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

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Introduction

The architecture, engineering, and construction (AEC) industry, and the facility management (FM) industry, are 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)

Literature Review

Many researchers (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

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Research Objectives

Main goals of the article:

- to present the results of selected life cycle analyses – (i) a life cycle cost analysis (LCCA), (ii) an environmental life cycle analysis (LCA) in terms of the generated carbon footprint (global warming potential – GWP)
- to present that integration of BIM technology with the principle of product lifecycle thinking (PLT), and specifically Building Lifecycle Management (BLM) provides the opportunity to optimize (limiting) the impact of various processes during the long-term operation of buildings and other engineering structures

Methodology

Table: A detailed comparison of the processes employed for quantity calculation, life cycle analysis and facility management

Stage/task	BIM dimension	Traditional method – process description and artefacts	BIM method – process description and artefacts	Added value in the case of BIM
Take-off and cost estimate (LCCA	BIM 5D	manual measurements, MS Excel, price sources	automatic compilation from 5D, linked costs and fees	aprox. 75% time reduction; reduced number of incorrect items
LCA – GWP calculation	BIM 6D	manual mapping (database)	automatic mapping with BIM and EPD (Environmental Product Declaration)	better traceability, faster scenarios
Operation / O&M	BIM 7D	paper manuals, scattered documents	7D: asset ID – manual, schedule	faster operation, lower risk of errors

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Methodology

LCCA (NPV – Net Present Value method recommended by ISO 15686-5:2017):

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

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)

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

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

EXAMPLE 1 – innovative anti-seismic protection systems		EXAMPLE 2 – selected elements of the works planned for a multi-story car park
☑	initial costs	☑
☑	operating costs (replacement costs)	☒
☑	end-of-life costs (disposal and decommissioning)	☒

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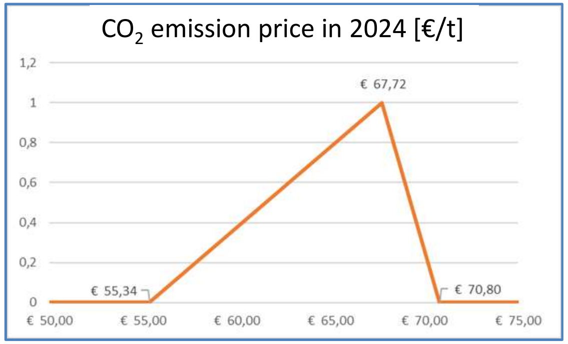
Methodology

LCA (GWP – global warming potential, taking into account initial embodied emissions):

$$\text{Embodied tCO}_2\text{e} = \sum_{i=0}^{n} (Qm_i \cdot Ef_i)$$

where: Qm_i means quantity of material [per unit];
Ef_i – Embodied tCO2e per unit of material factor

LCSA (social costs of CO_2 emissions calculated according to the average EU-ETS emission allowance price)



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Analysis – Example 1

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

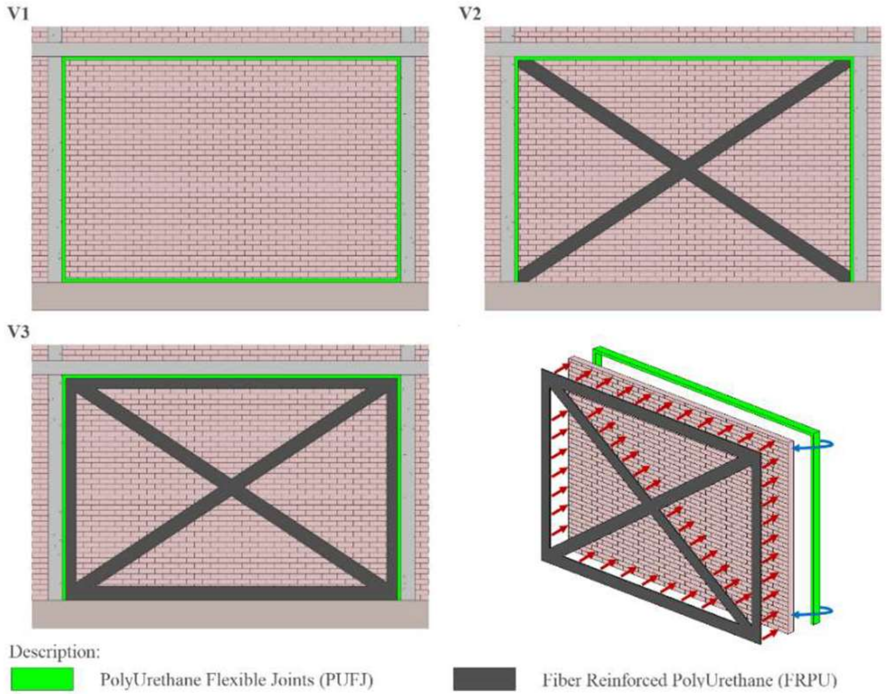

Figure: Innovative anti-seismic protection systems (views of parts of reinforced concrete frames and brick walls modeled in the Autodesk Revit): V1 – prefabricated PUFJ at 4 interfaces; V2 – injected PUFJ at 3 interfaces and application of FRPU at infill diagonals; V3 – injected PUFJ at 3 interfaces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

Analysis – Example 1

Table: 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 €

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frequency of earthquakes, which can cause 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

Results – Example 1

Table: 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 €)

Results – Example 1

Table: 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_{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 €)

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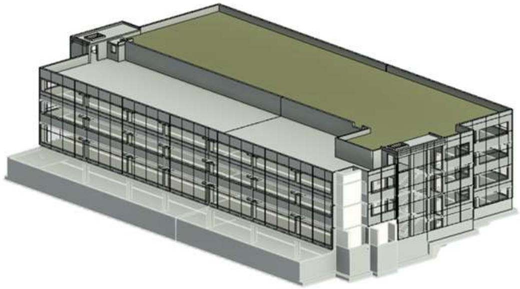
Analysis – Example 2

