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Mutual Impact of Design Decisions and Environmental Considerations - Life Cycle Analysis of an Alpine Hut

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Abstract: *This investigation about the design process of an alpine hut shows the mutual impact of design decisions and environmental considerations using the Hochwildehaus in the Austrian Alps as an exemplary project. Different design strategies were compared in the light of the environmental impact of construction, maintenance, and disassembly of the building project.*

Starting with an analysis of the differences in the LCA of a remote off-grid building compared to a regular building, four different designs are evaluated in terms of the most promising strategies to minimize ecological impact already during the design process. Helicopter transport and the relationship between energy standard and required technologies are taken into account. The study shows how far global warming potential and the use of primary energy can be reduced with designers and engineers working hand in hand.

Life Cycle Analysis, environmental impact, self-sufficient buildings, extreme environments

Introduction

Extreme environments constitute an ideal study area for sustainable architecture: independent from an urban context, buildings in remote sites derive the framework for their design from the surrounding conditions, such as climate and on-site materials. Resource scarcity has a strong influence on the way such buildings are developed, as building materials often have to be transported by helicopter and all services must be provided on-site. Therefore, material and resource flows are more obvious to the users through the immediacy of the impact of (un)sustainable practices. Such buildings have to distil the essence of self-sufficiency in their design strategies.

The following investigation shows the mutual impact of design decisions and environmental considerations using the Hochwildehaus in the Austrian Alps as a sample project. The designs were developed by students of the Master's program in architecture at the Technische Universität München (TUM) in the summer of 2013. The different design strategies were compared in the light of the environmental impacts during the entire life cycle of the building. An interdisciplinary investigation conducted by students of the Master's programs in environmental engineering, civil engineering and energy efficient and sustainable building provided the basis for this research.

Our research was guided by one central question: how far can we reduce ecological impacts of the building if designers and engineers work together during the design process making sure that high quality in architectural design is achieved at the same time?

Research approach and methodology

Multiple teams of designers and engineers cooperated in calculating life cycle assessments (LCAs) during the design process and in implementing the results into the final building design. We chose four out of the final twelve projects to compare and evaluate optimization strategies. We selected these designs because they represent the range of variations both in design as well as in life cycle optimization.

Figure 1 (from left to right): Design 1, design 2, design 3 initial and redesigned, design 4 [1]

The design task was a replacement building for an existing alpine hut owned by a regional chapter (Karlsruhe) of the German Alpine Club. The existing hut built in the 1930s needs to be replaced as the building's structure has become unsafe due to water damage and instability of the foundations caused by melting permafrost. The new hut provides accommodations for 50 mountaineers, the host and staff, with a large dining room, kitchen and sanitary facilities, all in all approximately 500 m² of gross floor area.

Operational energy for comfort conditions was calculated over the period of use of the hut (100 days from mid-June until mid-September). For the winter months some operational energy is required to keep the building interior above freezing temperatures.

The evaluation and comparison of the ecological impact of the different designs includes all systems and processes directly related to the building and its operation. For example this does not include food supply and travel of the visitors to the building. It does include all ecological impacts caused by fabrication of the building materials and components, transport of the materials to the site, maintenance, replacement and repair processes, operation of the building, and disassembly of the building over a lifetime of 50 years. Life expectancies for different building components were taken into account (e.g. 25 years for mechanical systems) by adding the ecological impacts of replacing the different components at appropriate intervals. Calculations were done with the online tool Sustainable Building Specifier [2], complemented by additional spreadsheets where data was not available within the tool. The tool calculates LCAs based on different data bases, in our case ökobau.dat 2011.

We calculated a complete set of impact categories, but gave most consideration to global warming potential (GWP) and primary energy (PE) demand. Since energy demand and the related global warming effect are the cause for melting permafrost, they are strongly related to the instability of the existing hut. We contribute to building longevity directly by minimizing

GWP and PE demand of the new hut and indirectly by setting a positive example which will be visited by many hikers and climbers.

