# A Visual Method for Detailed Analysis of Building Life Cycle Assessment Results

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**Keywords:** LCA; building life cycle assessment; result visualization; parameter analysis, optimization.

**Abstract.** In the environmental analysis of buildings, Life Cycle Assessment (LCA) is gaining more and more interest. It is due to the fact, that LCA is very comprehensive in considering many impacts in all life-cycle phases of the examined building. Since buildings have a complicated geometry that is built up with numerous constructions that consist of many materials, and the life-cycle includes many phases, the results of an assessment are likely to be difficult to analyze in detail. In this paper we introduce a visual method to help architects and analysts to quickly understand the results of an environmental assessment. It includes the hierarchic visualization of the performance of the individual elements of the building. Both energy use and environmental impacts can be presented. Also the contribution of the different life-cycle phases in the overall impact is visualized. There are increasing efforts nowadays to find the most efficient way to improve the environmental performance of buildings [1]. This can be supported with a detailed analysis of the results. The method is presented through a case study of a realized energy efficient one-family house.

## Introduction

The application of Life Cycle Assessment in the building sector has improved a lot in the recent years [2]. The increased interest is due to the comprehensiveness of the LCA method for considering many aspects of the environmental impacts of a building [3]. However, there are still many discussions about what kind of method should be used in the analysis of buildings, including the question of change of input data during the service period of the building (technologies, energy-mix, waste management, etc.) [4], or change of the building model because of retrofitting. Different weighting methods and the question of impact and resource localization are the topics of continuous discussions as well [5, 6]. With the development of methods, more and more software solutions are introduced to enhance the usage of LCA. Different scopes are defined for these software, such as building certification [7], design assistance [8] or environmental performance evaluation [9]. Also another scope is to perform fast and reliable environmental impact analysis in early design stages in order to make improvements in a cost- and time-effective way [10]. Depending on the scope of the calculations, the software offer results visualization in charts, reports or only an overall score.

The most widespread visualization method is the pie chart (not only in building related LCA). The overall result is usually divided into resources, main flows or life cycle stages. The diagram shows one layer of division. For visualizing energy and material flows a Sankey diagram is a proper choice [1], but only a few generic LCA software make it available. Another widely used visualization method is a stacked bar chart, or a multiple stacked bar chart (when comparison is necessary). However, this also allows only one layer of results division. Other, building related LCA software [11] provide more detailed results visualization, such as pie charts for each of the environmental indicators, divided into different construction category or detailed multiple stacked bar charts by impact category divided into life cycle stages.

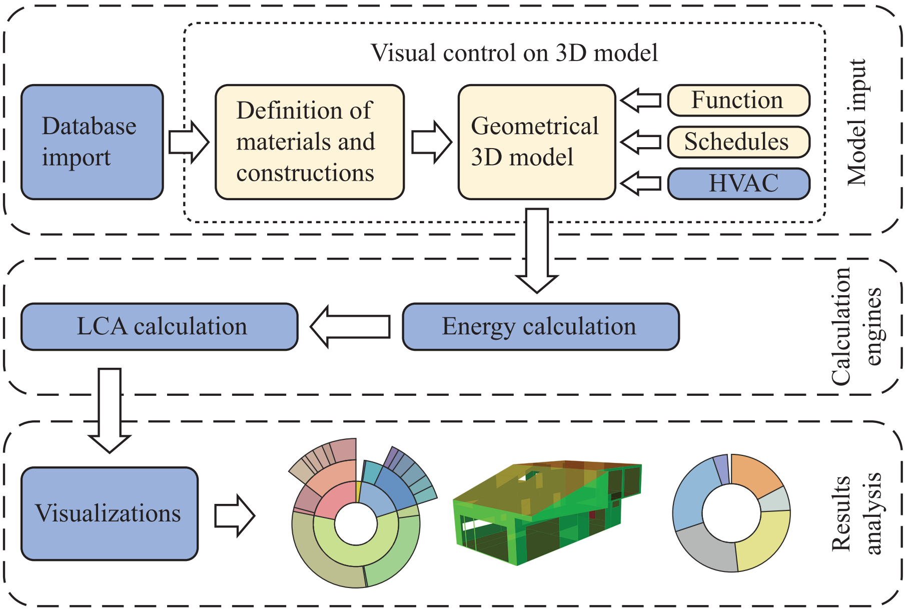


***Figure 1.*** *Calculation and modelling structure. The dark highlighted elements are self developed, the light ones are part of the Honeybee plugin [25]*

