FACTORS AND ISSUES RELATED TO THE ENVIRONMENTAL IMPACT CAUSED BY THE LIFE CYCLE OF TIMBER BUILDING CONSTRUCTION PROJECTS

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ABSTRACT

Timber construction offers a number of advantages in terms of environmental sustainability particularly in comparison to other construction technologies such as concrete construction. Although the calculation of the environmental impact caused by the life cycle of a timber construction project provides results that display some of these advantages, it is also necessary to examine the manner in which timber construction should move forward in order to maximize its sustainability potential. The aim of the current research is to determine the key factors and issues that are related to the environmental impact caused by timber construction and thus provide the basis for future considerations regarding the optimal delivery of such projects. A timber building is used as the basis for the calculations that are used to quantify the influence of the issues examined. Furthermore, the conclusions that are derived highlight recommendations intended for application in similar projects, while also providing suggestions for the way forward regarding sustainable practice within the timber building sector.

1 INTRODUCTION

All construction technologies utilize certain materials that are used to erect the various types of structures commissioned. Concrete construction mainly requires large quantities of concrete and also steel reinforcement bars, steel construction utilizes steel structural elements and timber construction utilizes wood. A significant difference in regard to these materials that are used for construction is that structural timber products require relatively less processing in regard to their manufacturing. While concrete requires the acquisition of raw materials such as gravel, sand and cement and steel can be produced either by the primary steelmaking route or based on recycling, timber products usually require much simpler manufacturing processes that are only required for the shaping of the final product and its protection against weather conditions, insects and fire.

Although wood is a material that does not exist in infinite resources, the total environmental impact of the manufacturing of structural timber elements appears to be less in comparison to other construction materials. All materials require certain quantities of raw materials, with the exception of those that can be recycled. However, even in these cases -steel, for example- the production processes required for the manufacturing of structural steel products increase the total environmental impact of the final products. Furthermore, recycling is a major advantage of timber products as well. In this case, timber elements are manufactured from the fibers of previously used wood that has been successfully retrieved and chipped.

Besides, there is also a number of other factors that influence the environmental impact caused by the life cycle of a timber structure. The current research quantifies the influence of a selection of such issues as highlighted by relevant research, in terms of the total environmental impact of a structure's life cycle. An existing timber building is used as the basis for the calculations and each factor is examined individually, while the remaining parameters are kept constant.

2 METHODOLOGY

2.1 Life cycle assessment (LCA)

The examination of the manner in which any aspect affects the total environmental impact of a building's life cycle requires, initially, the quantification of this impact. For the research presented, the life cycle assessment (LCA) methodology is used to achieve this quantification. LCA allows for the consideration of various factors of a building's life cycle and also provides tangible environmental impact assessment results [3]. The application of this methodology consists of four main steps, as displayed in Figure 1.

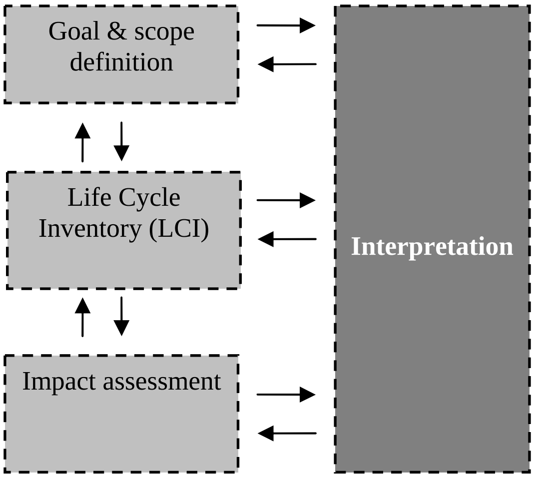

Figure 1. The four main stages of a life cycle assessment (LCA) analysis [2]

The first stage refers to the definition of a set of theoretical parameters that essentially describe the purpose and the extent of the LCA analysis. For the current research, the goal of the analyses is the quantification of the total environmental impact of the life cycle of the selected timber building. The scope of these analyses includes the acquisition of raw materials required for the construction of the building, their transport to the site and their handling at the end of the building's life cycle and after the decision for demolition has been made [4]. It is noted that the operation stage of the building or any maintenance processes are not included in the calculations, while the functional unit used is the construction of one timber building.

