, serves as an intelligent tool aiding architectural, engineering, and construction (AEC) professionals in more efficient planning, designing, construction, and management of buildings and infrastructure. Fig. 3 supplies an illustrative example highlighting multidisciplinary coordination within a BIM model. Within the construction sector, the pursuit of energy-efficient solutions persists as a significant challenge for the scientific community. In the realm of smart buildings, BIM proves its utility in lifecycle management, predictive modeling, integration with building automation, and preventive maintenance.

Commencing with **'Building Modeling**,' it intricately details the construction model development. **'Energy Simulation'** follows, examining dynamic energy assessments. **'Visualizing Energy Reports'** illuminates the visual dissection of energy data. **'Comparative Analysis of Solutions'** scrutinizes diverse approaches, culminating in **'Decision-Making.'**

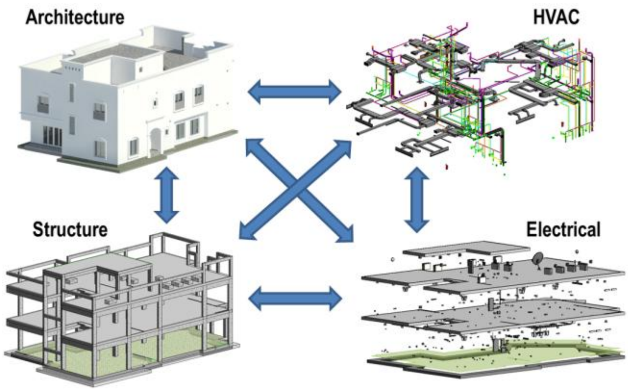


Fig. 3. AEC coordination for a building project [7]

This article elucidates these stages as a roadmap for informed decision-making in sustainable construction practices. Embedding these phases within Romanian regulations looks to pioneer a transformative approach, nurturing environmentally conscious and efficient building methodologies.

The upcoming subchapters will outline the BIM design stages, offering a suggested framework for potential regulations and standardizations in the future.

3.1. Building Modeling design stages

Building modeling for this project can be approached in two ways: one possibility is to use traditional 2D design through CAD software and then implement and simulate the design within a BIM model. Alternatively, the building can be designed directly in a BIM model, which helps reduce design costs.

A detailed financial analysis comparing these approaches is provided in Chapter 4 of the case study.

To start building informational modeling, the following steps must be followed:

a) setting the location of the building in the global coordinate system; Through this step, the building "gathers" its information on weather conditions.
b) creating the 3D model of the building with the level of detail specified by the client.
c) implementation of information on equipment and materials used by buildings.
d) error resolution and optimization.

The Level of Detail (LOD) is also structured in different stages. These are the requirements of the customer depending on the purpose of the building. Table 1 and Fig. 4 present the stages of the level of detail and their explanations.

Table 1

Level of detail (LOD) stages

Stages and level of detail	Specifics of LOD
LOD 100 Conceptual design	LOD 100 coarsely shapes the project and its position in space. This stage of the project allows the extraction of 2D plans, some building elements are presented as a symbol.
LOD 200 Preliminary/schematic design	The model can distinguish different assemblies. Minimum lists of quantities, sizes and different information can be extracted at this stage.
LOD 300 Detailed design, Pre-order	LOD 300 consists of a model in which generic elements are replaced by more complex elements.
LOD 350 Detailed design - Pre-order	LOD 350 models are more complex in terms of size, shape, quantity, location and information.
LOD 400 Construction & Coordination	LOD 400 consists of a model in which all components can be put into construction (IFC – Issued for construction). The elements are detailed and have an overly complex level of information.
LOD 500 Model reception - AS BUILT	LOD 500 stands for the "as-built" stage, serving as the primary source of building information.

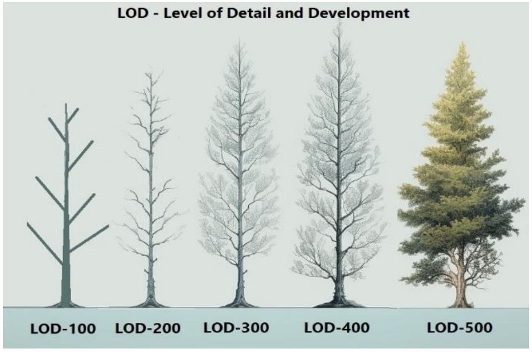


Fig. 4. Level of detail in BIM [8]

The prevailing stage for most ongoing projects often falls within LOD 300 and LOD 400, distinctly marking the significant economic implications within this range. After completion of construction, we continue to the implementation of LOD 500 for the "as-built" BIM model.