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A complete life cycle assessment of a building is a quite complex process (Fig. 1). There is a high demand for input data on both material and construction side and also on modelling side. Usually calculations are based on a predefined material database (Ecoinvent [12], GaBi [13], Ökobaudat [14], etc.). For complete building assessments, many input variables (geometry, materials, etc.) must be defined and numerous calculations (LCA modelling, energy calculations, etc.) have to be carried out to get a final result. Since these calculations are built on one another, the result can be very sensitive to the initial data. Therefore, a deeper understanding of the result is necessary to keep the process under control. One goal of a building related LCA is to achieve a reduction in environmental impacts. In early design stages there is a much higher potential of reduction than during the construction or operational stage [15], so there is a high demand of LCA during the conceptional and the detailed architectural design process. However, a development in the environmental performance of a design is only possible, if the weak-points are discovered. This also emphasizes the importance of a deep, quick and visual analysis of the LCA results. In the following we introduce a method to visually analyze the results in different depths.

**The analyzed building.** In year 2015 the company Wienerberger realized a single-family house as a demonstration project for energy efficient brick houses. The free standing house has $180m^2$ net heated floor area, two floors and an optimized self-shading geometry. It is located in the suburbs of Budapest. A previous study [16] showed that the development of the design in the early stages had some unused potential for environmental performance improvement, because life cycle assessment was carried out only after the realization. With the help of this case study we present the visualization techniques and show how these techniques can help to optimize the environmental performance of the building. For this analysis variables were described for each building material, for the layer thickness and for the HVAC system. Using the diagrams a manual improvement of the building is carried out with the modification of these variables.

## Calculation methodology

**The structure of the calculation set.** In the proposed method many layers of calculation are needed. Therefore the analysis process is divided into three major modules: model input, calculation engine and results analysis as shown in Fig. 1. Data input is based on a merged database that incorporates both LCIA (Life Cycle Impact Assessment) information of construction elements, building related elementary flows (material, energy, etc.) and physical properties such as thermal conductivity or density. Materials are assigned to layers that build up constructions. A 3D geometrical model of surfaces (e.g. walls, floors, roof) and subsurfaces (e.g. windows, doors) is prepared in a modelling environment to provide a base for building-assigned visualization and geometrical measurements. Then the desired construction is assigned to the 3D model. Other building-related information is added to the model, such as function, operational schedules and HVAC systems. At this level a visual control of the assignments is possible. The complex model is passed to the energy calculation module that besides of the calculation also passes the partial results to the next module. Then the LCA calculation is executed based on the energy results and on the calculated material quantities and assignments. These partial results are also stored in order to facilitate further in-depth analysis. The last module provides different visualization techniques which are discussed further in the next section.

**LCA methods.** Life Cycle Assessment calculation methods are based on the corresponding standards for general LCA [17, 18] and building-related LCA [19]. Product stages (A1-3) are covered by the material database that uses the LCIA information (cradle to gate) of ecoinvent 2 [12]. Construction stage A4 is covered by the consideration of different transport scenarios adjusted to Hungarian conditions. Modules B2 and B4 of the use stage (maintenance and replacement) are calculated with the formula $NR_j = Int(RSL/ESL_j)$ for each building component, where $NR_j$ is the number of replacement of the building component $j$, $RSL$ is the required service life of the building (in this study it equals to the reference service period, 50 years) and $ESL_j$ is the estimated service life of the component $j$ (included in the merged database) according to the applicable standards [20]. Module B6 (operational energy use) is calculated automatically based on the steady state seasonal method of the Hungarian building energy regulation [21]. End-of-life stages of C2 and C4 are considered using disposal and transport scenarios based on our assumptions, and are included in the merged database for each material. Other modules are not considered in this study, because they are expected to have low impact on the final environmental performance [22]. The material quantities are calculated automatically using the geometrical and construction data of the model. Different predefined HVAC systems are used. In the following only the results for cumulative energy demand (non-renewable) is presented, but the method is applicable for any other environmental indicator.