For the life cycle inventory (LCI) stage, the environmental datasets required for the LCA are used as found in existing LCI databases such as the Ecoinvent LCI database, the IDEMAT 2001 database or the European Life Cycle Database (ELCD) which contains a significant volume of environmental data for the European region [6]. The impact assessment is conducted according to the Global Warming Potential (GWP) methodology, which provides single index results based on the carbon dioxide (CO_2) emissions of the project's life cycle to the air.

2.2 Timber building and life cycle factors

The timber building which is used as the basis for the calculations is a ground floor industrial building with a plan view of 15 x 10m (Figures 2a,b,c). Its structural system consists of a series of four timber load-bearing frames. The main construction materials required for the construction of the building are 22.5m^3 of structural timber, 156.6m^2 of steel covering panels for the roof of the building and 265m^2 of steel wall panels.

The issues related to the life cycle of the timber building that are examined are presented in Table 1 along with a brief description. Each refers to a different life cycle stage, ranging from raw material acquisition (type of wood) and construction (material transport distances) to end-of-life scenarios (wood materials waste treatment).

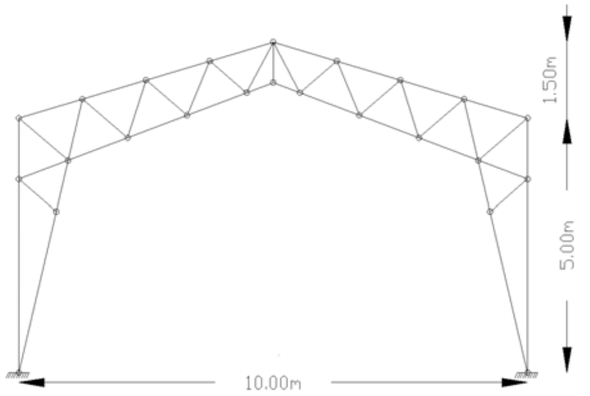

Figure 2a. Main structural frame of examined timber building [5]

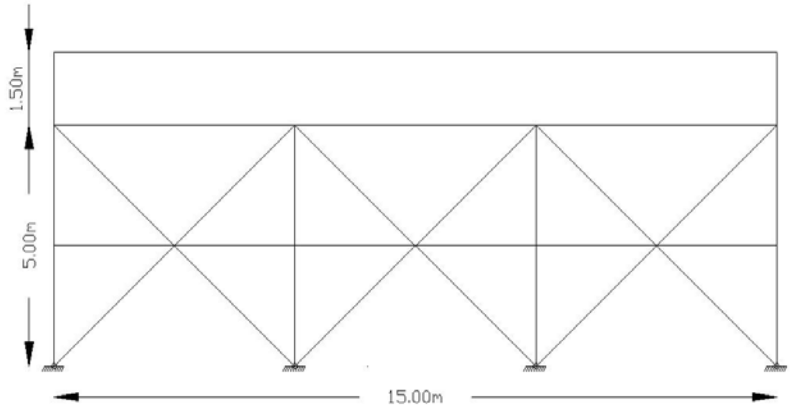

Figure 2b. Side view of examined timber building [5]

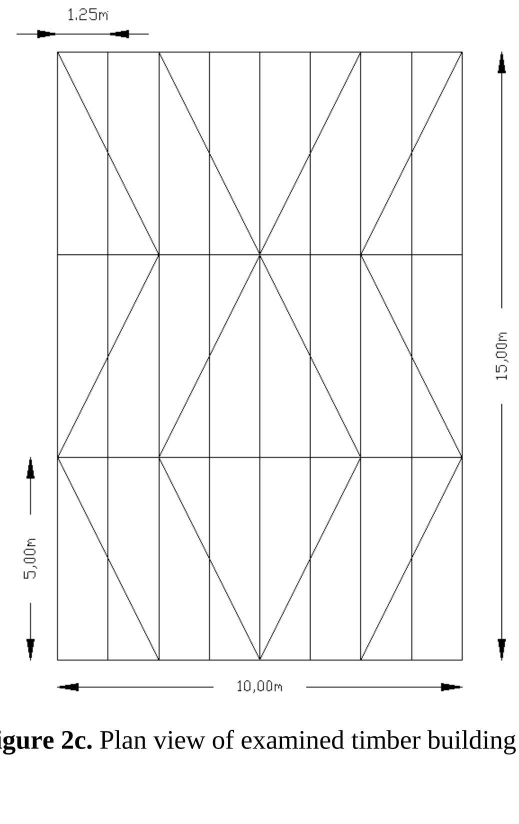

Figure 2c. Plan view of examined timber building [5]

