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Integration of BIM technology and Building Lifecycle Management on the example of selected analyses

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Abstract
Building life cycle management is a concept of efficient and effective planning, organizing, managing and supervising the implementation and operation of a building investment, without unnecessary waste but with the achievement of the expected effects in terms of: environmental, economic and socio-cultural. BIM technology – perceived as Building Information Model / Modeling / Management – is used throughout the life cycle of a building. Advanced BIM dimensions 5D, 6D and 7D extend the traditional 3D model with additional information that supports the management of the life cycle of a building. The 5D dimension concerns cost estimates, the 6D refers to the integration of data related to energy efficiency and the impact of the building on the environment, while the 7D dimension focuses on the management of the operation of the building after it has been put into use. The aim of the article is to present the results of selected life cycle analyses. The authors performed two examples of life cycle analyses: a life cycle cost analysis (LCCA) and an environmental life cycle analysis (LCA) in terms of the generated carbon footprint (global warming potential – GWP). Additionally, in the case of the second example, the authors estimated the value of the equivalent social cost of CO_2 emissions as an element of the social life cycle analysis – LCSA according to the average price of emission allowances in the EU-ETS system.

Keywords
BIM, lifecycle management, global warming potential, life cycle costs, social cost of CO_2 emissions.

1. Introduction

The architecture, engineering, and construction (AEC) industry, like the facility management (FM) industry, is currently undergoing a digital transformation, which appears essential due to the need to increase data transparency and standardization, adapt data to digital representation, improve the efficiency of complex construction projects, and optimize the impact of various processes occurring during the long-term operation of buildings to minimize total cost of ownership (TCO) and reduce environmental and social impacts using tools and techniques associated with product lifecycle thinking (PLT) and Building Lifecycle Management (BLM). Many researchers, including: (Hofmann & Rüsch, 2017), (Wang & Meng, 2019), (Skrzypczak et al., 2022), (Klungseth et al., 2023), and (Brozovsky et al., 2024) point out that Industry 4.0 transformation trends in the construction industry (Construction 4.0) are primarily oriented towards concepts related to the widespread implementation of:

- industrial production, e.g., prefabrication, modularization, 3D printing technology, and robotics,
- cyber-physical systems, e.g., the Internet of Things (IoT), sensor-based automated systems, robots, and drones,
- digital technologies, e.g., Building Information Modeling (BIM), 3D scanning of buildings and other engineering structures (Scan-to-BIM methods and related photogrammetry), artificial intelligence (AI), and cloud computing.

The development of BIM technology in Poland is constantly continuing. New solutions and computer software are being implemented to facilitate the adoption of this technology in construction (Juszczyk et al., 2015). Numerous studies are being conducted among construction companies to assess their knowledge and experience with BIM, the feasibility of implementing it in enterprises, and the use of computer tools to accelerate design processes (Zima et al., 2020). According to the data presented in the article (Leśniak et al., 2021), in 2019, of the 287 Polish architectural and

construction companies surveyed, only about 20% had experience in implementing investment projects using BIM. Furthermore, data from a publication (Apollo & Grzyl, 2023) indicate that approximately 46% of Polish companies have only had some experience with this technology, and most companies describe their level of involvement in BIM technology as at the first level of maturity, where information management is based on 3D technology (primarily CAD), but projects rely on shared files and libraries, lacking full data integration. According to Polish publications, the highest adoption is observed in the architecture and installation industries, where it amounts to approximately 50%. In construction, the adoption is smaller, accounting for approximately 25%.

Since the authors of this article recognize the need to integrate BIM technology with the principle of product lifecycle thinking (PLT), and specifically Building Lifecycle Management (BLM) as tools or techniques that enable optimization (limiting) the impact of various processes during the long-term operation of buildings and other engineering structures, the main goal of the article is to present the results of selected life cycle analyses. The authors performed two examples of life cycle analyses. The first is a life cycle cost analysis (LCCA) and the second an environmental life cycle analysis (LCA) in terms of the generated carbon footprint (global warming potential – GWP). Additionally, in the case of the second example, the authors estimated the value of the equivalent social cost of CO_2 emissions as an element of the social life cycle analysis – LCSA according to the average price of emission allowances in the EU-ETS system. The calculation examples are based on selected elements of works, respectively in the scope of the construction of building with a reinforced concrete frame structure with a brick wall infills, which is exposed to the effects of earthquakes due to its location in a seismic area and multi-story car park, for which elements of design for environment (DfE) have been introduced, aimed at proposing design and material solutions that will minimize environmental impact and promote innovative, sustainable solutions.