**Software environment** The whole calculation method is implemented in Rhinoceros3D [23] and Grasshopper [24] environment. The building geometry is modelled in Rhino and connected to the Grasshopper model. The energy model is built with Ladybug&Honeybee plug-in [25] for Grasshopper using the predefined materials of the database. Additional structures that do not affect the energy performance such as foundation and roof over the unheated attic were not considered in this study. HVAC assignment, energy calculation, LCA calculation and visualization modules are developed using Python elements in Grasshopper. The visualization is projected back to Rhino, in order to facilitate 3D views. The use of one environment for all the modules allows for automated calculations needed for optimization and also for real-time result views in case of parameter change.

## Data visualization and analysis

**Overall result views.** The analysis of the results is provided at three different levels. The first is the cumulated amount of the observed environmental indicator. For a more detailed analysis the result can be divided into subcategories by life cycle stages. These stages can also be subcategorized differently as described in the following. The operational energy use can be divided into heating, cooling, domestic hot water (DHW) and ventilation. Each of these has direct and auxiliary energy use, which can also be subject of subdivision. The production, maintenance and disposal stage that depend mostly on the embodied materials can be divided into impacts caused by the envelope, the internal structures and the HVAC systems. These can be further divided into individual surfaces, and the impact of the surfaces can be divided into the impact of the materials used for the assigned construction. This kind

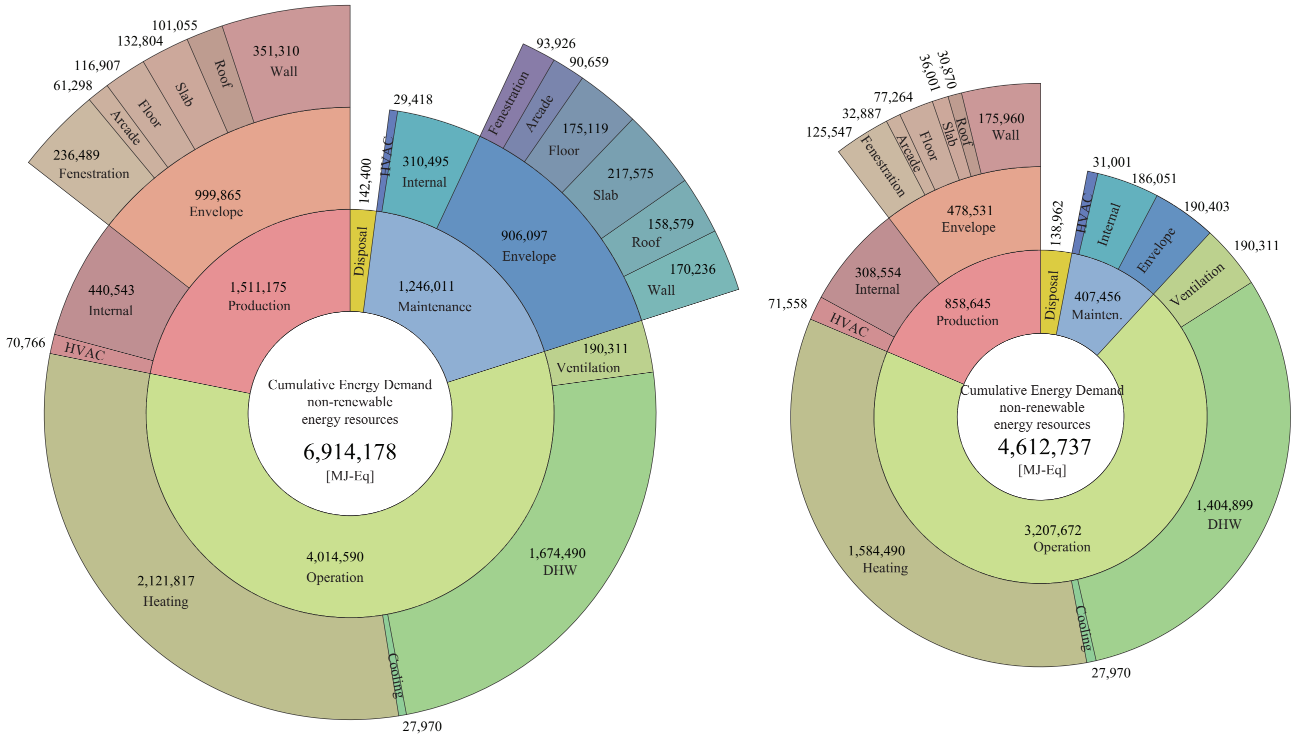
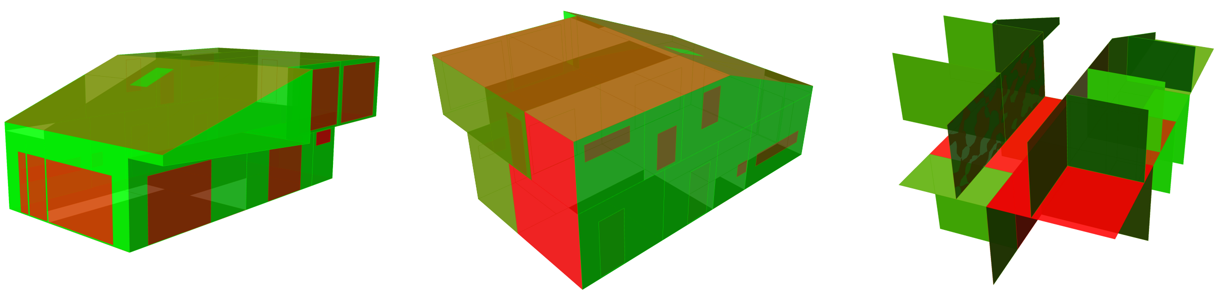



