Interdependence between Structural Engineering and Construction Management
Edited by Ozevin, D., Ataei, H., Modares, M., Gurgun, A., Yazdani, S., and Singh, A.

ISBN: 978-0-9960437-6-2

ECOLOGY IN MULTI-STORY RESIDENTIAL BUILDINGS – INTERDEPENDENCY BETWEEN ECOLOGY AND COSTS OF BUILDING MATERIALS

DANIELA KOPPELHUBER and JOHANNES WALL

Institute of Construction Management and Economics, Graz University of Technology, Graz, Austria

More than 95% of multi-story residential buildings in Austria are currently predominantly constructed with conventional mineral construction materials. This fact combined with the increasing demands for a healthy residential living atmosphere demonstrates the great potential for using ecological materials. Life cycle assessments provide information on the ecological performance of buildings, but the corresponding economical aspects are not considered. Nevertheless, the economic aspects of a certain draft are important to clients and designers. Therefore, simplified assessment-tools are needed that take into account the ecological impact as well as the building costs. This paper presents the results of an investigation supplemented by a case study of a multi-story residential building, which was finished 2016 in Austria, illustrating the differences between the state-of-the-art material selection and ecologically optimized alternatives. The ecological impacts and the costs for the selected building-system were determined based on the case study. Subsequently, ecological optimization potentials were identified according to the environmental indicator OI3. Finally, the effects on component and construction costs were evaluated. The steps of this simplified process reveal the interdependency between ecological aspects and the costs of materials. This procedure represents a decision-making tool that can be used by clients as well as designers. The results of this research emphasize the large environmental impact improvements with little expenses when implementing sustainability in multi-story residential buildings as a crucial part of a green design.

Keywords: Construction materials, Green design, Environmental indicator OI3, Life cycle assessments, Sustainable development, Ecological performance.

1 INTRODUCTION

Environmental effects of building materials, components and the buildings themselves can be quantified and compared using the method of life cycle assessment (LCA). The results of an LCA provide information about the ecological performance of a building. Focusing on a holistic assessment, the interdependency between ecological aspects and costs of buildings are extremely important. However, these are the key factors in the planning process for decision-makers. Therefore, the issue directs the focus toward developing tools, which can be used to simplify and illustrate the relationship between the environmental impacts and corresponding financial aspects of building projects (Kovacic and Zoller 2015).

2 GREENING POTENTIALS OF HOUSING PROJECTS

Multi-story residential buildings have a great potential to reach the goals of sustainable development, as more than 95% of national housing projects are currently predominantly designed as conventional mineral-massive buildings in Austria (Teischinger *et al.* 2015), built with a low proportion of ecological building materials, especially insulation materials (Steinmann 2014) (Adamczyk and Dylewski 2017). This fact, together with increasing demands for healthy indoor climate conditions (Neubauer 2015), illustrates the great potential for the use of environmentally friendly building materials (Wall and Hofstadler 2016). Therefore, designers have to face the challenge of performing quick, reliable calculations of ecological and economic parameters to provide transparent data that help them select building materials for their clients.

3 CALCULATION OF THE CASE STUDY

The present research illustrates how the design process can involve ecological and economic aspects of different design options in an easy, understandable way for the clients.

3.1 Aim and Method

In a case study of a multi-story housing project finished in Austria in 2016, the higher and lower costs of ecological building materials and their effects on the building costs were calculated. Furthermore, the potential for greening in terms of optimizing the ecological performance was identified, and the level of interdependency between the costs and ecological aspects of several building materials was described. This method provides a simple way for designers to compare the ecological and financial qualities of building materials at an early point in the design process.

In the first step, the building costs were calculated with reference to the Austrian standard *ÖNORM B 1801-1* (2015). Second, the costs and ecological parameters for relevant multilayer components were determined, calculating the ecological indicator OI3. Subsequently, the ecological potential was identified, and ecological building materials with appropriate fire protection, sound insulation, thermal insulation and technical applicability were selected to carry out further calculations and for comparison purposes. Finally, the effects of an ecological optimization of the selected components and their construction costs were calculated and summarized.

3.2 Conditions of the Case Study

As a case study, a residential building with 36 apartments on six floors and a basement car park for 45 cars, finished in autumn 2016, was selected. The calculation of the construction costs and the OI3-value were based on the architectural drawings and the results of the calculation of the coefficient of thermal transmission (U-value). The project was designed and built with for multi-story-constructions using conventional mineral building materials as summarized in chapter 3.4.