2. Integration of BIM technology and Building Lifecycle Management – literature review

BIM most often refers to the Building Information Model in its conceptual sense. However, in its functional sense, the acronym BIM also stands for Building Information Modeling – the process of creating a virtual model of a building, or Building Information Management – a comprehensive process encompassing planning, coordinating, and controlling a construction project from the conceptual phase through construction completion. In accordance with the terminology presented in the latest fourth edition of "The National BIM Standard – United States, Version 4", the section entitled "Terms and Definitions" (NBIMS-US, 2023), based on the previous version 3 of NBIMS-US, but also on the ISO/TS 12911:2012 standard "Framework for building information modelling (BIM) guidance" (ISO/TS 12911, 2012), the ISO/IEC 20944-1:2013 standard "Information technology – Metadata Registries Interoperability and Bindings (MDR-IB) – Part 1: Framework, common vocabulary, and common provisions for conformance" (ISO/IEC 20944-1, 2013) and the ISO 19650-1:2018 standard "Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) – Information management using building information modelling – Part 1: Concepts and principles" (ISO 19650-1, 2018):

- Building Information Model means a shared digital representation of physical and functional characteristics of a built environment asset,
- Building Information Modeling is concerned with generating and using a shared digital representation of a built environment asset to facilitate design, construction, and operation processes to form a reliable basis for decisions,
- Building Information Management is understood as a set of functions of controlling the acquisition, analysis, retention, retrieval, and distribution of built environment asset information all within an information processing system.

The common threads between the aforementioned terms include decision-making support, generating and using data and information about a building for design, construction, and maintenance (operation) purposes throughout its life cycle. Therefore, many researchers around the world highlight the significant implementation opportunities offered by BIM technology in the context of integrating data and information about buildings with the principle of product lifecycle thinking (PLT), and specifically Building Lifecycle Management (BLM). As for example stated in the publications (Ustinovičius et al., 2015), (Li et al., 2021) and (Lai et al., 2025) BLM can be perceived as a strategic and comprehensive approach to managing a building or asset from its initial concept and design through construction, operation, maintenance, and eventual deconstruction or disposal. It ensures a building's optimal long-term performance, efficiency, sustainability, and value by integrating people, processes, and technology to make informed decisions at each phase of its life cycle.

Many researchers also note the rapid development and growth of research on integrating BIM technology with Building Lifecycle Management (BLM) elements, but with a focus on automating certain processes. For example, in

the context of combining BIM with environmental life cycle analysis (LCA), the authors of publications (Parece et al., 2025) and (Tosi et al., 2025) present examples of the intensive development of LCA automation methods using data from BIM models. The authors also point to the possibility of faster comparison of design variants and integration of information on building materials, but they also emphasize that despite continuous progress, the need to standardize methodologies for data extraction, material property mapping, and linking to environmental databases remains a challenge. This problem, as also noted in publications (Mangialardi et al., 2017) and (Zhang et al., 2024), is expected to be a major integration challenge in the future, including semantic mapping and version management, which these authors see as an advantage resulting from the ability to treat building elements as single "products" with their own life cycle. This approach will facilitate tracking the history of components, planning their replacement, and assessing costs or environmental effects at the level of building components.

Regarding the integration of BIM and the Internet of Things (IoT) during the operational phase of buildings with facility management (FM), the authors of articles (Kim et al., 2018) and (Mannino et al., 2021) confirm the growing use of BIM after facility commissioning and the effectiveness of integration with FM systems in facilitating asset management, as well as supporting maintenance planning and optimizing facility operating costs. The literature review included in these publications also points to barriers such as the lack of standards for the transfer of operational data and the incompleteness of BIM models in terms of the information necessary for FM systems.

In turn, the authors (Omrany et al., 2023) and (Petri et al., 2025) describe examples from the literature that indicate a growing interest in "live" models (digital twins) combining BIM with IoT data. According to the authors, this approach enables dynamic assessment of operational parameters (e.g., energy consumption) in the context of changes that translate into LCA results, updated with actual data.