Comparison of life cycle phases

Typically, the results of building LCAs are highly influenced by the use phase of the building, especially through fossil energy use. The design of this alpine hut deviates from average buildings in several aspects: the strict use of renewable energy sources reduces the operational energy impacts to virtually zero. On the other hand, higher energy consumption is expected due to helicopter flights that are necessary to transport all of the building materials and equipment to the remote building site. They are integrated in the LCA, although standard building LCAs normally do not account for the transport from the material production site to the construction site. These aspects shift the focus of the LCA towards the construction, maintenance and disassembly of the hut. The results are therefore mainly influenced by the choice of building materials.

Figure 2 shows the distributions of the primary energy and the global warming potential (GWP) over the life cycle phases of two designs representing opposite ends of the value distribution.

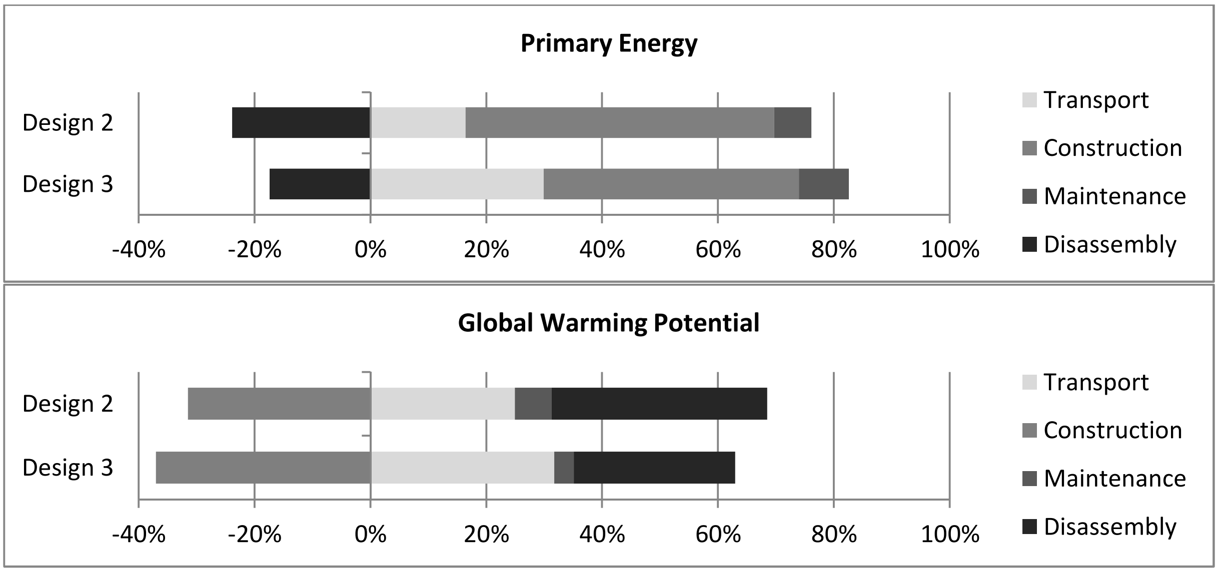

Figure 2: Distributions of the primary energy and the global warming potential over the life cycle phases of the alpine hut

The use phase, represented by maintenance in figure 2, has the lowest environmental impact. As the designs are optimized towards durability, the bulk of the materials does not have to be exchanged during the 50 year life cycle.

The construction materials are the main influence on the LCA, as opposed to the operational energy for average buildings. Two main consequences for an optimized material choice result from figure 2:

1. Contrary to other LCAs, the transport has to be incorporated in this case. It accounts for up to 30 % of the primary energy and the global warming potential respectively. As a consequence, light-weight materials are preferred in the design of the hut. Additionally, parts of the existing old hut can be re-used as they do not have to be transported to the site.
2. The negative GWP values indicate optimized material choice and can only be achieved by choosing renewable materials like wood. Alternatively, in the case of a solid construction, an optimized re-use of the materials of the old hut can decrease the environmental impacts.