3.3 Costs and Environmental Indicators for Conventional Building Materials

To calculate the costs, the unit prices from the German building cost database BKI were compared with the tender prices for the case study and supplemented by unit prices from similar construction projects. The ecological comparison of the components was based on the environmental indicator OI3, which can be used to assess the primary energy demand of the non-renewable energy, global warming potential and acidification potential of construction products from cradle-to-gate (Boogman and Mötzl 2010). Using the OI3-values of the individual materials, the ΔOI3-value for multilayer components was derived using the tool "*Baubook construction calculator*". The ΔOI3 illustrates the optimization potential of a construction element based on a score evaluation: The lower the score of a building material within the multilayer component, the better its ecological performance. The central theme, therefore, is to identify building materials, which have a high number of points and find appropriate alternatives. Finally, the calculated prices and ΔOI3-values of the conventional components were used to represent the basis for the comparison with ecological alternatives.

The eco-indicator OI3 is also the basis of calculations used for national subsidy programs as well as building certification systems such as *klimaaktiv* and *TQB 2010*. The selected method, which is used to assess the ecological improvement compared to the construction standard, is the principle of the ecological assessment in the *IBO Ökopass* certification system.

3.4 Selection of Ecological Building Materials

To select alternative ecological building materials, a number of parameters have been defined, in addition to technical serviceability and properties related to building physics. For example, the principles of construction and the U-value were not allowed to alter from those in the original design. Therefore, the thicknesses of the alternative thermal insulation material had to be adjusted. Finally, the ecological building materials listed below were selected for the comparative calculation with the conventionally constructed housing project:

- Exterior and structural walls: wood chip concrete instead of vertical coring bricks
- Apartment ceilings: prefabricated brick units instead of reinforced concrete
- Thermal insulation of walls: cork insulation slabs instead of EPS-F
- Thermal insulation of walls with fire protection: mineral foam instead of mineral wool
- Thermal insulation of flat roof: cork insulation slabs or mineral foam instead of XPS
- Thermal insulation of basement slab bottom: mineral foam instead of excelsior boards with a rock wool-core

3.5 Calculation of Costs and Environmental Indicators for Ecological Building Materials

After selecting the ecological building materials, the improvements in the ecological properties of the multilayer components were verified using the ΔOI3-value. Furthermore, the thermal insulation thickness was adjusted if necessary. The costs for the selected ecological material variants were calculated based on material price lists and added to the costs for delivery, wage assumptions, material offcut and, finally, the surcharge (Kropik 2016). While budgeting with conventional building materials is considered as a routine task for designers, the cost calculation for ecological building materials presents a challenge due to the lack of available databases for these materials.

4 RESULTS OF ANALYSIS

Applying the described method, a total of eight multilayer components with 20 ecological variants were examined for the use case. The results of the comparison as well as the ecological effects are summarized below.

4.1 Interdependency Between Ecology and Costs of Components

The outcome of the cost and environmental calculation is shown in Figure 1. The light bar on the left-hand side indicates the ecological improvements in the multilayer component, and the dark bar on the right illustrates the expenses of these components – compared with the conventional building elements.

