Ybl Journal of Built Environment, Volume 10. Issue 1. (2025)
10.12700/jbe-2025-0013

BUILDING DESIGN IN THE CONSTRUCTION INDUSTRY: COMPLEX ANALYSIS OF LOW-ENERGY BUILDINGS

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Abstract*: Global warming and the rise in the average temperature of the Earth's atmosphere is caused by excessive greenhouse gas emissions that the planet's biocapacity can no longer absorb. The continuously increasing population and improving living standards require more and more resources that nature can't provide in the long term. A conscious and green approach is urgently needed in all areas. A significant share of energy use and carbon emission is linked to the construction industry, with the amount of energy needed to build, maintain and operate buildings being very high, accounting for 40% of the global energy consumption. In addition to the energy efficient operation of buildings, a complex mindset and design methods are needed in order to reduce the energy and raw material usage in construction phase as well [1].*

Keywords*: energy efficient architectural design, passive house, material optimization, BIM-LCA integration*

1. INTRODUCTION

In addition to the energy used for heating and cooling buildings, a significant amount of CO_2 is emitted during the production of construction materials. Due to the carbon-intensive nature of material manufacturing, half of a building's total CO_2 emissions are already realized before it is even occupied. By 2050, it is expected that nearly 50% of the total carbon footprint of new buildings will be attributed to the embodied carbon in construction materials. In the design of a low-energy average family house, we sought to answer the question of how the choice of structural materials affects the life-cycle CO2 emissions of the building. In addition to examining the impact of different materials, we also looked at the proportion of typical construction elements. Construction-, energy- and whole life cycle-analysis was carried out as well in addition to the comprehensive summary of the methodological research required for the study.

2. LIFE CYCLE ASSESSMENT METHODOLOGY, FRAMEWORK AND STEPS

The framework for LCA in the construction industry is EN15978, which provides guidance on all aspects of the analysis. According to the standard, the life cycle of construction products and buildings can be divided into four (4) main phases [2]:
- A1-A3 Product stage: It includes the extraction, transport and manufacturing processes of raw materials, including energy flows and emissions.
- A4-A5 Construction process: The process of transporting construction products to site and construction, including energy and waste generation.
- B1-B7 Use: Covers the use of the building/construction product, maintenance, repair, replacement, renovation. During the lifetime of the building (50 years), these operations are repeated at certain intervals (5, 10, 15 years). During the use phase, the energy and water consumption required for operation represents a significant environmental burden. Achieving net zero energy buildings is a major challenge for the sector.
- C1-C4 End of life phase: Includes demolition, transport, waste treatment and landfilling. This phase involves dust pollution and noise. In order to reduce environmental impacts, selective separation of dismantled materials, on-site shredding operations contribute to recycling and minimize landfilling.

- D Beyond the life-cycle of the building: the phase of benefits and loads outside the life-cycle of the product, outside the system boundary, which is recycling, use or energy recovery. This stage offers new opportunities for innovation in circular solutions. There are potential benefits if waste avoidance is targeted at the design stage.
According to the EN15978 standard, LCA analysis is performed in the following steps [3,4] :

- Definition of the purpose of the analysis: the purpose and scope of the analysis are defined.
- Scope of analysis: identification of the physical model of the building.
- Scenarios for the life cycle of the building: different scenarios, e.g. no renovation, partial renovation or demolition and new construction are considered
- Determination of material quantities: preparation of a material balance for the building using databases or models.
- Gathering environmental data: obtaining environmental data, which can be from general data sources or independently verified product data (e.g. EPDs). The reliability of the data greatly influences the accuracy of the LCA analysis.
- Calculate environmental impacts
- Report and data analysis

Two main factors determine the accuracy of the results of the analysis:

- The quantities and types of materials included in the building material inventory.
- The quality of the environmental data.

In the building industry, LCA is used not only for product development, but also for the preparation of Environmental Product Declarations (EPDs) and as part of building sustainability schemes such as LEED and DGNB assessments.

2.1. BIM model-based design options

BIM (Building Information Modelling)-based modelling is playing an increasingly important role in the application of efficient design and construction methods today, partly due to the turbulence in the construction industry caused by the growing population and partly due to increasing project complexity. In addition to improving the efficiency of the design, construction and operation processes, BIM-based modelling can also be used to manage the entire life cycle of a building.