Table 1. Factors related to the timber building's life cycle that are examined

Life cycle aspect	Description
Type of wood used	Refers to the selection of the type of wood to be used for the construction of the structural frame of the timber building
Materials transport distance to site	Refers to the distance assumed for the transport of the construction materials from the suppliers to the site
Retrieved materials transport distance	Refers to the distance assumed for the transport of the construction materials that are retrieved at the building's demolition stage
Waste treatment of wood materials	Refers to the different options for the handling of the retrieved wood construction materials at the building's demolition stage

3 LIFE CYCLE ASSESSMENT (LCA)

3.1 Type of wood

Structural timber can be manufactured from many available types of wood. Each type has its own advantages and disadvantages, which are mostly related to material and mechanical properties such as strength or durability, but are also often of economic nature. It is also expected that each type of wood affects the total environmental impact of a timber structure's life cycle in a different way. For the current analysis, the impact of the selected timber building's life cycle is calculated for a series of available types of wood used in construction. These types of wood include hardwoods such as oak and teak which have broad leaves and also softwoods such as spruce and pine (pitch pine) which have needlelike or scalelike leaves. It is noted that these two categories are not in regard to the hardness of the wood, as some hardwoods have softer wood that softwoods and vice versa [1].

In regard to the other life cycle issues, the distance for the transport of the construction materials from the suppliers to the site is assumed to be 40 km, while the distance for their transport to the various waste treatment facilities (recycling plants, landfills, etc.) is assumed to be 100 km. In regard to the waste treatment of the retrieved construction materials at the end of the building's life cycle, it is assumed that 80% of the timber materials is successfully retrieved and sent for recycling, while the remaining 20% is considered irretrievable and is therefore disposed of in landfills. For the steel materials used for the walls and roof of the building, it is assumed that 90% is retrieved and sent for recycling, while 10% is considered irretrievable and disposed of in landfills.

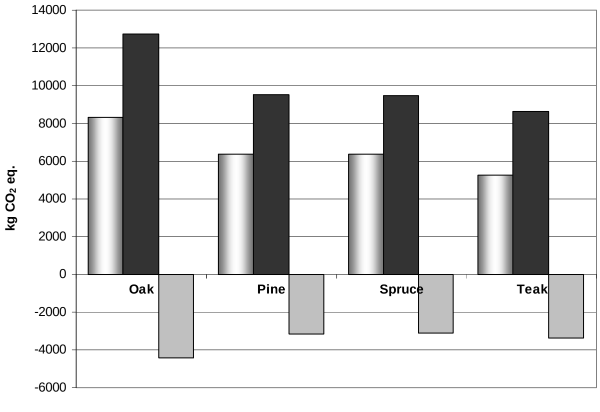

Figure 3. Environmental impact of timber building's construction and recycling scenario for oak, pine, spruce and teak wood

The environmental impact results for the life cycle of the timber building are presented in Figure 3. As can be observed, the impact caused by the building's construction with each type of wood varies for each type of wood that is used. The highest total life cycle environmental impact is caused by the oak wood (8320kg of carbon dioxide equivalent), followed by the pine and spruce life cycles (6375 and 6361kg of CO_2 eq.), while the teak life cycle causes the smallest total impact of 5272kg of CO_2 eq. The impact caused by the construction of the building also varies from 12756kg of CO_2 eq. (oak building construction) to 8620kg of CO_2 eq. (teak construction). The recycling scenario provides similarly varied environmental benefits, with the largest benefits being observed for the oak building life cycle -4436kg of CO_2 eq. -the negative values referring to environmental benefits rather than burden).

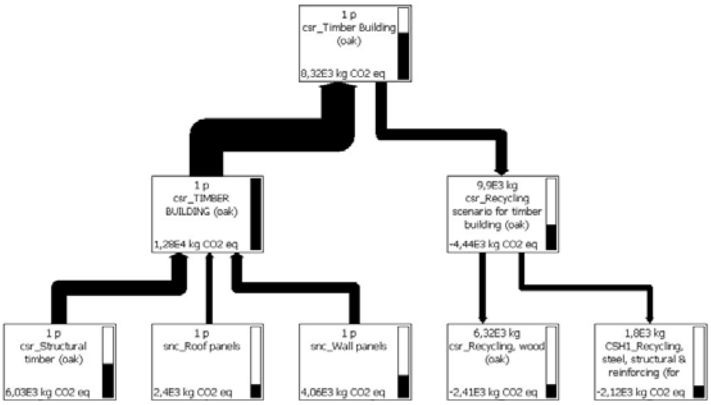

Figure 4. Environmental impact flow for the life cycle of the oak pine wood timber building

It is therefore obvious that the type of wood used in timber building projects can have a noticeable effect on the environmental impact caused by the construction of the building, the total impact of its life cycle and the potential recycling benefits at the end of the building's service life. In regard to the recycling scenario and as the environmental impact flow network for the oak wood building's life cycle shows (Figure 4), it is actually the recycling of both the timber and steel construction materials that provide the largest percentage of environmental benefits.