3. Materials, methods and discussion of the results of analyses

3.1 Example 1 – a life cycle cost analysis (LCCA)

The first example of life cycle analysis integrating data from a BIM model is a life cycle cost analysis (LCCA) for selected life cycle scenarios for innovative anti-seismic protection systems, which was developed at the Cracow University of Technology. The system is based on the PolyUrethane Flexible Joints – PUFJ, which is deformable structural connectors transferring high loads and high deformations, and Fiber Reinforced PolyUrethanes – FRPU, deformable adhesives and composite matrices, which have the ability to dissipate energy. Fig. 1 shows three variants of the anti-seismic protection system that were selected for analysis and the scheme developed in BIM technology for FRPU circumferential laying and PUFJ surface gluing.

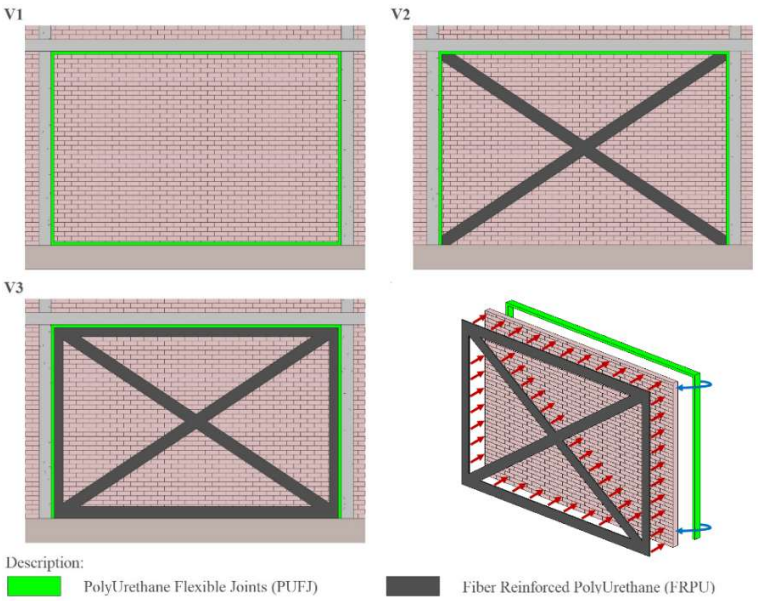


Fig. 1. Innovative anti-seismic protection systems (views of parts of reinforced concrete frames and brick walls modeled in BIM): V1 – prefabricated PUFJ at 4 interfaces; V2 – injected PUFJ at 3 interfaces and application of FRPU at infill diagonals; V3 – injected PUFJ at 3 interfaces and application of FRPU at infill diagonals and edges both.

The life cycle scenarios were subordinated to the guidelines of the ISO 15686-5:2017 standard "Buildings and constructed assets – Service life planning – Part 5: Life-cycle costing" (ISO 15686-5, 2017), which identifies the concept of a life cycle scenario with maintenance activities divided into three types of maintenance activities: preventive – including condition-based or predictive and planned, corrective – taking into account emergency events and unforeseen or reactive fault corrections, and deferred – a decision on time and urgency that may have financial consequences.

For the purpose of defining life cycle scenarios, for all variants of innovative anti-seismic protection systems (in the most earthquake-prone area), it was assumed that a complete set of maintenance works would be planned for a reinforced concrete frame building with masonry infill walls. The estimated service life of the building was assumed to be at least 50 years (up to 60 years), in accordance with the Eurocode approach. It was also determined that in the most unfavorable situation, the frequency of earthquakes, which can cause both material and social losses, could range from 9 to 12 years, with an average time for carrying out maintenance works and incurring repair costs of 10 years.

All life cycle scenarios were defined for the scope of work that could be performed on a sample wall filled with brick material. The scope of work assumed that initially, a 10 cm thick, 3.2 m high, and 4.8 m long masonry wall would be constructed to fill the reinforced concrete framework. Additionally, internal and external cladding in the form of cement-lime and cement plasters with a layer thickness of up to 15 mm was included. Furthermore, the scope of work included electrical and central heating installations, assuming that the cables for both types of installations would be installed on the analyzed wall, and that two electrical sockets and one radiator would be installed on them. The scope of work also included the need to repair the concrete edges on column elements and beams, which could crack and detach within the concrete cover during an earthquake.