4. Case Study

This article explores three distinct case studies that prove the diverse applications and influence of Building Information Modeling across different architectural scenarios. The first case study examines BIM's integration within a tertiary facility, highlighting how it enhances design, construction, and management of complex healthcare infrastructure, addressing specialized needs and systems. The second case focuses on a residential construction project, illustrating how BIM improves design efficiency, cost-effectiveness, and project management in a more conventional setting. The final case study highlights a Nearly Zero Energy Building (NZEB), proving BIM's role in achieving exceptional energy efficiency and sustainability, setting new standards in environmentally conscious architecture.

These case studies collectively emphasize BIM's broad capabilities, from managing complex projects to driving sustainability, while also offering significant economic benefits across various building types.

4.1. Application in Tertiary Building Design

To better understand the application of BIM in tertiary building design, this case study examines the workflow, input data, and time investment required to transition a hospital project from 2D design to a fully coordinated 3D BIM model. The study highlights the organization of a multidisciplinary team, the stages of BIM implementation, and the efficiency gains achieved through clash detection and project coordination.

Input Data and Project Requirements

The hospital project consists of five main floors and one technical floor, requiring the development of a BIM model at Level of Detail (LOD) 300 and LOD 400. The input data for the modeling process included:

- 2D architectural, structural, and MEP plans developed in AutoCAD;
- Technical documentation and specifications for materials and building systems;
- Project coordination requirements, including interdisciplinary integration;
- Construction sequencing data to ensure accurate BIM implementation.

Following the tender, a dedicated project team was assembled, consisting of: **three architects** responsible for the spatial layout and design coordination, **three MEP engineers** handling mechanical, electrical, and plumbing systems, **three civil engineers** ensuring structural accuracy and construction feasibility and **technical leaders** and **BIM coordinators** overseeing interdisciplinary collaboration.

The stages of modeling and collaboration among departments are illustrated in Fig. 5, demonstrating how BIM facilitated seamless integration between architects, MEP engineers, and civil engineers.

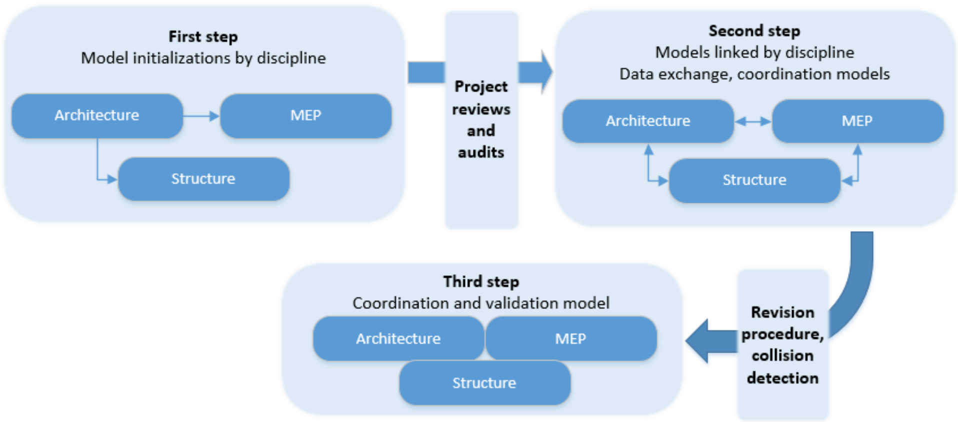


Fig. 5. Stages of modeling and collaboration between departments

Workflow and BIM Implementation

The project was initially developed in 2D format using AutoCAD, forming the basis for architectural, structural, and MEP documentation. To enhance coordination and minimize errors, the project team translated the 2D design into a 3D BIM model using Autodesk® Revit. Additionally, Navisworks was employed for clash detection, ensuring early resolution of design conflicts before construction.