The Lechner Knowledge Centre's BIM Handbook defines BIM as "a set of CAD-based design methods and guidelines that allows the actors involved in the construction and operation of buildings (builders, designers, contractors, operators) to collaborate and share information in a realistic virtual space and to visualize relevant data quickly" [5]. This model details all the elements of the building, making it easier for project participants to get to know and understand the building before it is built. A key difference between BIM and traditional 3D modelling is that the BIM model adds a wealth of information. This information determines how widely and in what detail the model can be used later. BIM modelling also allows the professionals involved in the project to share and upload data from their own domains, helping to refine the overall model.

A BIM model can help to understand the energy performance of a building, thus supporting energy efficient design. For example, the model allows the analysis of orientation, structural solutions and installed materials, helping to make optimal energy choices during the design process.

2.2. Integration of BIM-based design and LCA (Life Cycle Assessment)

Data exchange between different software is efficient if it is done without data loss. One of the best tools for ensuring interoperability is the IFC file format, which can transfer geometry and data from model elements to other software with minimal data loss. The increasing importance of full life cycle environmental impact assessment of buildings has led to a growing need for Life Cycle Assessment (LCA) to be carried out at an early stage of design. There are various LCA-BIM integration strategies that focus on practical usability. The levels of integration range from semi-manual methods to specialized LCA software linked to BIM software, where manual data input is minimal.

LCA-BIM integration steps:

- Modelling: building the BIM model with building geometry and related information.
- Quantity survey: Based on the BIM model, a list of elements and materials with the corresponding quantities is prepared.
- LCA Profiling: Determine the environmental impact of the materials used in the model using LCA profiles.

- Assigning a profile: the quantities of materials are linked to the corresponding LCA profiles.
- Calculate environmental impacts: calculate environmental impacts based on the LCA data assigned to the material quantities.
- Visualization and analysis: visualization and analysis of the results of the LCA calculation.

The integration of BIM and LCA provides the opportunity to consider environmental impacts at an early stage of design and to make decisions taking into account sustainability aspects, this supports the design of energy efficient and sustainable buildings [6,7,8,9,10].

2.3. Possible integration methods for BIM and LCA

Two basic integration methods can be highlighted: in the first one, the geometric and material data extracted from the BIM model are imported into a dedicated LCA software, where the LCA calculations are performed. The information from the BIM model is therefore processed by a dedicated LCA software. In the second, the LCA data is already integrated into the BIM model and the LCA calculations are performed directly within the BIM software using a plugin. For example, the One Click LCA plugin for Archicad or the Tally plugin for Revit can be used for this purpose. The integration of LCA and BIM allows the environmental impact of the planned construction materials to be quantified at an early stage of construction projects. The analysis allows necessary changes to be made at an early stage of the design process and allows comparisons to be made between different design alternatives in terms of environmental impact.

2.4. Low energy residential building survey, basic building structure data

A single dwelling masonry system, high and flat roofed, ground floor plus one storey design, with an unroofed 120 m2 of usable floor area was investigated. The building can be divided into 2 parts: a living area and a building unit for garage and storage. Unlike the living area, the garage unit is not heated, only temperature-controlled. The facade is rendered and the roof is covered with ceramic tiles.

The aim is to create a low-energy building with a low environmental impact, which requires a complex approach, the energy performance analysis alone is not sufficient, and the choice of materials should be based on monitoring the amount of energy input into the building.

The foundation of the building is a slab of gravel below the main walls down to the load-bearing soil or frost line. Leier-type concrete formwork plinth walls are made of infill concrete and reinforced concrete, over which a reinforced substrate and insulated floor construction are applied.

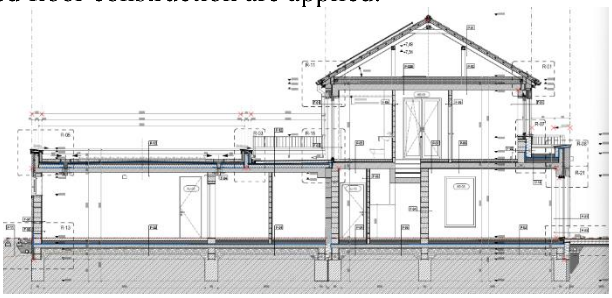

Figure 1. Architect's section [11]

22 cm of thermal insulation is applied to the wall structure in the living area, 20 cm of thermal insulation in the plinth zone, and 6 cm of insulation in the garage building unit. The facade windows are insulated, modern windows with 3 layers of insulating glazing.

The building's windows are designed to minimize thermal bridging, positioned on the outer plane of the external load-bearing calcium silicate masonry units, directly behind the facade insulation. PIR foam insulation will be installed between the envelope and the outrigger structures. The gable roof attic is unheated and the insulation lines run in line with the attic slab. The attic is ventilated along the eaves line, the ventilation tiles and the ridge frame. A ventilated air gap shall be formed between the counter-batten. The thermal insulation is applied to the attic slab.