Optimal material and supply strategies

The analysis of the design data of four initial designs shows that the proposed buildings vary greatly in volume and envelope area [figure 3]. During the following design process, two different strategies were chosen by the interdisciplinary teams. Teams 1 and 4 decided to concentrate on optimizing material and system choices, whereas team 2 significantly reduced the volume of their project. Team 3 opted for a complete redesign, only marginally reducing volume and area.

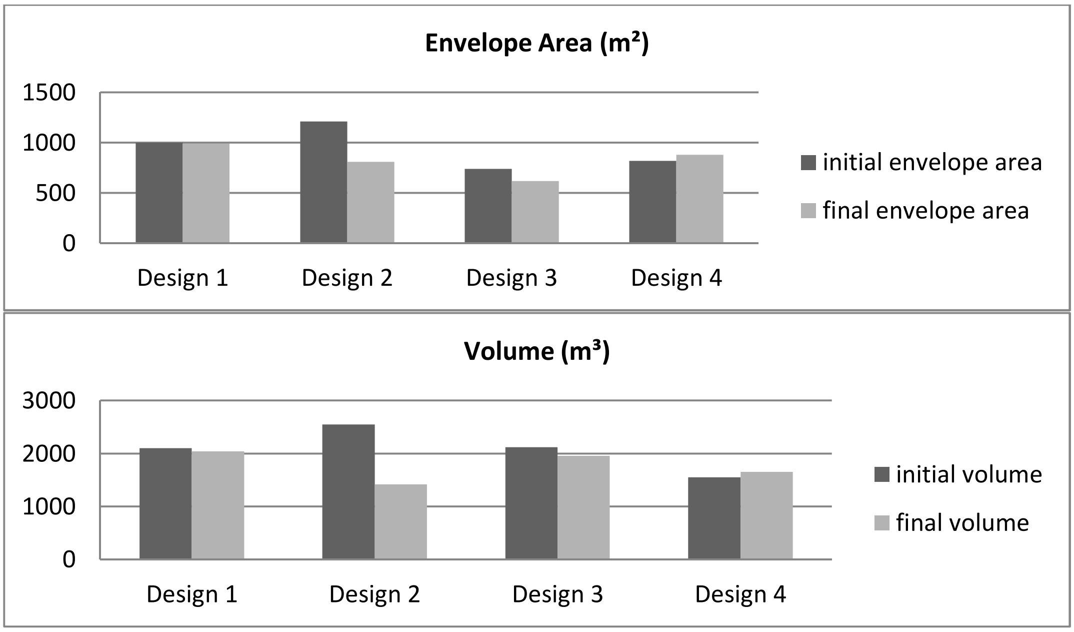

Figure 3: Envelope area and volume comparison of the four initial and final designs

Reducing building size and optimizing material choices

Design team 2 greatly reduced the volume and envelope area of the building, e.g. by changing the accommodation spaces from rooms of hotel standard to rooms with bunk beds as they are common in alpine huts. Circulation areas and sanitary facilities were redesigned in a less generous fashion. Additionally, the team replaced most of the heavy building elements by lighter materials. For example, a thermal storage wall which was initially planned to be built out of concrete included wood and phase changing materials in the final design. These changes resulted in a weight reduction of the building from 256 to 125 metric tons, greatly reducing the need for helicopter flights for material transport. Figure 4 shows the result: The optimized design uses 36 % less primary energy and the GWP of the optimized design is reduced by 46 % compared to the original design.