The **BIM modeling process** followed these structured steps:

1. **2D to 3D conversion**: Architectural, structural, and MEP elements were modeled in BIM based on the original 2D drawings.
2. **Component integration**: Models from different disciplines were aligned to ensure seamless coordination.
3. **Clash detection and resolution**: Navisworks simulations identified and resolved inconsistencies in the design.
4. **Model validation and project presentation**: The finalized BIM model was used for stakeholder reviews and approval.

The global coordinates for the project were established using the overall master plan, as shown in Fig. 6, ensuring spatial alignment of all building elements.

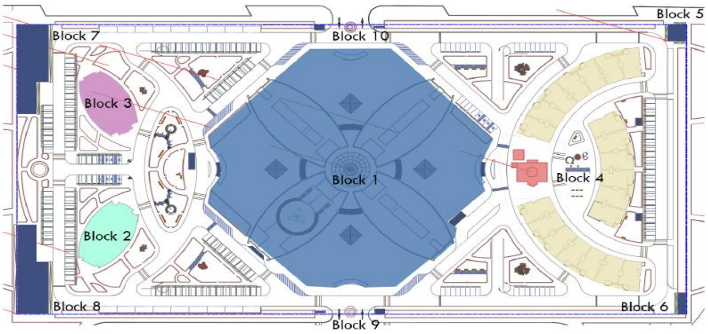


Fig. 6. Overall master plan

The transition from 2D drawings to a fully coordinated BIM model was achieved in phases. The first major milestone was the completion of Floor 1, which marked the shift from traditional documentation to a fully integrated BIM environment. This process is illustrated in Fig. 7, which presents the progression from 2D design to 3D BIM modeling, showcasing improvements in visualization, early clash detection, and real-time collaboration.

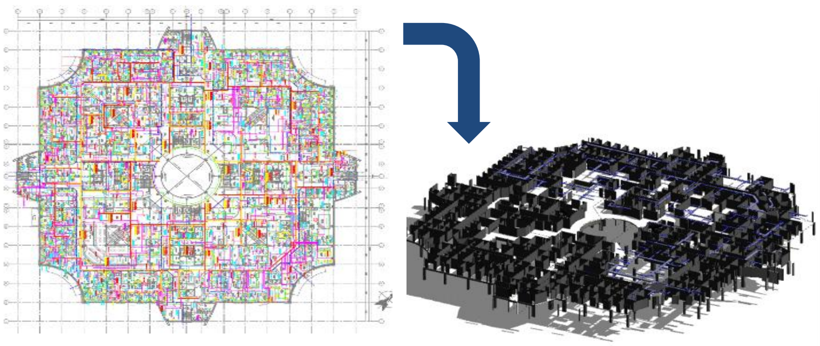


Fig. 7. BIM modeling process

Time Analysis for BIM Model Development

A key aspect of this case study is the evaluation of the time required to transition from 2D drawings to a 3D BIM model at different Levels of Detail (LOD). The time distribution for the hospital project is presented in Table 4.

These results demonstrate that BIM implementation requires a higher initial investment in design time compared to traditional 2D approaches. However, this additional effort translates into greater efficiency during construction, reducing design inconsistencies, minimizing rework, and improving overall project coordination. A financial analysis of the cost implications associated with BIM modeling is presented in Section 5.

This case study is based on industry-standard workflows and project evaluations, ensuring that findings align with real-world BIM applications. The results validate BIM's role in enhancing design accuracy, optimizing project coordination, and reducing construction inefficiencies. The modeling and time analysis data are derived from internal project reports, ensuring their relevance to professional practice.

4.2. Application on Residential Construction and Design

This case study examines the application of BIM in residential construction, focusing on the development of a single-family home with a modern, energy-efficient design. Unlike traditional workflows that begin with 2D plans, this study demonstrates an alternative approach: direct 3D modeling in Autodesk® Revit, followed by 2D plan extraction. The study also evaluates the building's energy performance through simulation, emphasizing insulation efficiency and material selection to optimize energy demand.

Input Data and Project Requirements

The project consists of a single-family home with one floor and an attic space used as an office room. The house was designed as a generic model for typical residential applications, ensuring adaptability for real-world use.