The building will have a non-accessible terrace, an accessible flat roof with a granite slab cladding, a green roof and a balcony opening from the upstairs corridor. The slab roof is a straight-layer internal drainage slab roof, the thermal insulation is 12 cm PIR foam insulation, the slope layer is a variable thickness of 2% slope expanded polystyrene foam. The waterproofing is made of FPO sheet, on which the layers of the walkable and green roof are placed.

In the study, the BIM model of the building was created in Archicad version 27, the multi-layered wall and floor structures were created as composite modelling elements, while the composites themselves were defined separately in the "Composites" menu.

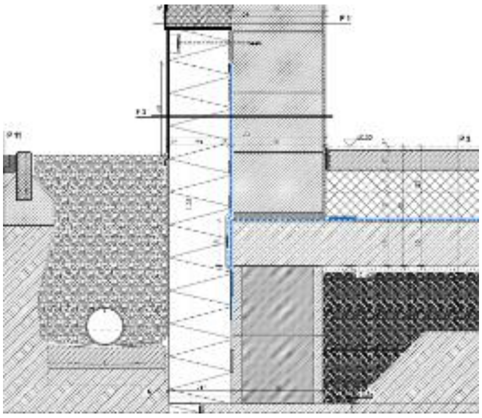

Figure 2. Building construction details, Plinth design [11]

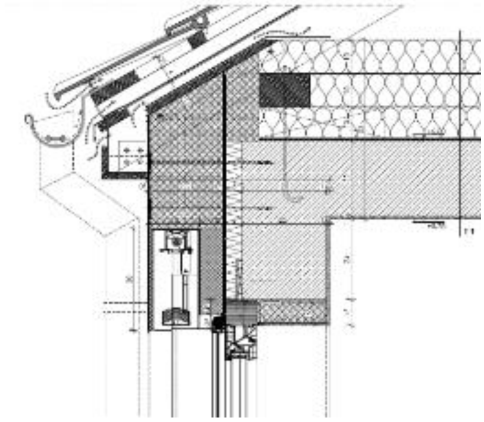

Figure 3. Building construction details, Eaves design [11]

2.5. Energy analysis and results

The energy performance of buildings is regulated by the Decree 9/2023 (25.V.) of the Ministry of Economic Affairs and Labor of the Republic of Hungary "On the Determination of the Energy Performance of Buildings". [12] Compliance with the energy parameters and heat transfer coefficients for the boundary structures is mandatory, and the choice of layered structures and thermal insulation is accordingly. When determining the heating demand of the building, the energy analysis is performed with 22 cm of mineral wool insulation. The mechanical installations are designed with electric air-source heat pumps, surface heat exchangers, underfloor, wall and ceiling heating.

The building's energy sizing is the most important feature:

- Overall energy performance: 62.98 kWh/m^2 Reference value: 95.00 kWh/m^{2}a
- Total energy performance requirement: 76.00 kWh/m^2
- Cumulative energy performance rating: A+ 2023 (82.9 %)
- Specific carbon dioxide emissions: 13.06 kg/m2a Reference value: 25.00 kg/m^{2}a
- Specific carbon dioxide emissions class: A+ 2023 (65.3 %).

2.6. Life cycle (LCA) analysis steps and results

The Bill of Quantities (BOQ) is extracted from the BIM model in tabular form and imported into the LCA software. LCA calculations and analysis are performed in the LCA software. This is a basic form of integration, where the BIM model provides the quantitative data, but the calculations are performed by independent LCA software. The integration of LCA and BIM allows to quantify the environmental impact of the planned construction materials at an early stage of the construction project. The analysis provides an opportunity in the early phase of planning to make different design alternatives comparable in terms of their environmental impacts. BIM-LCA model integration is important at the permit design and construction design stages, as this is when the most detailed information about the future building is available and provides the greatest opportunity to apply the technology [6,7,8,9,10].

According to EN15978, the steps of the analysis can be summarized as follows [2]:

- Purpose of analysis: the purpose is to determine the best combination of possible wall structures based on the environmental impacts.
- Subject of analysis: low-energy residential building, for a building model created with Archicad 27 software. The analysis is carried out in relation to the thermal insulation and wall construction type that can be applied on the wall structures.
- Scenarios for the building structure: Establishing various wall, slab, and partition wall structure scenarios for analytical purposes.