Regarding the precise characteristics of the individual life cycle scenarios adopted for the subsequent variants presented in Fig. 1 and for the reference scenario:

- in the reference scenario (variant V0), in which the PUFJ and FRPU systems are not applicable, a maintenance corrective activities in intention strategy was adopted according to which after every 10 years of use an earthquake may occur, causing in extreme cases up to 100% damage to the brick walls; in this variant it was also assumed that up to 100% of the costs for removing rubble after each wall damage and up to 100% of the costs of rebuilding the installations and performing up to 100% of the scope of repair of the concrete edges were to be incurred; the service life of the building in variant V0 is forecasted at 50 years,
- variant V1 assumes the simultaneous execution of a prefabricated PUFJ at 4 joints as an anti-seismic protection system before commencing the construction of the ceramic infill wall; therefore, at the beginning of the building's life cycle, there is a high initial cost for this variant, which, however, reduces the costs that may arise after each earthquake; the effect of using this anti-seismic protection system is to limit to a maximum of 25% material losses associated with wall damage and the costs of removing debris after each wall damage, including the scope of repairing the concrete edges, as well as to limit to no more than 10% the costs of rebuilding the installation; variant V1 is dedicated especially to newly constructed buildings and corresponds to the strategy of preventive actions, and thanks to the use of an effective anti-seismic protection system, the expected service life of the building in this variant is 60 years,
- variants V2 and V3 assume the implementation of PUFJ injection anti-seismic protection at 3 joints after the first occurrence of an earthquake causing damage at a level exceeding 75%; in the variant V2 there is an additional use of FRPU only on the diagonals of the filling, and in the variant V3 – additional use of FRPU on the edges of the filling; the scale of material damage may be limited by this, but only after 10 years of use; wall damage and the cost of removing rubble after each wall damage, including the scope of repairing the concrete edges, are reduced to a level of no more than 15% for the variant V2 and no more than 10% for the variant V3; the costs of rebuilding the installation are, in turn, no more than 5% for both variants (V2 and V3) due to the use of very effective anti-seismic protection systems; both variants mentioned here are dedicated in particular to existing buildings and correspond to both maintenance strategies, i.e. corrective (up to 10 years of use) and preventive (after 10 years of use); the expected service life of the building is 50 years for the variant V2 and 60 years for the variant V3.

All of the life cycle scenarios described above adopt a "cradle-to-grave" approach to decommissioning. According to this approach, a building's decommissioning phase ends after 50 or 60 years with its demolition, followed by the disposal and management of demolition materials.

For the life cycle costing method for all variants of innovative anti-seismic protection systems, the Net Present Value (NPV) method recommended by ISO 15686-5:2017 (ISO 15686-5, 2017) was adopted. According to the recommended method, the net present value (NPV) is the sum of discounted benefits from a given variant of the investment project (or implementation of a building system) reduced by the sum of discounted costs. When only costs

are considered, the NPV can be called the net present cost (NPC). The NPV or NPC is calculated using the following formula (1):

$$X_{NPV(NPC)} = \sum(C_n \cdot q) = \sum_{n=0}^{p} \frac{C_n}{(1+d)^n} \quad (1)$$

where: C_n means cash flow (the difference between benefit and cost) or cost in year, n; q – discount factor; d – expected real discount rate per annum; n – number of years between the base date and the occurrence of the cost; p – period of analysis (lifetime).

Since this example attempts to compare the obtained life cycle cost analysis (LCCA) results with the reference scenario (V0) using a traditional wall system without anti-seismic protection and assumes that the service lives of some variants of anti-seismic protection systems are 60 years instead of 50 years, the analysis also uses the annual cost (AC) indicator. The annual cost (AC) or annual equivalent value (AEV), in accordance with the adopted method according to (ISO 15686-5, 2017), means the annual equivalent value of the investment project costs, taking into account the change in the time value of money in the analyzed period when the service lives of a given variant of the investment project (or implementation of the building system) are different. AC or AEV is calculated according to the following formula (2):

$$X_{AC(AEV)} = \frac{X_{NPC} \cdot d}{1-(1+d)^{-n}} \quad (2)$$

where: X_{NPC} means net present cost; d – expected real discount rate per annum; n – number of years between the base date and the occurrence of the cost.

To perform a life cycle cost analysis (LCCA) using the method and economic indicators recommended by the standard (ISO 15686-5, 2017), the following time and cost parameters were adopted:

- the lifetime of a given building variant (or implementation of a building system) in years as the analysis period (p), after which the costs of decommissioning the building and the costs of disposal and management of demolition materials are calculated,
- the calculation times for subsequent operating costs are assumed to be n-values (the number of years between the base date and the cost occurrence),
- initial costs incurred in the implementation phase of the building immediately before its commencement (C_n in the initial year = 0),
- periodic operating costs (C_n) corresponding to the values of costs incurred during the building's use after n-years,
- withdrawal costs (C_n) accrued after the end of the building's lifetime (p),
- expected real discount rate per year (d).

