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Benefits of wooden structure reuse: the case of an Austrian building

E Hoxha[1, 3*], B Soust-Verdaguer[2], M Scherz[3] and A Passer[3 *]

[1] Department of the Built Environment, Aalborg University, Denmark.
[2] Instituto Universitario de Arquitectura y Ciencias de la Construcción, Escuela Técnica Superior de Arquitectura, Universidad de Sevilla, Spain.
[3] Working Group Sustainable Construction, Institute of Structural Design, Graz University of Technology, Graz, Austria.

[*] Corresponding author: enho@build.aau.dk, alexander.passer@tugraz.at

Abstract. The building sector is responsible for 39% of greenhouse gas (GHG) emissions; thus, it has a significant amount of potential to reduce the effects of climate change. Several active- and passive solutions and strategies have been developed and proposed in the literature. Among them, wood is highlighted as a promising solution to minimize GHG from buildings. However, the benefits, especially in the circular economy, are not fully evaluated due to methodological choices. Motivated by this knowledge gap, this article aims to evaluate the benefits of wood reuse compared to traditional building construction solutions. For this purpose, we have calculated the environmental impacts of a building situated in Graz, Austria. Four different scenarios are considered. The first scenario is a fully reinforced concrete building. The second scenario is a structural beam-column made from reinforced concrete with walls made of concrete blocks. The third scenario is a beam-column made from reinforced concrete with external walls based on clay blocks. Finally, the last scenario is a full wooden building. Following the standardized life cycle assessment (LCA) method, global warming potential (GWP) is calculated through a 0/0 approach. These evaluations were made possible by correlating the impacts released from producing wooden elements and the uptake of biogenic carbon from the forest. Without considering the possibility of material reuse, the wooden structure has a 5 % lower GWP value than the reinforced concrete building. Comparatively, the other building scenarios have almost similar impacts as the building in reinforced concrete. In the case of material reuse, the wooden structure building shows potential to develop projects with 44% lower environmental impacts.

Keywords: wooden construction, life cycle assessment, circular economy, material flow analysis, multi cycling.

1. Introduction

Additional efforts from building professionals should be devoted to developing low-carbon projects to achieve the targets set by the Paris Agreement [1-3]. Various strategies and solutions have been developed over the last 30 years, primarily focusing on minimizing the environmental impacts of the building's operational stages [4-9]. Active solutions such as furnaces, boilers, heat pumps, electric space heaters, and efficient wood-burning heaters have reduced the energy required for heating, cooling, and hot water and, consequently, the impacts on buildings [10-12]. Furthermore, scientists have developed photovoltaic panels to reduce reliance on energy from the grid for appliances [13].

Several projects have developed and implemented passive solutions for external walls, roofs, and smart design strategies [14-15]. Modern building designers have various solutions for reducing the environmental burdens related to the operational stage of the building. Several net-zero buildings have been designed and constructed [16-18]. However, to reach the targets set in the Paris agreement, the embodied impacts related to the materials employed in the building projects represent the next targets where the effort should be focused [19]. The employment of materials with low embodied impacts, such as wood, is promising [20-23]. However, studies have shown disagreements in recommending wood as a solution with low embodied impacts due to methodological reasons [24].

The increased disagreement has mainly come from the assessment methods, which create confusion and the end-of-life scenario of the timber components of the building. Motivated by this research gap, we aim to analyze the benefits of reusing timber components in the building. Several building scenarios with different materials are compared, and the benefits of wood and its end-of-life scenario for possible reuse of timber elements are analyzed.

2. **Method**

This section describes the method applied for assessing building scenarios' environmental impacts. The life cycle assessment (LCA) methodology, as recommended in the European Standard EN-15978 [25], is followed to calculate the environmental impacts. This standard suggests breaking down the building according to its life cycle stages: production (A1-A3), transport (A4), constitution (A5), use (B1-B7), end of life (C1-C4), and benefits or loads (D) beyond building life cycle. Based on the study's aims, the system boundary is limited only to the building fabrics over the life cycle stages of production (A1-A3), transport (A4), replacement (B4), end of life (C1-C4), and benefits (D). The scenarios are evaluated on the same functional unit, defined as a square meter energy floor area over one year (m^2_{ERA}/yr). The building scenarios are considered with a reference study period of 50 years. This study focused only on the global warming potential (GWP) indicator, relying on the characterization factors published in the IPCC 2013 report [26].