Scenarios	Wall Structure	Type of Thermal Insulation	Slab Structure	Partition Walls
1	Lime mortar brick masonry	Expanded polystyrene foam	Reinforced concrete slab	Silicate masonry
2	Lime mortar brick masonry	Mineral insulation panel (Multipor)	Reinforced concrete slab	Silicate masonry
3	Lime mortar brick masonry	Mineral wool	Reinforced concrete slab	Silicate masonry
4	CLT (Cross-Laminated Timber) wall construction	Expanded polystyrene foam	CLT panel slab	CLT panel walls
5	CLT wall construction	Mineral insulation panel (Multipor)	CLT panel slab	CLT panel walls
6	CLT wall construction	Mineral wool	CLT panel slab	CLT panel walls

Table 1: Examined wall, slab, and partition wall structure scenarios

- Determining quantities: quantities can be imported into the software using the BOQ (Bill of Quantities)
- Environmental data collection: the required data can be assigned to the construction materials used from the One Click LCA database
- Quantifying environmental impacts: the calculations are made using One Click LCA.
- Report preparation: the analysis was carried out using One Click LCA, a web-based automated program that can be used to calculate and reduce the environmental impacts of buildings, the materials can be imported into the software manually or in different formats (Excel, Revit, IFC, gbXML, etc.). The analysis used data from the world's largest EPD database, global and manufacturer specific information, verified EPDs. One Click LCA automatically prepares the results for publication.

Carbon-dioxide from built-in materials is calculated as global warming potential (GWP) and expressed in carbon-dioxide equivalent units (CO2e). Global warming potential (GWP) is defined as "an index measuring the radiative forcing of the emission of a substance per unit mass of a given substance over a chosen time horizon relative to the emission of the reference substance, carbon dioxide (CO2)". GWP thus represents the combined effect of the different residence times of substances in the atmosphere and their effectiveness in causing radiative forcing.

The study focuses on building structures, assessing the impact of facade insulation and wall materials. The energy demand of the operation is not considered in the comparative LCA calculation due to its stationarity [13,14].

What makes the LCA analysis reliable is the accuracy of the EPDs associated with each material, the One Click database contains a large number of EPDs, the selection of the right EPD is a research effort.

Comparative analysis of different materials

In order to meet the energy performance requirements, 22 cm of thermal insulation is applied to the main building walls, and 6 cm of insulation to the garage building unit. The total amount of facade insulation applied to the building is 55 m3. In the evaluated scenarios, the thickness of the thermal insulation — and consequently the volume of material applied — was kept constant to ensure comparability of environmental impacts across different insulation types. The results obtained within the A1-A3 as and C1-C4 as system boundaries, i.e. the energy required for the production of the material and the end-of-life waste management, are compared for 3 types of insulation, the insulation types tested being: 1. mineral wool, 2. expanded polystyrene foam, 3. Multipor insulation board.

Within the A1–A3 product stage, mineral-based insulation materials exhibit the highest environmental impact when comparing equivalent insulation volumes. However, when the analysis is extended to include the transportation (A4) and end-of-life stages (C1–C3), expanded polystyrene foam insulation emerges as the least favorable option, while Multipor insulation proves to be the most environmentally advantageous.

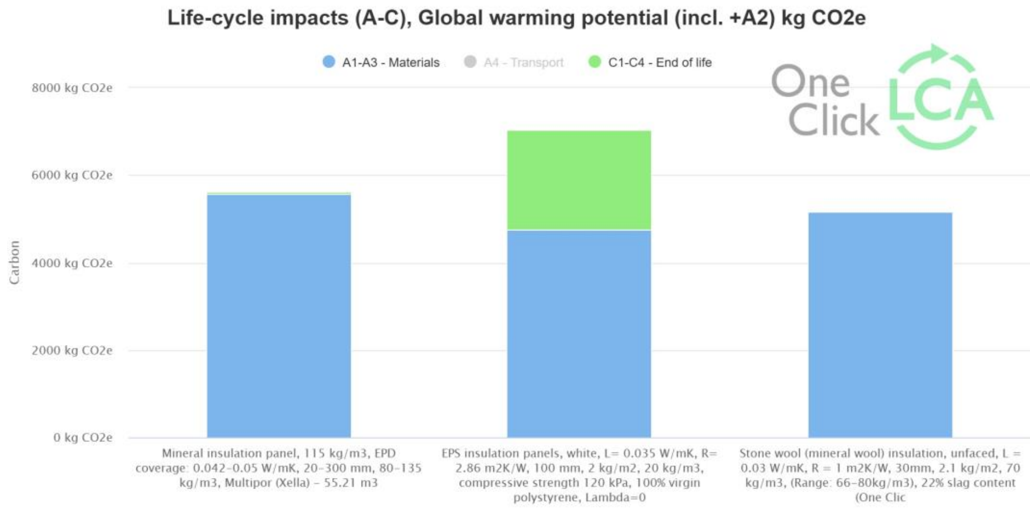

Figure 4. Elevation potential of facades (Multipor, EPS, mineral wool) thermal insulation in stages A-C of the life cycle [16]