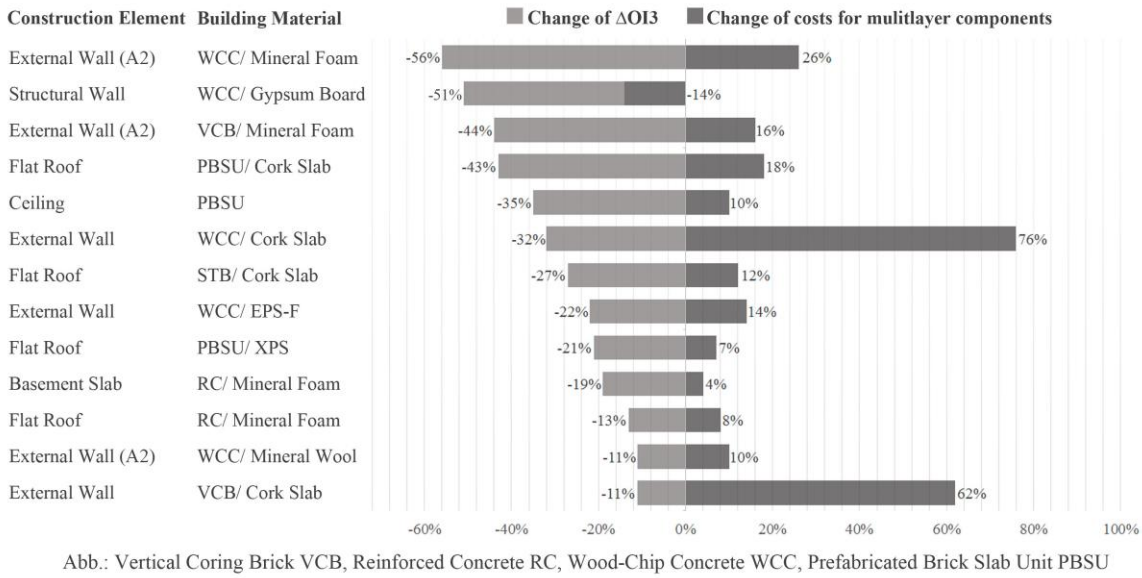

Figure 1. Changes in the costs and ecologically improvements in multilayer components.

It has been shown that structural alternatives cause fewer expenses, despite their exceptional ecological performance. The results of the comparison show that thermal insulation materials are more expensive despite their lower ecological potential to contribute towards the creation of a more ecological building.

4.2 Interdependency Between Ecology and Construction Costs

Perhaps more important than the results for the individual components were the illustration of the construction cost differences and the ecological improvement for the entire project. Therefore, the ΔOI3-value and the corresponding costs had to be multiplied by the surface of the components. To compare the construction costs, the costs of the shell and finish according to the national standard *ÖNORM B 1801-1* (2015) were considered. To illustrate the potential for greening, the ΔOI3-values of all components were summarized, based on their surfaces. For calculation purposes, design options with different ecologically optimized component structures had to be defined. Several calculated scenarios using different building materials and construction variants allowed the ecological and economic interdependency to be communicated transparently to the clients. Overall, the structural options were associated with fewer additional costs despite having excellent ecological performance values, as shown in Figure 2. On the contrary, insulation variants with lower ecological improvement values caused more expenses. The fact that the thermal conductivity of the alternative insulation material is higher than that of common materials is equally important to investors. This means that the ecological materials are thicker and results in a loss of usable area within the building up to 3% (Koppelhuber 2016).

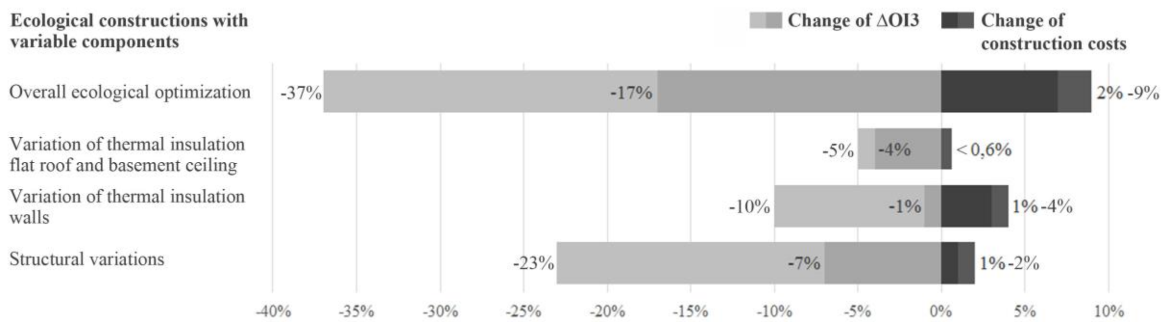

Figure 2. Changes in the construction costs and the ecologically improvement of the overall building.

4.3 Derived Benefits from Ecological Interventions

The outcome of this research illustrates the higher building costs and the loss of usable area affected by the use of ecological building materials. Although these are given facts, the designer has to motivate the client to choose environmentally friendly construction methods and materials for his or her project. The benefits of ecological-friendly materials to the environment and the indoor climate are well-known, but clients usually consider the financial benefits to be more relevant. Some financial rewards for the use of ecological building materials are listed in the following section, which illustrate selection criteria that supplement the environmental benefits:

- Improved evaluation results for building certifications: The results of an Austrian research project explain the influence of ecological building materials on the outcome of building certifications. The comparison of four frequently used national building certification systems illustrated that the selection of building materials could influence 29% to 59% of the overall assessment (Sölkner *et al.* 2014).
- Higher limits for construction costs for building certifications: In part, construction costs are prescribed for certifications. These cost limits may increase by using more ecological materials: In the case of the Swiss building certificate *Minergie*, this increase was up to 10% – or with *Minergie-Eco*, up to 15% – compared to the cost limits of a conventional residential building (Koppelhuber 2016).
- Higher limits for construction costs for promoting policies related to public housing: Maximum construction costs are generally defined for subsidized multi-story buildings. Depending on the funding systems, this upper limit increases by approximately 10% to 15% when ecological building materials are integrated into the construction of the building (Koppelhuber 2017).
- Higher subsidies for the owners of new apartments: Increasing the subsidy for first-time dwellers in the national subsidy scheme *Wohnbauscheck* by a maximum of 5% according to the ecological intervention would mean that cost increases caused by the use of environmentally friendly materials can be more easily covered by the new building owners (Koppelhuber 2017).