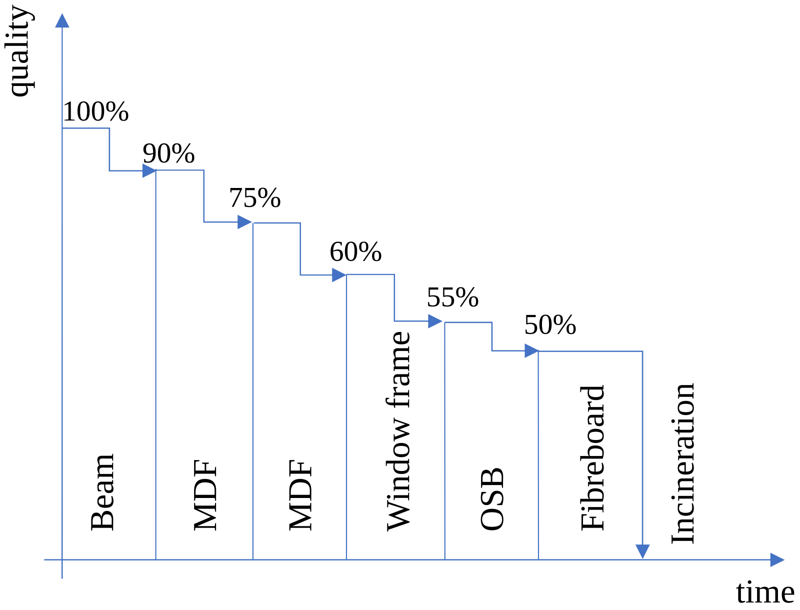

Figure 1: Scenarios of wood reuse in consecutive building life cycles.

In the case of wooden elements, biogenic carbon is calculated through the 0/0 approach [27]. According to this approach, only emissions related to fossil energy sources are considered. The impacts related to biogenic carbon emission are not included in the calculation of the GWP score since the 0/0 approach assumes carbon uptake by the trees during their growth will be released at the end of the life cycle when wooden elements are burned or landfilled. In the case of the wooden building, its elements are considered to be reused in the future. The percentage of wood element reuse in a consecutive building life cycle is presented in Figure 1.

The benefits of wooden elements reused beyond the building life cycle are allocated through the cut-off method. According to this method, the impacts of reused building components are accounted for in the life cycle stages where the elements experience end of life [28-29].

Finally, biogenic carbon uptake from forest regrowth is calculated through the PAS-2050 method [30]. The Ecoinvent database v3.6. [31] provides background data for calculating the impacts considering the system model “Allocation, recycled content.”

3. **Case study**

In order to analyze the benefits of wooden structure reuse, life cycle assessments (LCAs) were performed on four different scenarios. The first scenario is a concrete block building, the second is a clay brick building, and the third is a timber building. The Electronics Based Systems Building (EBS) was used for the architecture feasibility scenarios as a reference case study (see Figure 2). Three scenarios’ derivatives of the reference building present simplified cases and are used only for preliminary development concepts. The EBS building is located on the Graz University of Technology campus and serves as a research and development center for sensor technology and microelectronics.

The six-story building is a mix of laboratory space with office-like infrastructure (e.g., computer labs and measurement labs without special requirements) and traditional office space. Its structural components, such foundations, floors and external walls, are mainly in reinforced concrete. To assume the thermal insulation of the building various materials are employeed. The windows are in wooden/ aluminium frame and have triple glazing. Gypsum plasterboards and metal stud framing are used for the non-load-bearing walls separating the office spaces and sanitary facilities. The standard HVAC szstems are supported by supplement ventialation and colling systems in the spaces of the laboratories and server room. The operational energy demand is 289 kWh/m$^2_{ERA}$/year. The detailed life cycle inventory of the building can be found in [32]. The original scenario of the EBS building is then adapted to other scenarios.