Type of thermal insulation materials	System boundaries		
	A1-A3	A4	A5
	Material	Transport	Production
	[kg CO2e]		
Mineral insulation panel, 115 kg/m^3, EPD coverage: 0.042-0.05 W/mK, 20-300 mm, 80-135 kg/m^3, Multipor (Xella) - 55.21 m^3	5576,21	14,5875269	35,087385
EPS insulation panels, white, L= 0.035 W/mK, R= 2.86 m2K/W, 100 mm, 2 kg/m^2, 20 kg/m^3, compressive strength 120 kPa, 100% virgin polystyrene, Lambda=0.035 W/(m.K) (One Click LCA) - 55.21 m^3	4757,972	18,1815	2284,805
Stone wool (mineral wool) insulation, unfaced, L = 0.03 W/mK, R = 1 m^{2}K/W, 30mm, 2.1 kg/m^2, 70 kg/m^3, (Range: 66-80kg/m^3), 22% slag content (One Click LCA) - 55.21 m^3	5176,713	8,8793	21,357

Table 2. Global warming potential of thermal insulation of facades (Multipor, EPS, mineral wool) examined in stages “A” of the life cycle [15]

Comparative analysis of load-bearing wall structures of different materials

The use of materials for the wall construction is investigated with 2 different scenarios, in the first case the building is 30 cm thick masonry, the measure of material used is 89 m3, in the second case the wall construction is CLT (Cross Laminated Timber), a laminated glued wall panel with a thickness of 10 cm, the material used is 36 m3. The graph below is based on the Global Warming Potential (GWP) for comparison, the graph gives quantified data for 1 m3 of material within the A1-A3 and C1-C4 system boundaries.

Types of wall structures	**System boundaries**	
	A1-A3	A5
	Material	Production
	kg CO2e	
Ready-mix concrete, generic, C20/25 (2900/3600 PSI), XC1, 25% GGBS in cement, CEM II/B-S portland-slag cement, 2373 kg/m^3 (One Click LCA (2024)) - 1.0 m3	288,1461	7,7645
Cross laminated timber (CLT), 481 kg/m^3, 12% (± 3%) moisture content (One Click LCA) - 1.0 m^3	151,0201	8,0261
Calcium silicate block, 240x115x52-998x365x623 mm, 1000-2400 kg/m^3, Silka (Xella) - 1.0 m^3	181,3665	5,8897

Table 3. Global warming potential of wall structures (CLT, brick, concrete) tested at stages A1-A3-A5 of the life cycle, without A4 section [16]

Results of the whole building test

To compare the different construction methods, two Archicad models and material databases need to be created, the brick and reinforced concrete building is constructed with reinforced concrete slab structure, the CLT panel building is also constructed with CLT material for the wall and slab structure. The quality of the foundation, the flat roof insulation system and high roof design, the quality of the windows and the cladding are all the same and therefore not relevant for the assessment.

The report provides quantified data for the six scenarios analyzed, with the comparison based on the Global Warming Potential (GWP) within the system boundaries of A1-A5, in relation to the building.