The conditions used in this project are typical for Central Europe, but the options presented clearly show that there are additional benefits for ecological building systems. These findings underline well-known arguments that support environmental protection and the promotion of a healthy indoor climate in residential buildings.

5 CONCLUSIONS AND OUTLOOK

The ecological and financial results of the calculations clearly illustrate the ecological potential and the associated low additional costs associated with the use of different combinations of alternative materials. It has been demonstrated that environmental improvements can already be achieved with little financial input. For example, if additional costs of 2% are accepted, an ecological improvement in the examined components of 23% is possible. A simplified and comprehensive cost calculation combined additionally with ecological indicators (such as the ΔOI3-value) can simplify the decision-making process for designers and strengthen the clients' understanding. This paper highlighted the challenges faced when budgeting ecological construction methods, which can be viewed as a major obstacle to making cost comparisons with ecological materials.

In conclusion, the results of this research can make it easier for designers to argue with the investors to bring about the acceptance of environmental improvements and illustrate the financial benefits of using ecological building materials. However, construction projects cannot only be evaluated on the basis of ecological properties; therefore, integrated, lifecycle-based strategies that include both economical and socio-cultural aspects in the decision-making process must be undertaken (Ofek *et al.* 2018).

References

Adamczyk, J., and Dylewski, R., The Impact of Thermal Insulation Investments on Sustainability in The Construction Sector, *Renewable and Sustainable Energy Reviews*, Volume 80, 421-429, 2017.

Boogman, P. and Mötzl, H, *IBO-Richtwerte für Baumaterialien – Wesentliche Methodische Annahmen. Version 2.2*, IBO, Vienna, 2010.

Koppelhuber, D., *Ökologie als Planungsaufgabe im Geschoßwohnbau – Aspekte der Nachhaltigkeit im Kostenvergleich der Baustoffe*, Graz University of Technology, Graz, 2016.

Koppelhuber, D., *Ökologie als Planungsaufgabe im Geschoßwohnbau – Vergleichende Betrachtung ökologischer Baustoffe unter Berücksichtigung von Bauherren- und Planungsaspekten*, Graz University of Technology, Graz, 2017.

Kovacic I, and Zoller V., Building Life Cycle Optimization Tools for Early Design Phases, 92(3), *Energy*, 409-419, 2015.

Ofek, S., Akron, S., Portnov, B.A Stimulating Green Construction by Influencing The Decision-Making of Main Players, *Sustainable Cities and Society*, 40, 165-173, 2018.

Kropik, A., *Baukalkulation und Kostenrechnung,* Perchtoldsdorf., 2016.

Neubauer, M.: *Immobilien Fokus – Die große Umfrage zum Thema nachhaltiges Wohnen*. Wien, Linz. Immobilien Fokus, 2015.

ÖNORM B 1801-1: Bauprojekt und Objektmanagement – Teil 1: Objekterrichtung. Wien. Austrian Standards, 2015.

Sölkner, P. J., Oberhuber, S., and Spaun et al., *Innovative Gebäudekonzepte im Ökologischen und Ökonomischen Vergleich über den Lebenszyklus*, BMVIT, Vienna, 2014.

Steinmann, H., Alternative Dämmstoffe – „Der Markt ist da", *a3 Das Baumagazin,* Oktober, 2014.

Teischinger, A., Stingl, R., and Berger, V., *Studie Holzbauanteil in Österreich und Wien*, proholz, 2015. Retrieved from www.proholz .at/news/news/detail/studie-holzbauanteil-in-oesterreich-und-wien/ on November 10, 2016.

Wall, J., and Hofstadler, C., *How Can Sustainability Issues be Considered in The Public Procurement Process?* Proceedings of the CIB World Building Congress 2016: Understanding Impacts and Functioning of Different Solutions. Nenonen, S. & Junnonen, J-M. (eds.). Tampere University of Technology, 4, 2016.