The time and cost data used in the calculations are presented in Table 1 for all compared variants (V0 and V1-V3). All cost data ($C_{n,0}$, $C_{n,n}$, and $C_{n,p}$) showed in the table include the sum of the costs of labor, purchase of construction materials (including transportation costs), equipment, and indirect costs, along with a calculated profit that takes into account the risk of construction companies able to perform specific scopes of construction and assembly works. To implement the innovative anti-seismic protection system, solutions were adopted based on systems using SIKA® PM materials (a flexible, highly elastic two-component adhesive based on polyurethane resins) for the implementation of prefabricated and injectable PUFJ anti-seismic systems, and SIKA® PS (a solvent-free, flexible two-component adhesive based on polyurethane resins) for FRPU repairs. In the case of prefabricated PUFJ, the costs of prefabrication of a joint with an average cross-section of 20×150 mm were also added, and in the case of injected PUFJ – the costs of preparing cuts and injections around the wall perimeter on three edges of contact with the reinforced concrete frame with a cross-section of approximately 20×100 mm.

Table 1. Data assumed for life cycle costs analysis (LCCA).

Parameter	Variant V0	Variant V1	Variant V2	Variant V3
Type of the innovative anti-seismic protection system application	no anti-seismic protection system applied	prefabricated PUFJ at 4 interfaces	injected PUFJ at 3 interfaces and application of FRPU only at infill diagonals	injected PUFJ at 3 interfaces and application of FRPU at infill diagonals and edges both
Lifetime (p)	50 yrs.	60 yrs.	50 yrs.	60 yrs.

Discount rate (d)		8%	8%	8%	8%
Initial costs ($C_{n,0}$)		1,440.00 €	2,314.00 €	1,440.00 €	1,440.00 €
Periodic operation costs ($C_{n,n}$) after …	10 yrs.	2,010.00 €	445.00 €	3,090.00 €	3,592.00 €
	20 yrs.	2,110.00 €	467.00 €	276.00 €	191.00 €
	30 yrs.	2,215.00 €	490.00 €	290.00 €	200.00 €
	40 yrs.	2,325.00 €	515.00 €	304.00 €	210.00 €
	50 yrs.	not applicable	541.00 €	not applicable	221.00 €
Withdrawal costs ($C_{n,p}$)		404.00 €	425.00 €	404.00 €	425.00 €

With regard to the data values presented in Table 1, it should be added that:

- periodic operating costs ($C_{n,n}$) are calculated over a 10-year period, which corresponds to the assumption that the frequency of earthquakes causing significant material and social losses may range from 9 to 12 years (i.e. 10 years on average),
- withdrawal costs ($C_{n,p}$), as well as part of the periodic operating costs ($C_{n,n}$) related to the removal of debris after any damage to the wall and installations, include the costs of disposal of construction waste, including environmental fees.

In the discussed LCCA example, for each of the defined variants of innovative anti-seismic protection systems (V1-V3) and the reference scenario using a traditional system without anti-seismic protection (V0), values were determined in terms of: net present cost (X_{NPC}) and annual cost (X_{AC}) in euro (€). Table 2 presents the results of the analysis in terms of the values calculated for the X_{NPC} and X_{AC} comparative criteria.

Table 2. Results of life cycle costs analysis (LCCA).

Comparative criterion	Variant V0	Variant V1	Variant V2	Variant V3
X_{NPC}	3,159.00 €	2,704.00 €	2,982.00 €	3,179.00 €
X_{AC}	258.23 €	218.48 €	243.76 €	256.86 €

The life cycle cost analysis showed that:

- the lowest X_{NPC} value was obtained for the variant V1; X_{NPC} = 2,704.00 € which is approximately 14.40% lower than the value calculated for the variant V0 (X_{NPC} = 3,159.00 €),
- the highest X_{NPC} value is 3,179.00 € for the variant V3, which is only approximately 0.63% higher than the value calculated for the variant V0 (X_{NPC} = 3,159.00 €),
- the lowest X_{AC} value was calculated for the variant V1; X_{AC} = 218.48 € which is approximately 15.39% lower than the value calculated for variant V0 (X_{AC} = 258.23 €),
- the highest X_{AC} value is 256.86 € for the V3 variant, which is approximately 0.53% lower than the value calculated for the variant V0 (X_{AC} = 258.23 €).