Gross Floor Area (GFA) (Area a - acc. to ÖN B 1800:2013)	5.412,34 m^2
Net Floor Area (NFA) (Area a - acc. to ÖN B 1800:2013)	4.560,28 m^2
Energy Reference Area (ERA)	4.204,20 m^2
Gross Building Volume (Area a - acc. to ÖN B 1800:2013)	21.671,25 m^3
Energy Consumtion acc. to Element Design	289 kWh/m2$_{ERA}$a
Energy Consumtion acc. to Energy Certificate	96,5 kWh/m2$_{ERA}$a

Figure 2: EBS building – Key facts [32].

The external and internal walls were executed as concrete block constructions for the second scenario. The thickness of the external wall is about 46 cm, and the structure consists of five layers. On the inside of the external wall, a plaster coating was applied. Concrete blocks formed the load-bearing layer with a thickness of 15 cm, connected with adhesive mortar. XPS thermal insulation with a width of around 22 cm was installed between wooden battens. The wooden counter-battening measured about 6 cm, and on the outside of the wall, a zinc sheet was mounted. The internal walls were made with 9 cm thick concrete blocks, which were also connected with adhesive mortar. A plaster coating was applied on the outside and inside of the internal wall. The roof structure was about 48 cm, with a plaster coating also applied on the inside. The horizontal bearing layer was made of a 20 cm thick reinforced concrete slab, onto which 10 cm of masonry concrete was applied. After the vapor barrier, a 4 cm thick thermal insulation made of PUR was installed, on which the bituminous sealant and a protective film were applied. On the outside, a ballast of 4 cm in gravel was used. The ceiling construction was about 30 cm. On top, a vinyl floor was installed, while underneath, there was a cement screed with a thickness of 7 cm, followed by the PE film and 2 cm thick acoustic insulation made of rock wool. Finally, a compression screed with a thickness of 5 cm was applied on the concrete slab of 15 cm. On the ceiling underside, a plaster coating was applied.

The difference between the clay brick and concrete block scenarios is in the wall material. In the former, instead of concrete blocks, clay bricks were used with a thickness of 15 cm for the external walls and 9 cm for the internal walls. The structures for the roof and ceiling remained unchanged in this scenario.

The last scenario features timber components. The external wall in this scenario had a thickness of about 35 cm. The layered structure consisted of plasterboard (1,5 cm), a wooden batten (9 cm), an OSB board (2 cm), a vapor barrier, a wooden counter-batten (18 cm) with rock wool insulation, an MDF board (4 cm), another layer of rock wool insulation (4 cm) and a mineral cement board (1cm). The thickness of the internal wall was about 19 cm. On the inside and outside, plasterboard panels were mounted. Between them was a wooden frame with a thickness of 8 cm, filled with glass wool. The roof structure was about 35 cm. On the underside of the roof, plasterboard (1,5 cm) was installed, followed by a vapor barrier, wooden lathing, and rock wool insulation with a thickness of 16 cm each. After that, a multiplex board (2 cm) and another insulation layer of PUR (2,5 cm) were mounted. Finally, the bituminous sealant, protective film, and gravel ballast (4 cm) were applied. The ceiling was around 15 cm in the timber scenario. Once again, the floor was vinyl, mounted on a dry screed panel (2,5 cm). A PE membrane film was applied, followed by the PE film and an OSB board (2 cm). The acoustic insulation consisted of glass wool between wooden battens (18 cm). Finally, a wooden counter-battening (4 cm) and plasterboard (1,5 cm) were applied.