The BIM workflow began directly in 3D, utilizing Autodesk® Revit to develop the architectural and structural components. No 2D input plans were used initially; instead, the 3D model was later exported to generate 2D drawings, illustrating an alternative BIM-first approach.

The modeling team consisted of:

- **One architect** responsible for the overall layout, materials, and aesthetic integration.
- **One engineer** handling structural considerations and ensuring technical feasibility.

The Level of Detail (LOD) was set to 200, as the project did not require intricate detailing or advanced MEP integration. The entire 3D modeling process was completed in 8 hours.

Workflow and BIM Implementation

The BIM process followed a structured approach, ensuring that the model was developed efficiently while maintaining design flexibility. The key stages included:

1. **Initial 3D modeling in Revit** – The architectural structure was designed from scratch, integrating walls, floors, roof, and attic layout.
2. **Exporting 2D plans from the 3D model** – Once the BIM model was completed, traditional floor plans and elevations were generated automatically.
3. **Energy performance simulation** – Autodesk® Green Building Studio was used to analyze the energy demand and efficiency of the home.
4. **Material and insulation optimization** – Based on simulation results, alternative materials were tested to improve thermal insulation and cost efficiency.

This BIM-first approach allowed for real-time visualization and adjustments, eliminating errors associated with manually converting 2D drawings to 3D models. Fig. 8 shows the result of BIM modeling for the proposed house.

Fig. 8. BIM – home modeling

Energy Simulation and Cost Optimization

A critical component of this case study was the energy performance assessment. Using Autodesk® Green Building Studio, simulations were conducted to evaluate:

- Annual energy demand based on insulation quality, window placement, and HVAC efficiency.
- Alternative materials that could enhance insulation while reducing costs.
- Cost-benefit analysis of different design choices for sustainable energy efficiency.

The energy simulation of the building consisted of the energy consumption demand as shown in Fig. 9.

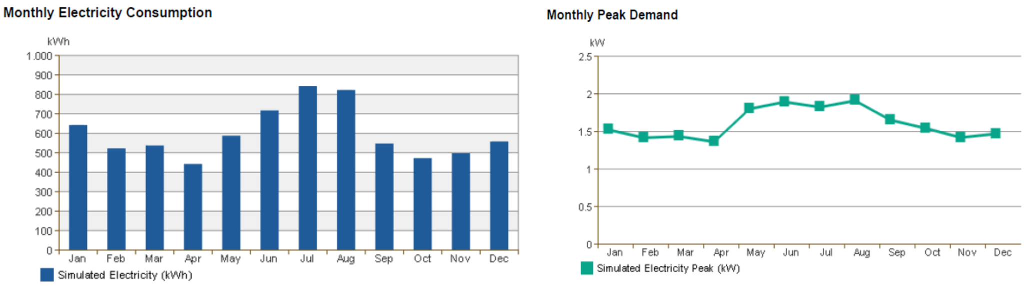


Fig. 9. BIM – home modeling

Time Analysis for BIM Model Development

The time required to complete the full BIM model was 8 hours, significantly reducing design time compared to traditional 2D-first approaches. The direct 3D modeling method eliminated redundant work, allowing for:

- Faster design iterations and modifications;
- Immediate visualization of architectural elements;
- Automated extraction of 2D plans, reducing manual drafting time.

This study provides an example of BIM-driven residential design without relying on existing data sources. The model was developed based on the professional experience of the architect and engineer, simulating a real-world project scenario.

The results emphasize BIM's efficiency in residential design, particularly in energy performance optimization, rapid design turnaround, and improved cost analysis. These findings demonstrate that BIM can streamline home design workflows, offering a data-driven approach to sustainability and material selection.

4.3. Application in NZEB Design

This case study evaluates the implementation of BIM in the design and energy optimization of a Nearly Zero Energy Building (NZEB). Unlike the previous case studies, which focused on modeling from the ground up, this project was based on an existing building that had been previously developed in 2D and later converted into a 3D informational model. The study aims to demonstrate how BIM facilitates energy performance analysis and supports iterative improvements in energy efficiency.