However, it should be noted that variants V1 and V2 assume a 10-year longer service life for the analyzed building wall equipped with innovative anti-seismic protection systems.

3.2 Example 2 – an integrated investment cost and carbon footprint analysis (LCA) with element of the social life cycle analysis (LCSA)

The second example was dedicated to integrating elements of investment cost analysis and the generated carbon footprint based on selected elements of the works planned for a multi-story car park. The analysis included elements of design for environment (DfE), aimed at proposing design and material solutions that will minimize environmental impact and promote innovative, sustainable solutions. The analysis also included an investment cost assessment element, which, in the decision-making process regarding the selection of an implementation option, allows for determining whether a given option is attractive not only from the perspective of reducing environmental impact by minimizing the carbon footprint, but also from the perspective of the economic viability of the construction project.

The multi-story car park structure was modeled in BIM. The design variants included the following combinations of different solutions for the work elements related to: construction of the reinforced concrete structural elements, layering of the flat roof, and the parking structure's façade:

1. Structural elements made of C20/25 concrete, with perforated aluminum panels for the façade and a green roof in the form of a flower meadow – in this variant, the original concept of the multi-story car park design was retained using ordinary concrete with natural aggregate,
2. Concrete construction elements with fly ash, aluminum mesh for the façade and a green roof allowing for plant cultivation – in this variant, the main focus was on replacing ordinary concrete with a more environmentally friendly concrete with fly ash in order to reduce the cement mass by 30%,
3. Structural elements made of architectural concrete with recycled aggregate, without additional façade and a green roof to reduce the "heat island" effect – in this variant, a solution based on architectural concrete with 30% recycled aggregate content was implemented; the introduction of architectural concrete eliminates the need for an aluminum-based façade.

Table 3 presents information on the costs of the work elements included in the comparative analysis for the design and material variants described above (costs current as of the 4th quarter of 2024). The last column of the table shows a visualization of the multi-story car park from the BIM model.

Table 3. Summary of investment costs of work elements in the analyzed variants.

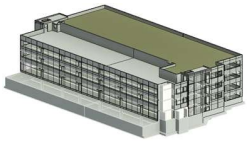
Work elements	Variant 1	Variant 2	Variant 3	Visualization
Reinforced Concrete Structures	261,189.16 €	256,452.82 €	257,919.44 €	
Roof Layering	182,492.79 €	124,165.89 €	148,901.42 €	
Façade	27,235.81 €	68,044.53 €	0.00 €	
Net Total	470,917.76 €	448,663.23 €	406,820.86 €	

Table 4 summarizes the results of the LCA environmental analysis in terms of global warming potential (GWP) for emissions, taking into account initial embodied emissions. The carbon footprint was calculated for the following phases: product A1-A3 (raw material extraction and production, transport to the production plant, and final manufacturing of the product, respectively), construction A4 and A5 (transport to the construction site and installation), and end-of-life C2 and C3 (waste transport and treatment). The analysis omitted the facility's use phase, but included the benefits of waste reuse (recovery, recycling). Based on the GWP value, the social costs of CO_2 emissions were calculated according to the average EU-ETS emission allowance price (67.72 € / [tCO_2]) in force in December 2024.

Table 4. Summary of the GWP value and the social cost of CO_2 emissions in the analyzed variants.

Indicator	Variant 1	Variant 2	Variant 3
GWP [$kgCO_2e$]	245.700	201.960	180.260
The social cost of CO_2 emissions	16,638.80 €	13,676.73 €	12,207.21 €

Based on the obtained results it can be noticed that:

- the cost difference for all work elements between variants 2 and 3 and the original design variant 1 is -22,254.52 € (-4.73%) and -64,096.90 € (-13.61%), respectively,
- the GWP difference between variants 2 and 3 and the original design variant 1 is -43,740 $kgCO_2e$ (-17.80%) and -65,440 $kgCO_2e$ (-26.63%), respectively.

Taking into account both criteria – cost and environmental – it should be concluded that alternative design variants 2 and 3 generate lower (more advantageous) values of the costs of performing the analyzed works and lower values of the carbon footprint corresponding to them, and consequently – lower values of the social cost of CO_2 emissions. The most favorable values for both comparative criteria were obtained for alternative variant 3 (investment cost = 406,820.86 € and GWP = 180,260 $kgCO_2e$, respectively). This is due to the use of architectural concrete with 30% recycled aggregate content for reinforced concrete structural elements, which additionally eliminated the need for an aluminum-based façade, a material that generates high CO_2 emissions.