4. **Results**

Figure 3 summarize the results for the global warming potential (GWP) indicator results of four building scenarios analyzed in this study. The base scenario of the EBS building has an impact equal to 10,53 kg $CO_2e/m^2_{ERA}yr$. The other concrete block, clay brick, and timber scenarios have GWP scores equal to 10,41 kg $CO_2e/m^2_{ERA}yr$, 10,71 kg $CO_2e/m^2_{ERA}yr$, and 10,08 kg $CO_2e/m^2_{ERA}yr$, respectively. Although the scenarios are significantly different in terms of their material composition, the final GWP score shows slight variation. With a relative difference of 1,1 %, the concrete blocks scenario presents a lower environmental impact than the original building, which was made mainly from reinforced concrete. On the other hand, the scenario in clay bricks has a relative GWP score of 1,8 % higher. While the scenario in timber with 4,3 % relative lower impacts presents the case with more considerable significant differences.

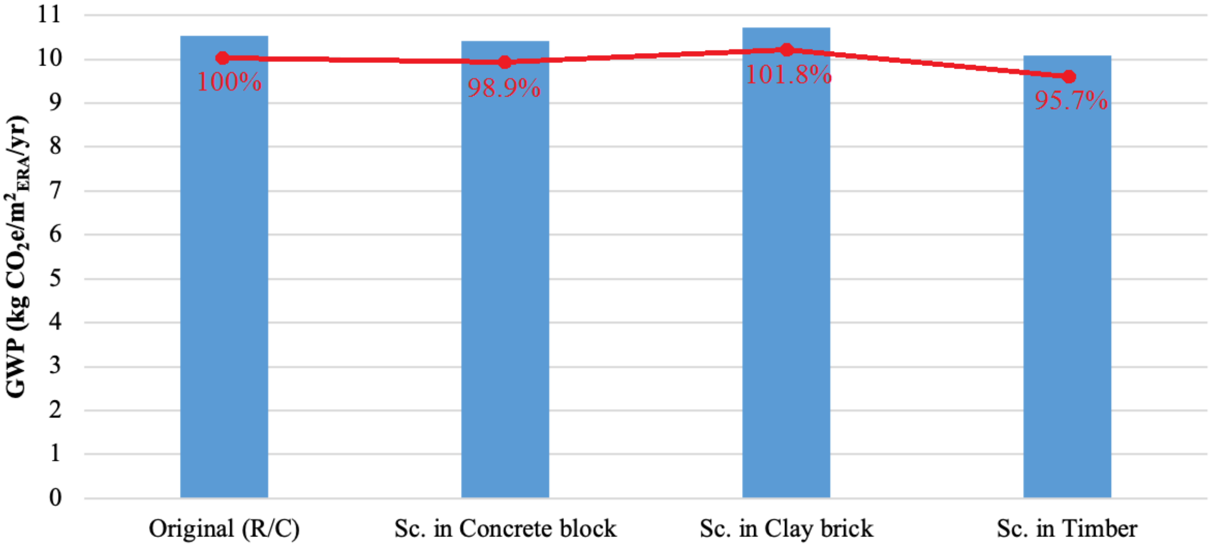

Figure 3: Environmental impacts of four EBS scenarios

To better analyze the impacts of each scenario, Figure 4 presents the relative contribution of each building component to the overall GWP score. Slabs are the building components with the largest contribution to overall impacts and present a contribution of 28,3 % in the original scenario. For the other scenarios, the slabs contribute around 22% - 23 %. In absolute value, the GWP score of slabs in the timber building scenario is equal to 2,28 kg $CO_2e/m^2_{ERA}yr$. It presents a lower value than the original, having an impact equal to 2,98 kg $CO_2e/m^2_{ERA}yr$. For the two other scenarios, the impacts of the slab are equal to 2,38 kg $CO_2e/m^2_{ERA}yr$. Referring to the original scenario, the foundation's second contributor to the impacts. A GWP score equal to 2,04 kg $CO_2e/m^2_{ERA}yr$ has a relative contribution equal to 19 % - 20 % in all scenarios. Roofs present the third most impactful building component. The original scenario has a contribution equal to 18%, but for the rest, the contribution is as low as 11,6 % for the clay bricks and 16,1 % in the case of timber. This component has a GWP score equal to 1,89 kg $CO_2e/m^2_{ERA}yr$ in the case of the original scenario, while for the concrete blocks and clay bricks equal to 1,25 kg $CO_2e/m^2_{ERA}yr$. In the case of timber building, the impact of the roof component is equal to 1,62 kg $CO_2e/m^2_{ERA}yr$. In all building scenarios, the windows and doors with an impact equal to 1,82 kg $CO_2e/m^2_{ERA}yr$ are the components ranked fourth in terms of their contribution to overall impacts.