***Figure 2.*** *Sunburst diagram of Cumulative Energy Demand (non-renewable energy sources). The left diagram represents the initial variant, the right one represents the final, improved variant of the case study building.*

of data structure is visualized in a sunburst diagram (Fig. 2). The subcategories of the tree branches with little impact – for example disposal stage in Fig. 2 – are not visible in order to make the diagram more interpretable. Also the division of branches with many subcategories – for example the individual surfaces of the envelope – are not shown because of the same reason. The overall size of the diagram represents the cumulated environmental impact in order to facilitate comparison.

**Improvement potential of the case study building.** The left diagram of Fig. 2 shows the results of the initial variant of the building. It is visible that the operational stage has the highest impact and within that heating and domestic hot water production has the most influence. In order to lower this impact, the condensing gas boiler is changed to heat pump for both heating and DHW. The diagram also shows that on the production and maintenance side the envelope of the building is the most significant, and within that the walls and fenestrations have high contribution.



***(a).*** *Envelope constructions(front)* ***(b).*** *Envelope constructions (back)* ***(c).*** *Internal constructions*

***Figure 3.*** *Cumulative Energy Demand of the individual constructions in the Production stage (A1-3). The envelope and internal constructions are displayed separately.*

**3D representation of partial results.** For further understanding, the results are also visualized on the geometrical 3D model of the building. The life cycle environmental impact of the individual constructions are shown in Fig. 3. The color of the surface represents the contribution in the overall environmental impact. The impact is differentiated between inner (Fig. 3c) and outer (Fig. 3a,3b) surfaces. This enables the analyzer (architect, engineer, etc.) to find the building elements with the highest improvement potential. The further analysis of the construction is possible with the help of a donut chart that shows the distribution of the indicator between the building materials shown in Fig. 4.

**Application for the case study.** The geometrical representation in Fig. 3b shows that the construction of the top slab, the arcade slab and the bracing walls have the highest impact per square meter. The diagrams of Fig. 4 show that the insulation materials have the most significant influence, so as a next step of improvement these materials are changed from mineral wool and extruded polystyrene to cellulose insulation.