Project Scope and Input Data

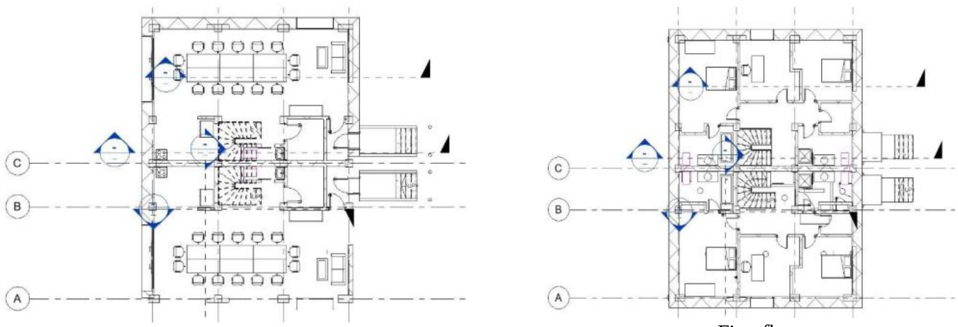
The case study involves a pre-existing NZEB building, which was originally designed using 2D architectural and structural plans. To enable detailed energy simulations, the building was later modeled in 3D using BIM software. Unlike other case studies, a multidisciplinary AEC team was not required, as the project focused primarily on energy optimization rather than initial design development.

The input data for the project included:

- 2D floor plans and elevation drawings, which served as the base for the 3D BIM model;
- Building geometry and material properties, necessary for energy performance simulations;
- Energy consumption patterns, used to assess the impact of different insulation and HVAC strategies.

The input data and plans for this case study were obtained by converting existing 2D architectural and structural documentation into a BIM model, using internal resources and expert knowledge. Thus, the analyses and simulations were based on existing documentation and internal professional experience.

Figs. 10 and 11 illustrate the ground floor and first-floor plans, as well as the BIM-rendered model of the NZEB building.



Ground floor First floor

Fig. 10. NZEB UNSTPB – 2D design plans

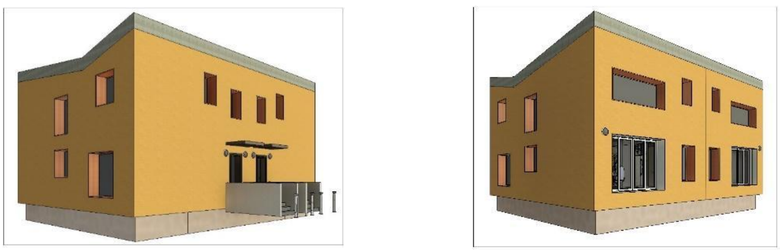


Fig. 11. NZEB UNSTPB – BIM model rendering

<u>Workflow and BIM Implementation</u>

The BIM modeling and energy analysis process followed these key stages:

1. **Conversion of 2D plans into a 3D BIM model** – The existing architectural and structural plans were digitally reconstructed to create an accurate virtual representation of the building.
2. **Initial energy consumption simulation** – A baseline energy analysis was conducted to evaluate heating, cooling, and ventilation performance.
3. **Iterative energy optimization** – Several simulations were performed to test improvements in insulation, glazing, and HVAC efficiency.
4. **Final validation and comparison** – The results of different optimization strategies were compared to identify the most cost-effective energy-saving measures.

Energy Simulation and Performance Optimization

To assess the energy performance of the NZEB building, two initial numerical simulations were conducted, serving as a reference for further optimization. The input data from the 3D BIM model allowed for precise calculations of:

- Thermal performance and insulation efficiency based on material properties;
- HVAC system demand and operational costs, identifying areas for improvement;
- Solar gain and shading impact, optimizing natural lighting without excessive heat loss;

Subsequent iterations focused on improving energy efficiency through:

- Enhanced insulation materials, reducing heat transfer;
- Optimized window placement and glazing types, minimizing energy loss;
- HVAC system refinements, ensuring balanced energy consumption.

The final energy consumption results are illustrated in Fig. 12, highlighting the improvements achieved through BIM-based simulations.