Walls have lower contributions to the overall impacts of the original scenario. The internal and external walls contribute respectively with 3,3 % and 13,6 % and a GWP score equal to 0,35 kg $CO_2e/m^2_{ERA}yr$ and 1,43kg $CO_2e/m^2_{ERA}yr$. However, in the case of concrete block and clay brick scenarios, the external walls are the components presenting the most significant contributions. In the clay brick scenario, the external wall has an impact equal to 3,05 kg $CO_2e/m^2_{ERA}yr$ and a relative contribution of 28,4 %. The external wall contributes 26,4 % to the impact in the concrete block scenario and has a GWP score of 2,75 kg $CO_2e/m^2_{ERA}yr$. Meanwhile, in the timber scenario, the external walls have an impact equal to 1,85 kg $CO_2e/m^2_{ERA}yr$, and their contribution is 18,4 %. The findings show that foundations and slabs have the largest contribution, but, on the other hand, the walls offer the highest possibility of reducing the impacts of the building. Based on the results obtained, we can conclude that the external walls and slabs are the components with the largest contributions. Consequently improving their environmental impacts will have significant influence in the reduction of the GWP of building projects. The use of timber may hence provide a potential solution to reduce the impacts of the building.

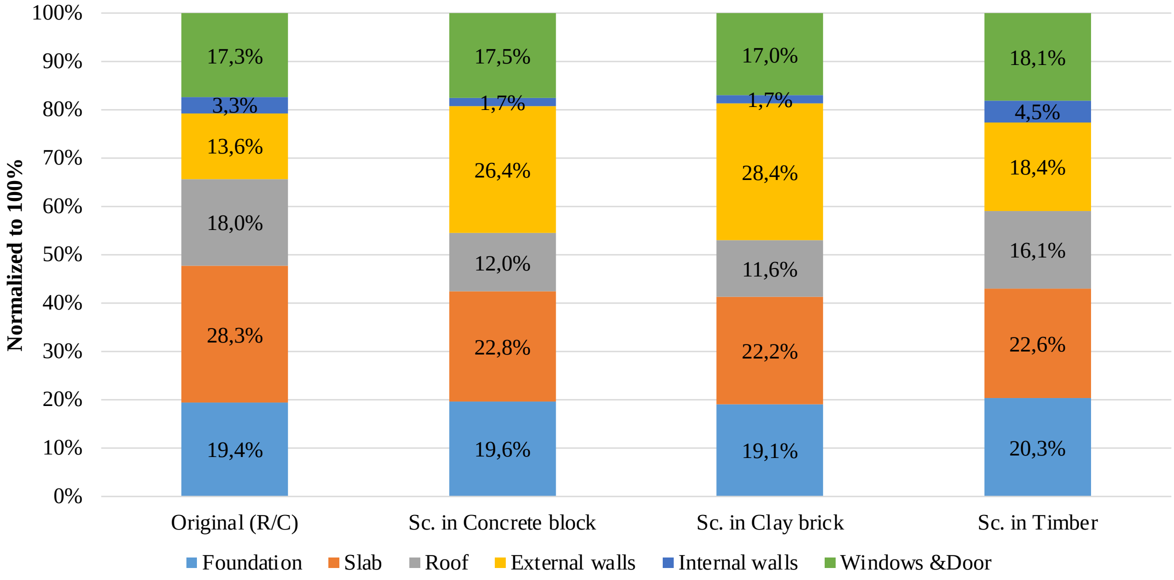

Figure 4: Global warming potential indicator of four building scenarios.