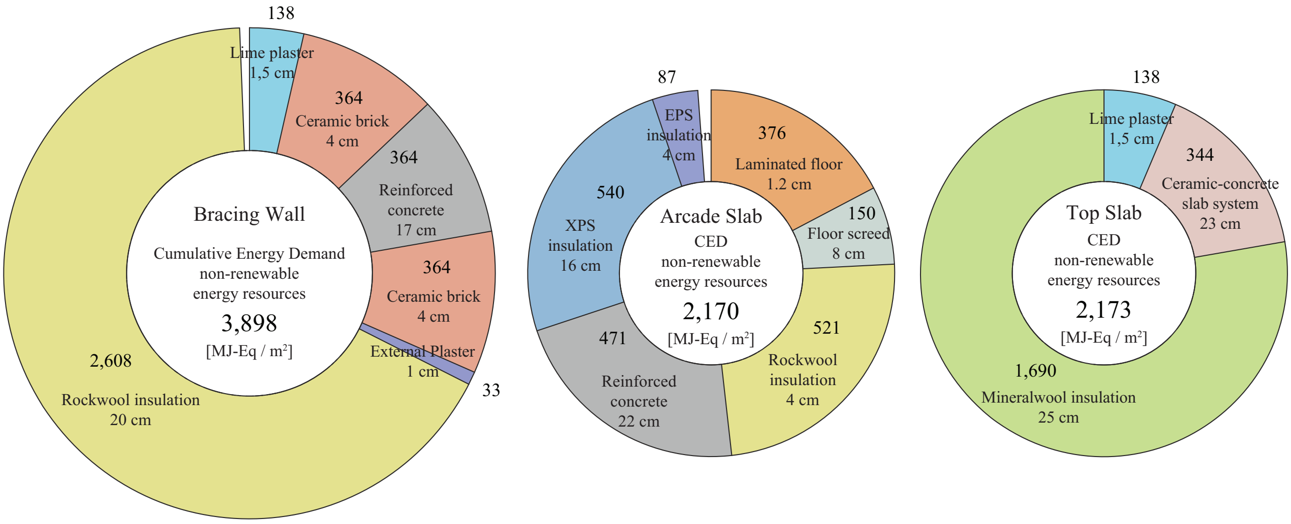



***Figure 4.*** *Cumulative Energy Demand of the Production Stage (A1-3) of the most significant constructions.*

Fig. 5 represents a different categorization of the impacts apart from the operational stage. The impacts are allocated to the materials, and the materials are subcategorized into life cycle stages. The left diagram shows that the autoclaved aerated concrete material of the walls has a high impact because of the high amount of material used in the house, so the material is changed to ceramic brick. Because of the same reason the windows are changed from plastic to wooden frame.

**Energy performance visualization.** To analyze the operational stage, a deeper understanding of the energy performance is needed. Therefore a visual representation of the solar gains and heat losses is shown in Fig. 6a and Fig. 6b for each zone. The integration of these two gives the energy balance (Fig. 6c). In order to achieve improvement in the energy performance, the total heat loss for each surface of the envelope is represented on Fig. 7a. In comparison, the solar gains of the fenestration surfaces are shown in Fig. 7b. Numerous further methods for the analysis of the energy performance are discussed in the literature, but the review of them would exceed the scope of this study.

**Application for the case study** Fig. 7a shows, that within the opaque constructions of the envelope, the pitched roof structure of the living room has the highest energy losses. Although this would lead the intuition of the designer into an increase of the insulation in the roof construction, the sunburst diagram of the overall environmental performance shows, that the increase in the embodied energy would exceed the decrease of the operational energy use, so no change is applied in this situation.

Goals of these representations is to discover the weak-points of the building either in the environmental or the energy performance. The integrated environment enables manual intuitive performance development through immediate response on a variable change as presented above.