4. Conclusions

This article presents examples of a life cycle cost analysis (LCCA) and an environmental life cycle analysis (LCA) in terms of the generated carbon footprint (global warming potential – GWP), including the estimation of the value of the equivalent social cost of CO_2 emissions as an element of the social life cycle analysis – LCSA according to the average price of emission allowances in the EU-ETS system. Both examples involved different types of buildings. The first example focuses on selected elements of works in the field of the construction of building with a reinforced concrete frame structure with a brick wall infills, which is exposed to the effects of earthquakes due to its location in a seismic area. The second example concerned a multi-story car park, for which elements of design for the environment (DfE) have been introduced, aimed at proposing design and material solutions that will minimize environmental impact and promote innovative, sustainable solutions.

What both examples presented in the article have in common is the possibility of using BIM models as a source of information on the geometry of building components for the purpose of automatic bill of quantities of works in the cost estimation process, as well as a source of data on project parameters related to the life cycle of building components (e.g. information on the declared service life of components, global warming potential – GWP values in various life cycle phases, or declared material recovery values for the recycling process).

Integrating data stored in the BIM model with information related to Building Lifecycle Management (BLM) elements made it possible to conduct variant analyses in Section 3 of the article. These analyses demonstrated which of the proposed variants was the most advantageous in terms of a given criterion related to the building's life cycle. Example 1 analyzed design variants involving the use of innovative anti-seismic protection systems for brick wall infills in the construction of a building with a reinforced concrete frame structure, considering cost criteria – life cycle costs (LCC) and annual cost (AC) indicators over the brick wall infills' service life of 50 and 60 years. Example 2 analyzed variants of the initial and alternative design solutions to identify the most advantageous design variants, taking into account investment costs and the environmental criterion – global warming potential (GWP).

The integration of BIM technology and Building Lifecycle Management (BLM) significantly supports and accelerates the decision-making process when selecting design options that also address environmental and operational aspects of buildings. It also impacts the quality and accuracy of analyses. According to the authors, key barriers to this development include the lack of interoperable and standardized data exchange frameworks (especially for LCA), as well as the incompleteness of BIM models regarding material and operational data. The authors indicate the directions of further research as validation of dynamic analyses using data from the Internet of Things (IoT), development of model architectures integrating BIM with PLM and FM, and the possibility of conducting empirical cost-benefit analyses for implementations that could accelerate the adoption of BIM technology as a comprehensive tool supporting Building Lifecycle Management (BLM).

References

1. Apollo, M. E., & Grzyl, B. (2023). Aktualny stan wdrożenia BIM w polskich firmach budowlanych. *Materiały Budowlane*, *2*, 28-31. https://doi.org/10.15199/33.2023.02.07
2. Brozovsky, J., Labonnote, N., & Vigren, O. (2024). Digital technologies in architecture, engineering, and construction. *Automation in Construction*, *158*, 105212. https://doi.org/10.1016/j.autcon.2023.105212
3. Hofmann, E., & Rüsch, M. (2017). Industry 4.0 and the current status as well as future prospects on logistics. *Computers in industry*, *89*, 23-34. https://doi.org/10.1016/j.compind.2017.04.002
4. ISO 15686-5:2017 standard "Buildings and constructed assets – Service life planning – Part 5: Life-cycle costing".
5. ISO 19650-1:2018 standard "Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) – Information management using building information modelling – Part 1: Concepts and principles".
6. ISO/IEC 20944-1:2013 standard "Information technology – Metadata Registries Interoperability and Bindings (MDR-IB) – Part 1: Framework, common vocabulary, and common provisions for conformance".
7. ISO/TS 12911:2012 standard "Framework for building information modelling (BIM) guidance".
8. Juszczyk, M., Výskala, M., & Zima, K. (2015). Prospects for the use of BIM in Poland and the Czech Republic–Preliminary research results. *Procedia Engineering*, *123*, 250-259. https://doi.org/10.1016/j.proeng.2015.10.086
9. Kim, K., Kim, H., Kim, W., Kim, C., Kim, J., & Yu, J. (2018). Integration of ifc objects and facility management work information using Semantic Web. *Automation in Construction*, *87*, 173-187. https://doi.org/10.1016/j.autcon.2017.12.019
10. Klungseth, N. J., Nielsen, S. B., Alves da Graça, M. E., & Lavy, S. (2023). Research and evidence-based standards paving the way for a digital and sustainable transformation of the built environment. *Facilities*, *41*(5-6), 454-475. https://doi.org/10.1108/F-06-2022-0088