Figure 5 presents the reduction potential of the reuse of timber elements in consecutive building life cycle phases. Reusing wood in consecutive stages avoids the burdens of end-of-life stages. Consequently, the environmental impacts of timber building can be reduced by 0,3 %. Furthermore, the reuse of wooden elements will provide benefits in terms of impacts since it will avoid producing new building components from virgin recourses. The reuse of timber can reduce building impacts by up to 18 %. New trees are planted to reduce impacts due to the reuse of components in consecutive life cycle stages of buildings. The capture of carbon for the regrowth of new trees can significantly reduce the impact. Considering the overall impact reduction from the reuse of wood elements and regrowth of the forest, the GWP score of timber scenarios could be reduced by 44 %.

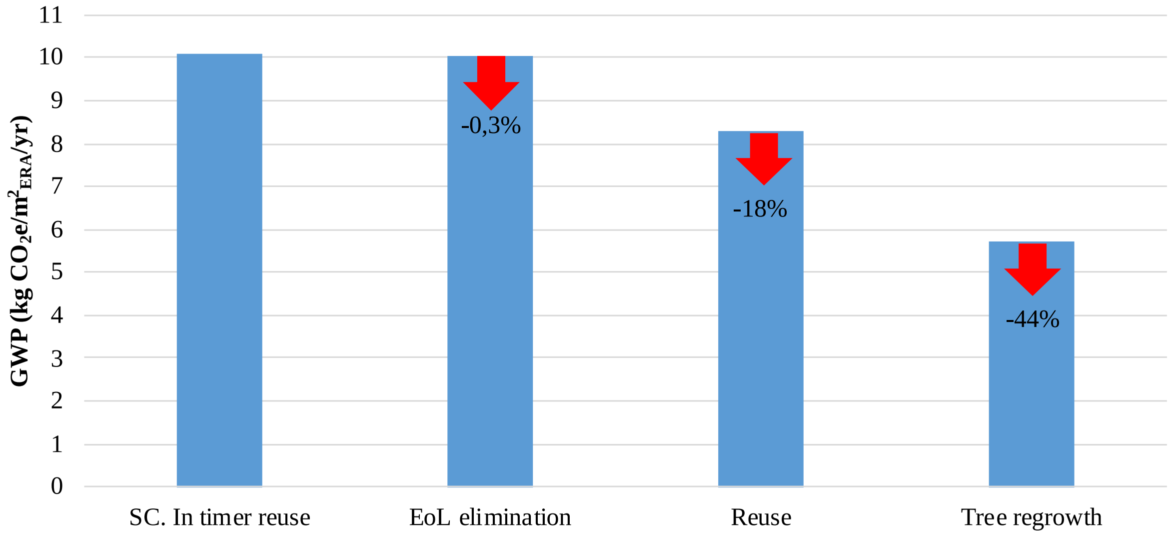

Figure 5: Reductions in the potential impacts of strategies

5. Conclusion

The results presented in this study show the potential to reduce buildings' environmental impacts by implementing alternative materials other than concrete. The use of concrete blocks shows an insignificant reduction in impacts; however, the use of clay bricks, on the other hand, increased and showed higher impacts than the building scenario with reinforced concrete. In addition, building scenarios with timber components presented the solution with a lower GWP score. To further reduce the impacts of buildings with timber elements, the reuse of components was considered in consecutive building life cycle phases. By reusing some building elements, the GWP score of the timber scenario reduced by 18 %. Moreover, due to the tree regrowth, building impacts reduced by 44 % in total.

Based on analysis of the relative contribution of building components in terms of overall impacts, we can conclude that the slab and walls show the largest contribution. However, an unexpected result occurs from the contribution analysis. In the case of the building in reinforced concrete the slab and foundations influenced mostly to the GWP indicator. Although these components had the largest contributions, the walls nevertheless showed the highest possibility of reducing buildings' environmental impacts.

Further research may still be needed to identify more specifically the quality of wood components in the end of life of building and alternative options to reuse these elements in other construction sectors.

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