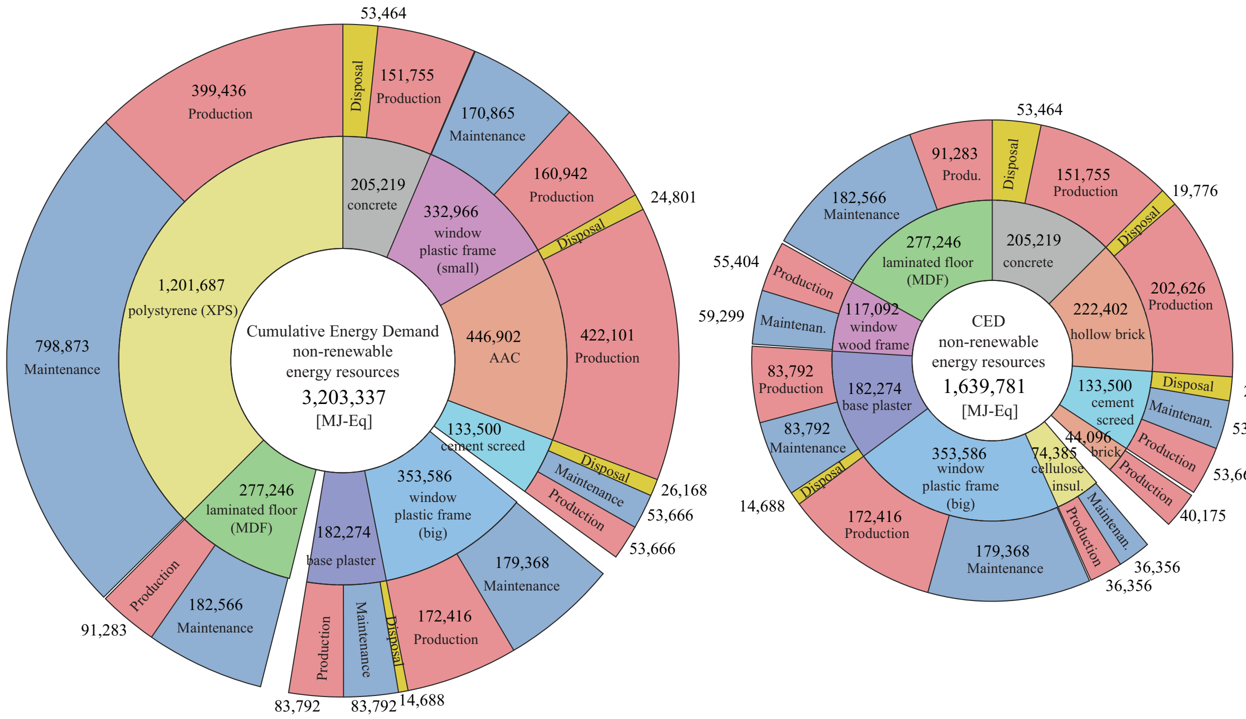
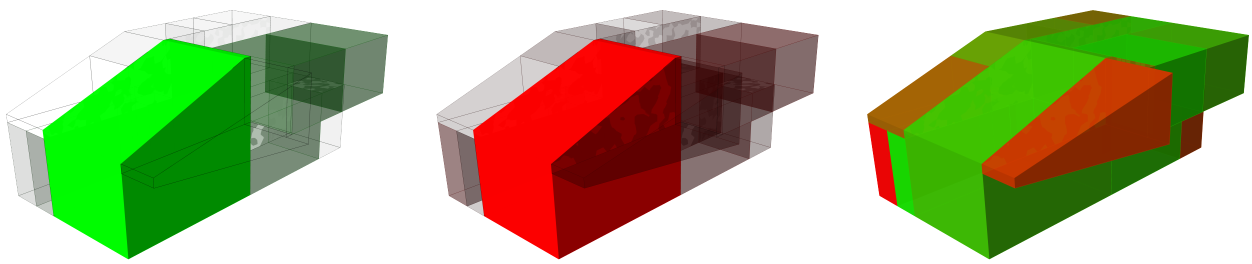



***Figure 5.*** *Cumulative Energy Demand of the materials (production, maintenance and disposal) used in the case study house. The left diagram represents the initial variant, the right one represents the final, improved variant.*