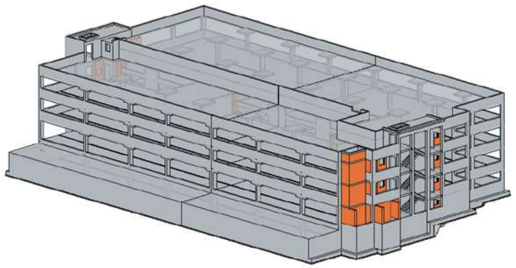
An integrated investment cost and carbon footprint analysis (LCA) with element of the social life cycle analysis (LCSA) based on selected elements of the works planned for a multi-story car park

The design variants were combinations of different solutions for the elements of works related to the execution:

- reinforced concrete structural elements in the facility
- layering of the flat roof
- parking facade



model variant

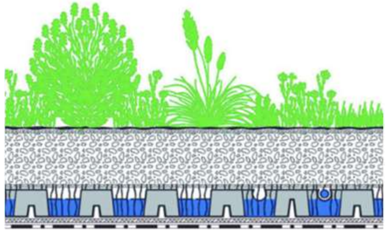


construction model

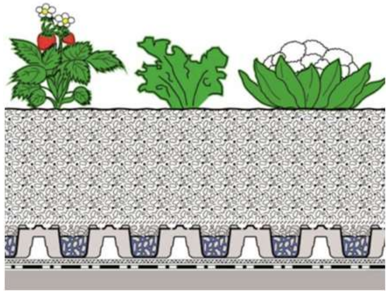
Analysis – Example 2

Design variants characteristics:

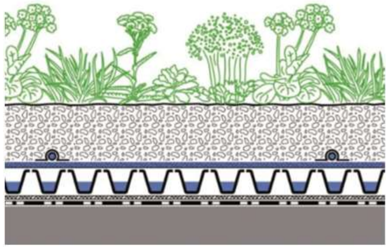
- structural elements made of C20/25 concrete, with perforated aluminum panels for the facade and a green roof in the form of a flower meadow - in this variant the original concept of the multi-story car park design was retained using ordinary concrete with natural aggregate



- structural elements made of concrete with the addition of fly ash, with an aluminum mesh for the facade and a green roof allowing for the cultivation of plants – in this variant, ordinary concrete was replaced with a more environmentally friendly concrete with the addition of fly ash to reduce the cement mass by 30%



- structural elements made of architectural concrete with recycled aggregate, without additional facade 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 use of architectural concrete eliminates the need for an aluminum-based facade

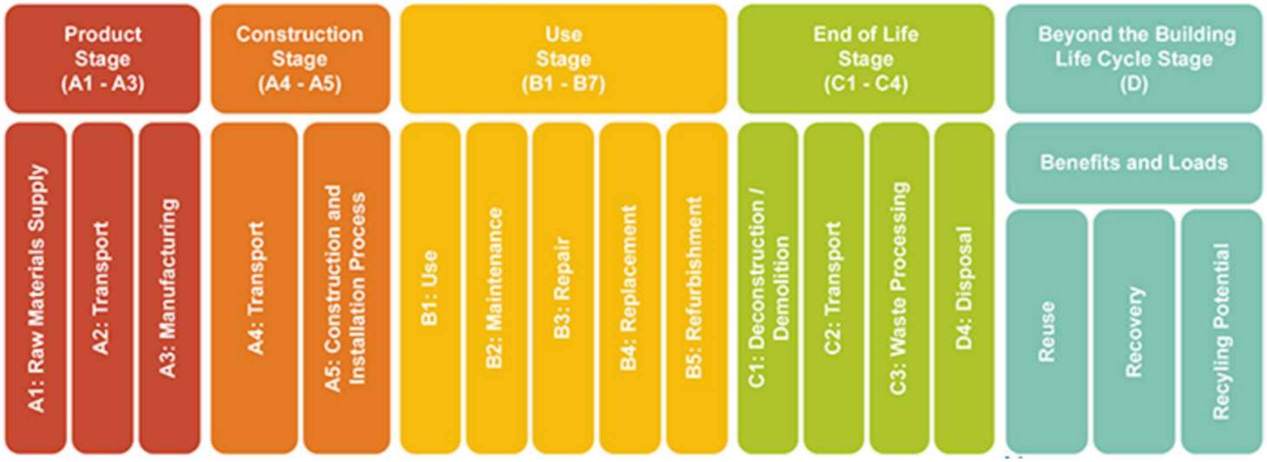


Analysis – Example 2

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)
- 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)



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Results – Example 2

Table: Summary of investment costs of work elements in the analyzed variants

Work elements	Variant 1	Variant 2	Variant 3
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 €

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

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Results – Example 2

Table: Summary of investment costs of work elements 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 *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] alternative design variants 2 and 3 generate lower 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 criteria were obtained for alternative variant 3 (investment cost = 406,820.86 € and *GWP* = 180,260 kgCO_2e, respectively)

Conclusions

The 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

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Conclusions

Both examples showed 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)

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Conclusions

Integrating data stored in the BIM model with information related to Building Lifecycle Management (BLM) elements:

- made it possible to conduct variant analyses; the analyses demonstrated which of the proposed variants was the most advantageous in terms of a given criterion related to the building's life cycle
- significantly supports and accelerates the decision-making process when selecting design options that also address environmental and operational aspects of buildings

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Conclusions

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

Recommendation for Future Research

Directions of further research:

- validation of dynamic analyses using data from IoT
- development of model architectures integrating BIM with PLM and FM
- 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)

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Thank you

For any questions, please contact

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