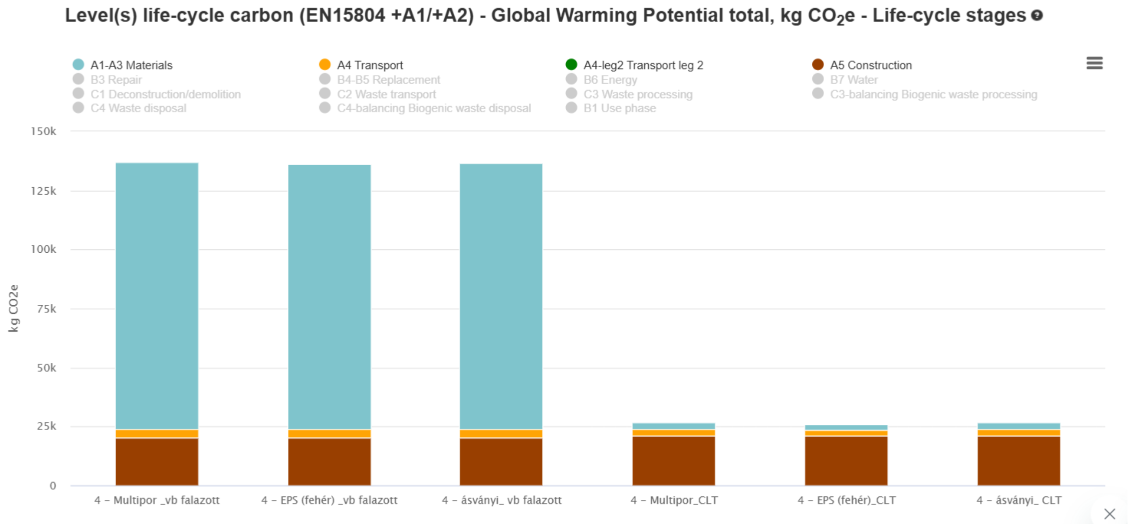

Figure 5. Global warming potential of facade laminated masonry structures at life cycle stages A1-A5 [16]

In the statement, the operational phase is not taken into account, as the energy used for operation is almost the same in all cases and is not an integral part of the study.

For the "A5" section, only the general construction data - defined by the One Click program - is taken into account, which only shows the correct value in terms of magnitude compared to the other sections, and is not based on concrete data. For CLT panels and other timber structures, we can talk about negative CO2 emissions in stage A, as the organic material captures and stores CO2 until the end of its life cycle. However, the same amount is also released in the C3 stage, so both values can be considered as zero from the perspective of GWP, which is why this data is also not included in the statement. The main difference is in stages A1-A3: the production of reinforced concrete and masonry elements causes the highest environmental load, much higher than timber structures. In comparison, the quality of the thermal insulation has less impact on the overall GWP of the building. Big differences can therefore be achieved in the choice of the basic structural design. The choice of the type of thermal insulation in addition to the appropriate energy design also influences the amount of GHG emissions, but to a significantly lesser extent than the development of a more favorable structural design concept.

Type of wall construction	**System boundaries**		
	A1-A3	A4	A5
	Raw material	Transport	Manufacturing
	[kg CO2e]		
Multipor thermal insulation and brick masonry	113011,8467	3798,720008	20267,73331
Expanded polystyrene thermal insulation and brick masonry	112193,6903	3802,314162	20100,11129
Mineral wool thermal insulation and brick masonry	112617,4444	3793,011646	20234,62599
Multipor thermal insulation and CLT masonry	2953,819077	2627,842973	21107,34614
Expanded polystyrene foam insulation and CLT masonry	2420,571415	2631,437127	20951,12047
Mineral wool thermal insulation and CLT masonry	3086,497811	2622,134611	21116,4053

Table 4. Heating potential of facade laminated masonry structures tested in life cycle stages A1-A5

Based on the results obtained from examining the CO2 distribution associated with the building's structures, the main structural system, foundation, vertical and horizontal load-bearing structures, masonry, and slab structures are the most significant factors. The environmental impact of internal partitions, the roof structure, doors and windows, and specialized construction elements is significantly smaller. For heavy structures, the wall structures account for 18-19% of the total emissions, while for CLT structures, they contribute 8-9%.