***(a).*** *Cumulated solar gains* ***(b).*** *Cumulated heat losses* ***(c).*** *Energy balance*

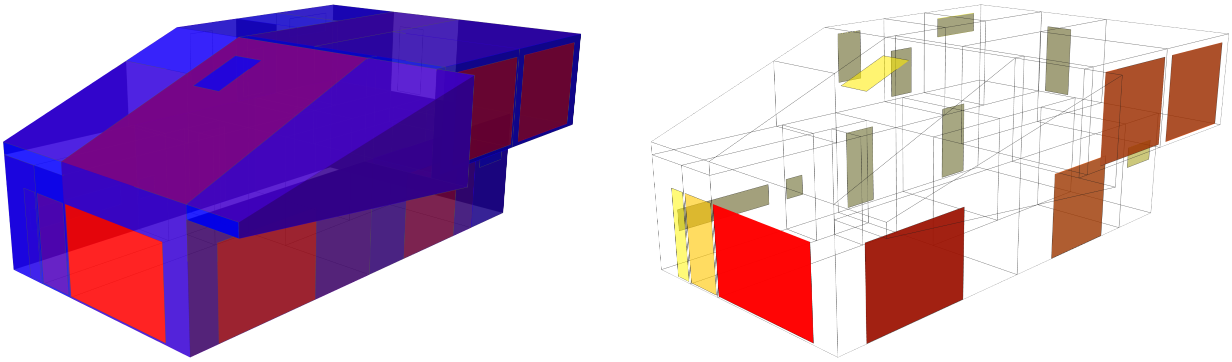
***Figure 6.*** *Energy balance of zones*

## Discussion

The right diagrams of Fig. 2 and Fig. 5 represent the final, improved variant of the house. The overall score shows, that with these few steps a significant reduction of 34% was achieved. The case study showed, that such visualization tools can help to deeply analyze the results of an LCA calculation. This technique also facilitates an efficient manual optimization process. However, the designer still does not have any information about how far the overall optimum is. Also, this process would lead to different solutions for different environmental indicators. Apart from these weaknesses, understanding the structure of the result is still important, because it also helps to discover errors in the calculation.

## Further development

As a further development of this technique the implementation of an automated process of the above described optimization, and the use of dynamic responsive charts would be desirable. As a help for the architect, suggestions for alternative variants for a specific design would be also beneficial. Different methods for the energy calculation module would probably alter the results, and more precise calculations (e.g. energy simulations) would help to increase the reliability. On the other hand, this



***(a).*** *Heat losses. The more red the surface is, the more loss it accounts for.* ***(b).*** *Solar gains. The more red the window is, the more solar gain it collects.*

***Figure 7.*** *Energy balance of the envelope surfaces*

would require a higher computational cost that would decrease the possibility for real-time results visualization. Also, the integration with BIM models would extend the use of these visualizations.


**Acknowledgement**

We are grateful to the Hungarian Academy of Sciences for awarding the János Bólyai Research Scholarship to Zsuzsa Szalay, which supported her work, and to Wienerberger Téglaipari Zrt for providing data on their demonstration project.


**References**


[1] F. Pomponi, A. Moncaster, A Method for Visualising Embodied and Whole Life Carbon of Buildings, in: M. Dastbaz, C. Gorse, A. Moncaster (Eds.), Building Information Modelling, Building Performance, Design and Smart Construction, Springer International Publishing AG, Cham, 2017, pp. 185-189.

[2] S. Lasvaux, J. Gantner, B. Wittstock, M. Bazzana, N. Schiopu, T. Saunders, C. Gazulla, J. A. Mundy, C. Sjöström, P. Fullana-i Palmer, T. Barrow-Williams, A. Braune, J. Anderson, K. Lenz, Z. Takacs, J. Hans, and J. Chevalier, Achieving consistency in life cycle assessment practice within the European construction sector: the role of the EeBGuide InfoHub, International Journal of Life Cycle Assessment 19 (2014) pp. 1783–1793.

[3] European Commission, Resource efficiency opportunities in the building sector (2014) p. 10.