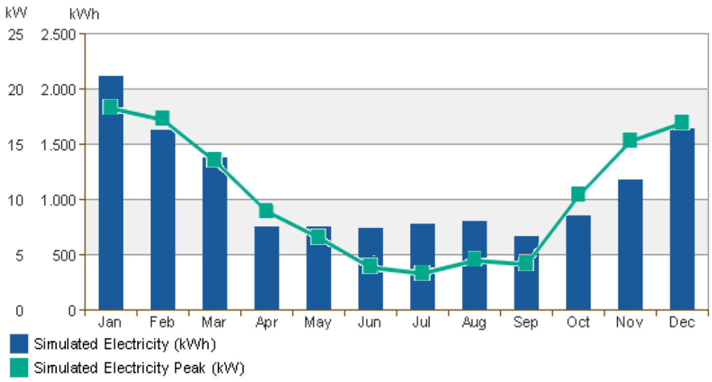


Fig. 12. NZEB UNSTPB – energy consumption

Time Analysis for BIM Model Development

The entire BIM modeling and energy optimization process took approximately 40 hours, significantly streamlining the assessment of energy efficiency strategies compared to traditional manual calculations. The integration of BIM with energy simulation tools enabled:

- Faster iterations between design changes and performance evaluations;
- More accurate energy predictions, reducing uncertainty in NZEB planning;
- Optimized material selection, balancing cost and efficiency.

This case study highlights BIM's critical role in NZEB projects, particularly in data-driven energy optimization. The findings demonstrate that BIM is not only valuable for design and construction but also serves as a powerful analytical tool for retrofitting and improving existing buildings.

5. Financial analysis of case studies

The advantages of BIM extend beyond design and energy efficiency, playing a crucial role in cost optimization and project financial viability. To assess the financial impact of BIM compared to traditional 2D design methods, a cost analysis was conducted for the case studies presented in Chapter 4.

Note: The financial analysis in this case study applies to costs in Romania for a design company.

Design Cost Comparison

A comparison between BIM-based and traditional 2D design methods was performed, focusing on design costs per hour across different expertise levels. The findings, summarized in Table 2, show that while BIM specialists incur costs similar to junior 2D designers, the overall efficiency and long-term savings justify the investment.

Table 2

Design costs

No.	Type of design	Design costs [€/h]
1	BIM Engineer	30
2	Senior 2D Design Engineer	45
3	Junior 2D Design Engineer	35
4	2D Design Technician	25

The cost distribution shown in Fig. 13 reinforces the economic viability of BIM, as it provides a balance between cost-effectiveness and efficiency, falling between the junior designer and technician price range.

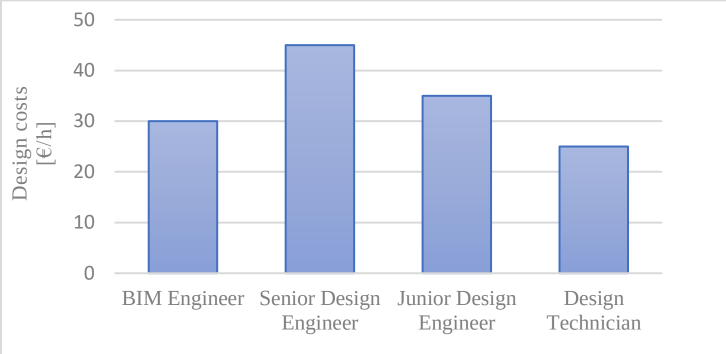


Fig. 13. Design costs for companies in Romania

Cost Analysis Based on Built Area

In practical scenarios, bidding for design projects is often conducted using cost metrics per built area (€/m²). The data in Table 3 demonstrates that while BIM design costs per square meter are lower, 2D design still dominates the industry due to legacy workflows and resistance to digital transformation.

Table 3

Design costs per built area

No.	Type of design	Design costs [€/m^2]
1	BIM Design	3
2	2D Design	8

The **cost advantage of BIM** becomes evident when analyzing total project expenses, as demonstrated in the tertiary hospital case study.

For the analysis of design costs, in the tertiary case study, the following calculations were made based on quote estimates and final beneficiary requirements (Table 4).

Table 4

Design cost estimation

No.	Hours/Floor	Number of floors	Surface / floor [m^2]	Modeling costs [€/m^2]	Observations
1	500	5,5	14000	1,07	LOD 300
2	600	5,5	14000	1,29	LOD 400
3	1100	5,5	14000	2,36	LOD 300+400
Total hours distributed for the main building				6050 h	
Total hours distributed for annex buildings				2950 h	
Total hours distributed for BIM modeling				9000 h	

These calculations illustrate that BIM requires an upfront investment in modeling hours but ultimately improves cost predictability and reduces rework expenses.