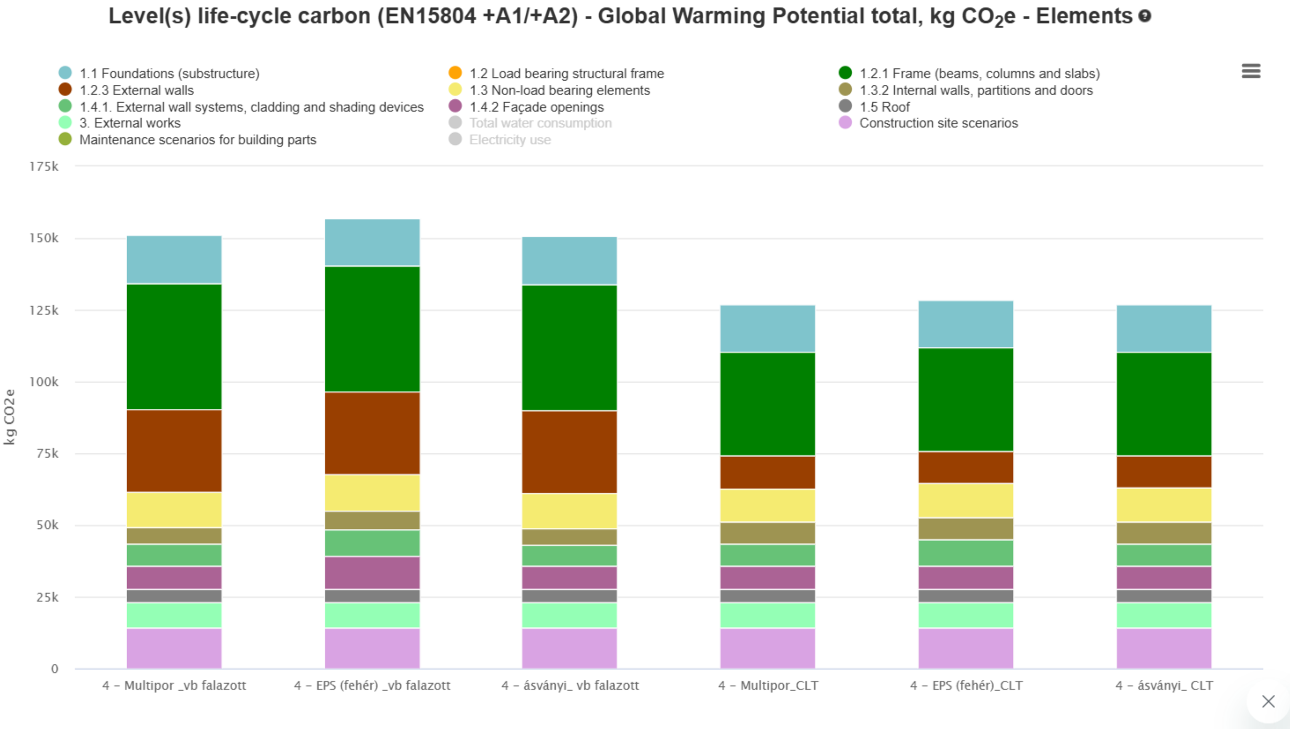

Figure 6. Heating potential of building structures adjacent to a building, tested in life cycle stages A1-A5 [16]

3. CONCLUSION

As a result of the methodological analysis of the possibilities of a complex life cycle assessment of a building, it was concluded that the BIM model and LCA One Click built in Archicad are suitable for integration. Due to the model-based construction of the building designed in Archicad software, an accurate statement of the quantity of construction products was obtained, and the quantified data can be integrated into One Click software. The software uses an internal database, the accuracy of the environmental data quality of the material quantities and material types in the building material statement affects the final calculation, therefore the accurate determination of the quantity and type of building products requires careful work. The building under consideration is a low-energy building, the mechanical systems are designed with electric air source heat pumps, surface heat exchangers, underfloor, wall and ceiling heating, and the current regulatory classification is A+. In addition to the energy analysis, a life-cycle assessment was carried out to quantify the environmental impacts associated with the choice of materials for the structures. The results of the study show that the environmental impact of the materials used in the design of the foundations, wall and slab construction is the most significant, and that the most rapid reduction in the CO2 load of the building can be achieved by the environmentally responsible choice of the materials used in the design of the building products. Without replacing the foundation system, the CLT wall and slab construction, together with the use of Multipor insulation on the walls, provided the most favorable solution for the vertical and horizontal support system.

The results of the study confirmed the hypothesis that a material-efficient design approach combined with the use of low environmental impact building materials contributes most significantly to achieving favorable ecological indicators. The application of modular or prefabricated lightweight structural elements enables not only material savings but also faster construction processes. Lightweight floors and walls have lower self-weight and reduced material demand compared to traditional heavy structures. In the case of lightweight construction technologies, material-efficient foundation solutions—such as ground screws—can also be applied, which significantly reduce concrete use and construction time.

REFERENCES

[1] **Boehm, S., et al.** (2023). *State of Climate Action 2023*. Systems Change Lab, pp. 4–5.
[2] EN 15978. *Sustainability of construction works – Assessment of environmental performance of buildings*.