[4] C. Roux, P. Schalbart, E. Assoumou, and B. Peuportier, Integrating climate change and energy mix scenarios in LCA of buildings and districts, Applied Energy 184 (2016) pp. 619–629.

[5] S. Lasvaux, G. Habert, B. Peuportier, and J. Chevalier, Comparison of generic and productspecific Life Cycle Assessment databases: application to construction materials used in building LCA studies, International Journal of Life Cycle Assessment 20 (2015) pp. 1473–1490.

[6] M. Buyle, J. Braet, A. Audenaert, and W. Debacker, Strategies for optimizing the environmental profile of dwellings in a Belgian context: A consequential versus an attributional approach, Journal of Cleaner Production (2015) pp. 1–10.

[7] One Click LCA Software, Bionova Ltd, Helsinki (2017), available at: http://www.oneclicklca.com/

[8] A. Hollberg, J. Ruth, LCA in architectural design—a parametric approach, International Journal of Life Cycle Assessment, vol. 21 (2016) 943–960.

[9] X. Oregi Isasi, J. A. Tenorio, C. Gazulla, I. Zabalza, D. Cambra, S. O. Leao, L. Mabe, S. Otero, and J. Raigosa, SOFIAS – Software for life-cycle assessment and environmental rating of buildings, Informes de la Construcción 68 (2016), p. e151.

[10] A. Hollberg, N. Klüber, S. Schneider, J. Ruth, and D. Donath, A Method for Evaluating the Environmental Life Cycle Potential of Building Geometry, Sustainable Built Environment (SBE) regional conference, 2016.

[11] Tally Software Version 2016.05.08.01, KT Innovations, Philadelphia (2017), available at: http://choosetally.com/

[12] Ecoinvent data v1.3 and final reports ecoinvent 2000, Swiss Centre for Life Cycle Inventories, Dübendorf, 2005.

[13] GaBi Databases, Thinkstep, Leinfelden-Echterdingen, 2017.

[14] Ökobau.dat 2016-I (18.05.2016) Database, Bundesinstitut für Bau-, Stadt- und Raumforschung, Bonn, 2016.

[15] M. Hegger, M. Fuchs, T. Stark, M. Zeumer, Energie Atlas. Nachhaltige Architektur, Birkhäuser, Berlin, Basel, 2012.

[16] B. Kiss and Zs. Szalay, The Impact of Decisions Made in Various Architectural Design Stages on Life Cycle Assessment Results, Applied Mechanics and Materials 861 (2016) pp. 593–600.

[17] ISO 14040 Environmental management — Life cycle assessment — Principles and framework, International Organization for Standardization, Geneva, 2006.

[18] ISO 14044 Environmental management — Life cycle assessment — Requirements and guidelines, International Organization for Standardization, Geneva, 2006.

[19] EN 15978 Sustainability of construction works — Assessment of environmental performance of buildings — Calculation method, European Committee for Standardization, Brussels, 2011.

[20] ISO 15686 Buildings and constructed assets — Service life planning, International Organization for Standardization, Geneva, 2008.

[21] A tárca nélküli miniszter 7/2006. (V.24.) TNM rendelete az épületek energetikai jellemzőinek meghatározásáról, Magyar Közlöny 62 (2006) 5134–5175.

[22] A. Takano, S. K. Pal, M. Kuittinen, K. Alanne, M. Hughes, and S. Winter, The effect of material selection on life cycle energy balance: A case study on a hypothetical building model in Finland, Building and Environment 89 (2015) pp. 192–202.

[23] Rhinoceros Software Version 5 SR12, Robert McNeel & Associates, Seattle (2017), available at: https://www.rhino3d.com/

[24] Grasshopper 3D Software Version August-27 2014, Robert McNeel & Associates, Seattle (2017), available at: http://www.grasshopper3d.com/

[25] M. S. Roudsari, M. Pak, Ladybug: a parametric environmental plugin for grasshopper to help designers create an environmentally-conscious design, in: Proceedings of the 13th International IBPSA Conference, Lyon (2013) pp. 3128-3135.