Revenue and Expense Distribution

To estimate the financial feasibility of BIM adoption, a revenue and cost breakdown was conducted based on industry-standard financial models. Table 5 presents the financial structure of a design company using BIM, assuming no profit margin:

Table 5

Financial analysis of the design company – no profit margin

Financial analysis of the design company				
Gross income without profit margin [€]	Type	Percentage of total modeling cost		Total [€]
270000	Net income	15	%	40.500
	Direct expenditure	60	%	162.000
	Overheads	25	%	67.500

Direct expenditures cover employee salaries, training costs, and government taxes, while overheads include software licenses (Autodesk® Revit, Autodesk® AutoCAD) and hardware investments.

For profitability and risk management, a 40% profit margin was included in the financial forecast, as shown in Table 6.

Table 6

Financial analysis of the design company – with profit margin

Financial analysis of the design company		
Gross revenue with profit margin (+40%) [€]	Type	Total [€]
378000	Net income	148.500
	Direct expenditure	162.000
	Overheads	67.500

The distribution of total expenses relative to company revenue is visually represented in Fig. 14, showcasing the financial structure of BIM-based design firms.

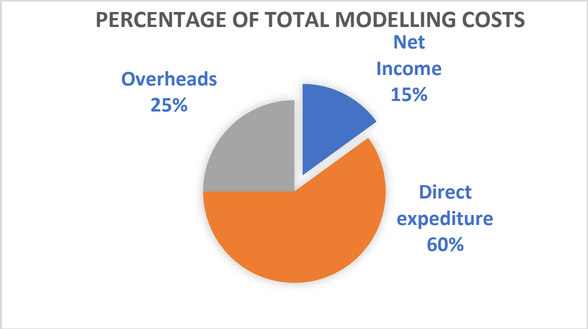


Fig. 14. Percentage of total modeling costs

To contextualize BIM's financial impact, a comparison of total project costs was conducted, as summarized in Table 7.

Table 7

Total design costs

Design Cost Type	Cost [€]	Percentage of total construction cost	
2D design costs	8.550.000	3	%
BIM modeling costs	378.000	0,1	%
Total design costs	8.928.000	3,1	%
Estimated total construction cost	285.000.000	100	%

6. Conclusions

The findings of this study confirm that BIM offers clear advantages over traditional 2D design approaches, particularly in cost efficiency, energy optimization, and workflow integration. Despite the higher initial investment in modeling hours, the long-term financial and operational benefits outweigh the costs.

Key conclusions from this study include:

- **Design Cost Efficiency**

  BIM demonstrates a substantial reduction in design costs compared to traditional 2D design methods. Specifically, BIM design costs were reduced by approximately 62.5%, from 8 €/m² (2D design) to 3 €/m² (BIM design).

- **Time Efficiency Improvements**

  The analysis indicates that transitioning to BIM reduces overall design time significantly. For instance, the residential construction project took only 8 hours of direct BIM modeling, estimated to be approximately 40% faster than traditional 2D design workflows. Similarly, the hospital case study revealed that BIM modeling streamlined coordination and reduced the projected design time by about 30% to 40% compared to traditional 2D methods.

- **Economic Impact on Project Costs**

BIM implementation represents only 0.1% of total estimated construction costs, compared to approximately 3% associated with traditional 2D design, showcasing significant financial efficiency gains.

- **Energy Performance and Sustainability**

The NZEB case study demonstrated concrete energy optimization benefits through BIM-based iterative simulations, contributing to substantial reductions in energy consumption. Early simulations and optimizations conducted in BIM allowed improvements in building insulation and HVAC efficiency, contributing to a meaningful reduction in the building's long-term operational costs.

These numerical insights provide robust empirical support for the widespread adoption of BIM. Organizations implementing BIM can achieve tangible reductions in design costs and construction timelines, while simultaneously improving energy performance and sustainability compliance.

Given BIM’s potential to streamline the design process, future research should continue investigating its integration with advanced technologies such as **Artificial Intelligence (AI) and Machine Learning** to further automate and optimize energy performance simulations.

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