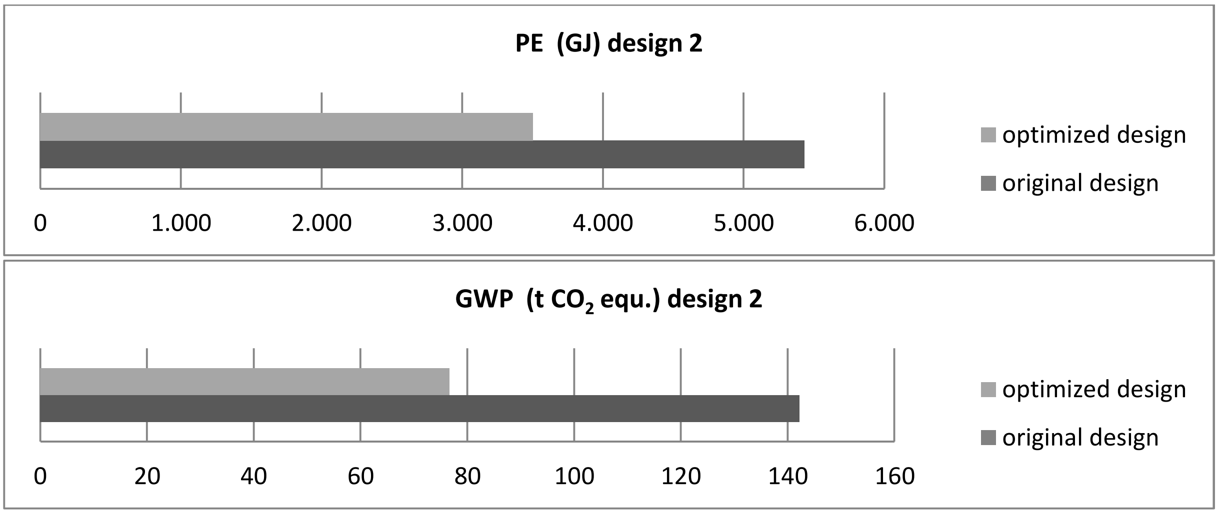

Figure 4: Comparison of PE demand and GWP of original and optimized design 2

Effect of complete redesign

As mentioned, design team 3 decided to completely redesign the building. The original shape was replaced by a simpler design built with more sensible construction techniques and using more robust building technology. For example, the original slab foundation was replaced by pile foundations using less concrete and the original aluminum cladding was replaced by wood. Energy supply was shifted from PV cells with batteries to air collectors covering the entire roof. The overall weight of the building was reduced from 246 to 170 metric tons, although the built volume stayed almost the same (see figure 3). Generally, the redesign aimed to include features that would generate energy and absorb CO_2 rather than merely reducing negative impacts. Figure 5 shows the effect of this redesign process:

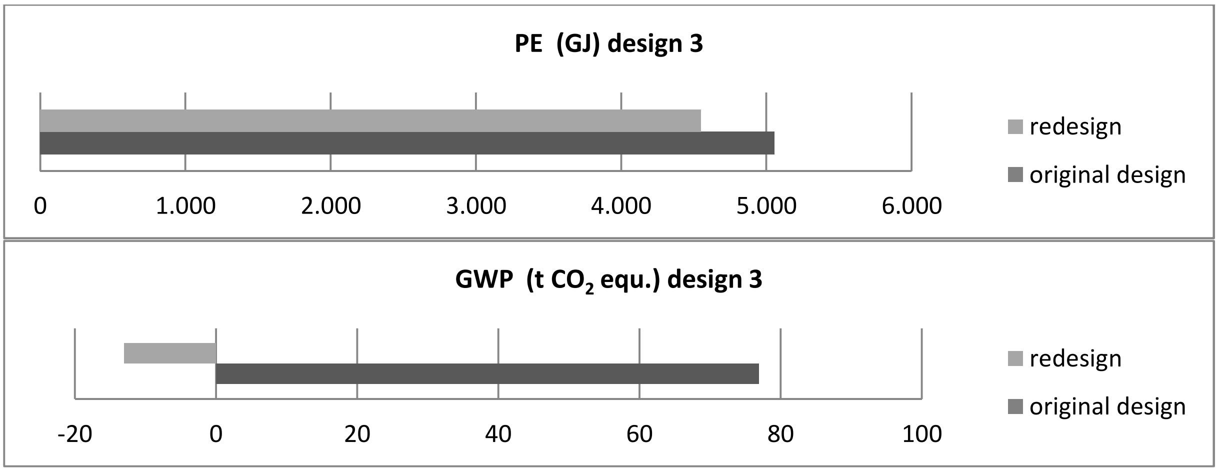

Figure 5: Comparison of PE demand and GWP of original design and redesign of design 3

Overall PE demand was reduced by 10 %, increasing the renewable part from 52 % in the original design to 78 % in the redesign. GWP was switched from a positive value indicating that CO_2 is released into the atmosphere to a negative value showing that CO_2 is absorbed. This stems from the fact that almost exclusively wood and other renewable materials were used.