[3] Építésügyi Minőségellenőrző Innovációs Nonprofit Kft. (2022). *Possible Methods and Evaluation Criteria of Life Cycle Assessment* (in Hungarian), ÉPMI 10_2022, v1_2022.09.16.
[4] **Kotaji, S., Schuurmans, A., & Edwards, S.** (2003). *Life-Cycle Assessment in Building and Construction: A State-of-the-Art Report*. SETAC.
[5] **Zagorácz, M., & Szabó, B. (**n.d.). *BIM Handbook Vol. 1: Introduction to Building Information Modelling* (in Hungarian). Lechner Knowledge Center.
[6] **Wastiels, L., & Decuypere, R. (**2019). Identification and comparison of LCA-BIM integration strategies. *IOP Conference Series: Earth and Environmental Science, 323*, 012101.
[7] **Shadram, F., Johansson, T. D., Lu, W., Schade, J., & Olofsson, T. (**2016). An integrated BIM-based framework for minimizing embodied energy during building design. *Energy and Buildings, 128*, 592–604.
[8] **Llatas, C., Soust-Verdaguer, B., & Passer, A**. (n.d.). Implementing life cycle sustainability assessment during design stages in Building Information Modelling: From systematic literature review to a methodological approach. *Journal of Building Engineering* (if published, please update with year and volume), 2020. https://doi.org/10.1016/j.buildenv.2020.107164
[9] **Jrade, A., & Abdulla, R**. (2012). Integrating Building Information Modeling and Life-Cycle Assessment Tools to Design Sustainable Buildings. In Proceedings of the 29th International Conference of CIB W78 (pp. 173–182). Beirut, Lebanon. ISSN 2706-6568.
[10] **Nagy, M. M., Szalay, Zs., & Nagy, B.** (2020). *Environmentally Conscious Building Renovation Using BIM Technologies* (in Hungarian). Budapest University of Technology and Economics, Department of Construction Materials and Technologies, TDK.
[11] **Szecskő, H**. (2024). *Execution Plan of a Family House – Structural Design Documents* (in Hungarian).
[12] 9/2023. (V. 25.) ÉKM decree on the determination of the energy performance of buildings (in Hungarian).
[13] One Click LCA. (2018). *The Embodied Carbon Review: Embodied Carbon Reduction in 100+ Regulations & Rating Systems Globally*. Retrieved from https://oneclicklca.com/resources/ebooks/the-embodied-carbon-review (Accessed: 20 Nov. 2023).
[14] One Click LCA. (2018). *The Embodied Carbon Review: Embodied Carbon Reduction in 100+ Regulations & Rating Systems Globally* (Accessed: 20 Nov. 2023).
[15] One Click LCA. *Product Carbon Footprint*. https://oneclicklca.com (accessed: 11.2024).
[16] One Click LCA. *Product Carbon Footprint Calculation*. https://oneclicklca.com (accessed: 11.2024).
[17] **Boehm, S., et al**. (2023). State of Climate Action 2023. Systems Change Lab, pp. 4–5.
[18] EN 15978. Sustainability of construction works. Assessment of environmental performance of buildings.
[19] Építésügyi Minőségellenőrző Innovációs Nonprofit Kft. (2022). Az életciklus-elemzés lehetséges módszerei és értékelési szempontjai, 10_2022. ÉPMI (v1_2022. IX. 16.).
[20] **Kotaji, S., Schuurmans, A., & Edwards, S**. (2003). Life-Cycle Assessment in Building and Construction: A State-of-the-Art Report.
[21] **Zagorácz, M., & Szabó, B.** (n.d.). Lechner Tudásközpont – BIM kézikönyv 1. kötet: Bevezetés az épületinformációs modellezésbe.
[22] **Wastiels, L., & Decuypere, R. (**2019). Identification and comparison of LCA-BIM integration strategies. IOP Conference Series: Earth and Environmental Science, 323, 012101.
[23] **Shadram, F., Johansson, T. D., Lu, W., Schade, J., & Olofsson, T. (**2016). An integrated BIM-based framework for minimizing embodied energy during building design. Energy and Buildings.
[24] **Llatas, C., Soust-Verdaguer, B., & Passer, A.** (n.d.). Implementing Life Cycle Sustainability Assessment during design stages in Building Information Modelling: From systematic literature review to a methodological approach. 2020. https://doi.org/10.1016/j.buildenv.2020.107164
[25] **Abdulla, R., & Jrade, A. (2012**). Integrating building information modeling and life cycle assessment tools to design. Proceedings of the 29th International Conference, Beirut, Lebanon.
[26] **Nagy, M. M., Szalay, Zs., & Nagy, B. (**2020). Környezettudatos épületfelújítás BIM technológiákkal. Budapesti Műszaki és Gazdaságtudományi Egyetem, Építőanyagok és Magasépítés Tanszék TDK.
[27] **Szecskő, H**. (2024). Családi lakóház kiviteli terve – Pallérterv és épületszerkezeti munkarész.
[28] 9/2023. (V. 25.) ÉKM rendelet az épületek energetikai jellemzőinek meghatározásáról.
[29] The Embodied Carbon Review: Embodied carbon reduction in 100+ regulations & rating systems globally. Retrieved from https://oneclicklca.com/resources/ebooks/the-embodied-carbon-review (Accessed: 2023.11.20).
[30] The Embodied Carbon Review: Embodied carbon reduction in 100+ regulations & rating systems globally. (Accessed: 2023.11.20).
[31] Product Carbon Footprint. One Click LCA.
[32] Product Carbon Footprint Calculation, One Click LCA.