11. Lai, J., Wan, R., Chong, H. Y., & Liao, X. (2025). Digital Intelligence in Building Lifecycle Management: A Mixed-Methods Approach. *Sustainability*, *17*(11), 5121. https://doi.org/10.3390/su17115121
12. Leśniak, A., Górka, M., & Skrzypczak, I. (2021). Barriers to BIM implementation in architecture, construction, and engineering projects – The polish study. *Energies*, *14*(8), 2090. https://doi.org/10.3390/en14082090
13. Li, L., Yuan, J., Tang, M., Xu, Z., Xu, W., & Cheng, Y. (2021). Developing a BIM-enabled building lifecycle management system for owners: Architecture and case scenario. *Automation in Construction*, *129*, 103814. https://doi.org/10.1016/j.autcon.2021.103814
14. Mangialardi, G., Di Biccari, C., Pascarelli, C., Lazoi, M., & Corallo, A. (2017). BIM and PLM associations in current literature. In *IFIP International Conference on Product Lifecycle Management* (pp. 345-357). Springer, Cham. https://doi.org/10.1007/978-3-319-72905-3_31
15. Mannino, A., Dejaco, M. C., & Re Cecconi, F. (2021). Building information modelling and internet of things integration for facility management—Literature review and future needs. *Applied Sciences*, *11*(7), 3062. https://doi.org/10.3390/app11073062
16. Omrany, H., Al-Obaidi, K. M., Husain, A., & Ghaffarianhoseini, A. (2023). Digital twins in the construction industry: a comprehensive review of current implementations, enabling technologies, and future directions. *Sustainability*, *15*(14), 10908. https://doi.org/10.3390/su151410908
17. Parece, S., Resende, R., & Rato, V. (2025). BIM-based life cycle assessment: A systematic review on automation and decision-making during design. *Building and Environment*, 113248. https://doi.org/10.1016/j.buildenv.2025.113248
18. Petri, I., Amin, A., Ghoroghi, A., Hodorog, A., & Rezgui, Y. (2025). Digital twins for dynamic life cycle assessment in the built environment. *Science of The Total Environment*, *993*, 179930. https://doi.org/10.1016/j.scitotenv.2025.179930
19. Skrzypczak, I., Oleniacz, G., Leśniak, A., Zima, K., Mrówczyńska, M., & Kazak, J. K. (2022). Scan-to-BIM method in construction: assessment of the 3D buildings model accuracy in terms inventory measurements. *Building Research & Information*, *50*(8), 859-880. https://doi.org/10.1080/09613218.2021.2011703
20. The National BIM Standard – United States, Version 4.
21. Tosi, J., Marzio, S., Poggi, F., Avgoustaki, D., Esteves, L., & Amado, M. (2025). Environmental Benefits of Digital Integration in the Built Environment: A Systematic Literature Review of Building Information Modelling–Life Cycle Assessment Practices. *Buildings*, *15*(17), 3157. https://doi.org/10.3390/buildings15173157
22. Ustinovičius, L., Rasiulis, R., Nazarko, L., Vilutienė, T., & Reizgevicius, M. (2015). Innovative research projects in the field of building lifecycle management. *Procedia Engineering*, *122*, 166-171. https://doi.org/10.1016/j.proeng.2015.10.021
23. Wang, H., & Meng, X. (2019). Transformation from IT-based knowledge management into BIM-supported knowledge management: A literature review. *Expert Systems with Applications*, *121*, 170-187. https://doi.org/10.1016/j.eswa.2018.12.017
24. Zhang, S., Tang, Y., Zou, Y., Yang, H., Chen, Y., & Liang, J. (2024). Optimization of architectural design and construction with integrated BIM and PLM methodologies. *Scientific Reports*, *14*(1), 26153. https://doi.org/10.1038/s41598-024-75940-x
25. Zima, K., Plebankiewicz, E., & Wieczorek, D. (2020). A SWOT analysis of the use of BIM technology in the polish construction industry. *Buildings*, *10*(1), 16. https://doi.org/10.3390/buildings10010016