Optimization strategies: better insulation or larger energy systems?

To investigate the potential savings achieved by optimizing material choices in more detail, we used the quality and amount of insulation of the exterior walls of design 1 as an example. Figure 6 shows the different versions of the design.

Design Version	Construction	Insulation	Energy supply	Transparent facade
1.1	Solid wood	No	Air collectors and rock storage	9 %
1.2	Wood frame	Yes	Air collectors and rock storage	9 %
1.3	Wood frame	Yes	Air collectors and rock storage	25 %

Figure 6: Design versions project 1

For this particular design, the uninsulated version 1.1 has the lowest GWP (60 % less than version 1.3, which has the highest GWP), since only solid wood is used for the exterior walls. It also shows the lowest demand for non-renewable PE (35 % less than version 1.2). These calculations show that better insulation may result in a larger ecological impact for the construction of the building. Since the building's energy supply comes from renewable sources, it might appear that it is therefore ecologically preferable to use as little insulation as possible. However, the lack of insulation demands larger systems for energy supply. These systems in turn have their own ecological impacts and must be exchanged frequently, especially in the harsh climatic conditions of our case study. This frequent replacement also increases the need for helicopter transport causing a large share of the overall GWP and PE consumption of the hut (see figure 2). For this particular design a small amount of insulation keeping the building frost-free in the winter is the optimum strategy, since the building uses air collectors and rock storage, a very robust system. The increase in operational energy caused by the smaller amount of insulation is compensated by a larger rock storage wall. Since this storage wall is built out of rocks from the site and the existing building, no transport or production energy is required.

In the case of design 4, however, a similar investigation shows a different picture. This design uses PV cells and battery storage for the entire energy supply, backed up by a wood burning stove for emergencies only. Since the PV cells and batteries need to be replaced every 20 years, two replacements are necessary over the 50 year life cycle. In this case, the optimum strategy is to provide exterior walls insulated with cellulose to reduce heating demand to keep the size of the PV and battery equipment small, and thereby minimize ecological impacts caused by replacing the building technology.

Conclusions

Our calculations show that the LCA results of this secluded alpine hut are not comparable to LCAs done for a regular building connected to an energy supply grid and transport infrastructure. Helicopter transports have to be included since they significantly increase the ecological impact. The operational energy from renewable sources, on the other hand, influences the LCA positively. This leads to an increased importance of the building materials over the whole life cycle. Also, robust building technology should be selected; otherwise, frequent replacements would augment the transport impacts.

The design approach has to be adapted compared to standard buildings. Basic concept considerations and teamwork right from the start are fundamental in achieving optimized solutions both from an ecological as well as from a design perspective. LCA calculations should accompany the entire design process, so that building design and LCA calculations are refined in parallel and can interact in a positive fashion. Therefore, LCA comparison of design alternatives as well as for details such as different materials should be included in early design stages.

Our study shows the potential of interdisciplinary teams using LCA as an ecological optimization tool during the design process. In an interdisciplinary process primary energy demand can be reduced by a significant amount and overall ecological impacts can be minimized. If the entire team cooperates, it can even be achieved that CO_2 is stored in the building rather than released into the atmosphere.

Acknowledgements

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References

[1] Design 1: Samuel Harm, Manuel Margesin, Agatha Link (students of architecture); Sarah Heisig, Simon Marold
Design 2: Samuel Mora, Carolina Sepulveda (students of architecture); Carla Joas, Ursula Kellerer (students of civil engineering)
Design 3: Mariya Georgieva, Franziska Schlenk (students of architecture); Claudia Aderbauer, Daniela Setzer (students of civil engineering), Judith Lennartz (student of energy efficient and sustainable building)
Design 4: Markus Bobik, Michaela Eizenberger (students of architecture); Benjamin Kurmulis, Caroline Martner (students of civil engineering)

[2] Sustainable Building Specifier: www.sbs-onlinetool.com