3.2 Transport to site

The construction of the timber building requires a certain amount of materials to be transported to the site of the project from the various suppliers. The distance that has to be covered, along with the weight of the transported materials influence the environmental impact caused by the transport, which, for the current analyses, is assumed to be executed by road and with trucks. In order to examine the effects of the transport distance from the suppliers to the construction site, three scenarios are defined; the first with a 40km distance for suppliers that are in relatively close proximity to the site, the second with a 100km distance for suppliers that are further away from the site and the third with 300km for suppliers that are far from the project's site. It is noted that these distance scenarios are assumed on the basis that timber construction products are not as common as other types of materials such as concrete or steel-related materials and are thus likely to be found in fewer suppliers and in larger distances from the site.

In regard to the other life cycle issues, it is assumed that pine is used for the construction of the building, while the distance for the transport of the retrieved materials to the various waste treatment facilities (recycling plants, landfills, etc.) at the end of the building's service life is assumed to be 100km. It is also assumed that 80% of the timber and 90% of the steel materials are recycled, while the remaining 20% and 10% respectively are considered irretrievable and are therefore disposed of in landfills.

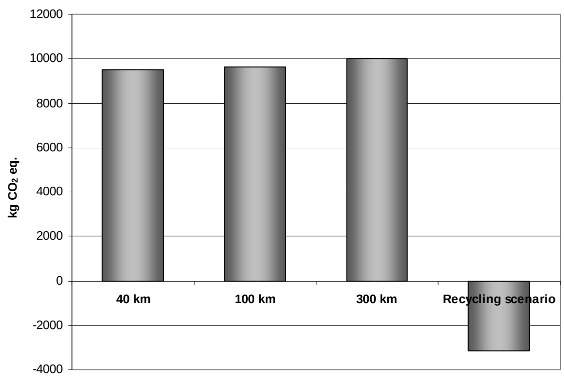

Figure 5. Environmental impact of timber (pine wood) building's construction for each transport distance to the site facilities and recycling scenario

Based on the above assumptions, the environmental impact results obtained for the construction of the building according to each of the three transport distance scenarios are presented in Figure 5. The environmental benefits provided by the recycling scenario, which are the same for each transport scenario, are also displayed. As expected, the environmental impact caused by the construction of the timber building slightly increases as the transport distance of the materials to the site is increased. The differences, however, are only slight. The impact of the 40km scenario construction is calculated at 9514kg CO_2 eq., 9629kg CO_2 eq. for the 100 km distance and 10013kg CO_2 eq. for the 300km distance scenario construction. It is therefore shown that the transport distance of the construction materials from the suppliers to the site has a relatively small effect on the environmental impact of the construction of the timber building. This can be attributed to the fact that both structural timber elements and steel sheet panels -the main construction materials used for the timber building- are relatively light. As a result, the environmental impact of their transport, which is mainly influenced by weight, distance and means of transport, is not as large as it would be in the case of heavier materials such as structural steel or concrete. With this in mind and in regard to timber building projects, it is preferable to select construction materials that cause lower environmental impacts when manufactured, even though they might be found in distant suppliers.

3.3 Transport to waste treatment facilities

At some point in time after its service life has ended, the timber building will be demolished. At this stage, the construction materials that are retrieved have to be transported to a number of waste treatment facilities such as recycling plants or landfills. These facilities are less in numbers in comparison to construction material suppliers and operate only in specific locations covering specific regions. As a result, the construction materials that are collected after a building's demolition often have to be transported across relatively large distances, thus causing noticeable environmental impact.

It is again assumed that all retrieved materials are transported by trucks and three scenarios are defined. For the first scenario a 100km distance is assumed, for the second a 300km distance and thirdly, a 500km distance is examined. In regard to the other life cycle issues, it is again assumed that pine is used for the construction of the building, while the distance for the transport of the construction materials to the site is assumed to be 40km. It is also assumed that 80% of the timber and 90% of the steel materials are recycled, while the remaining 20% and 10% respectively are considered irretrievable and are therefore disposed of in landfills.

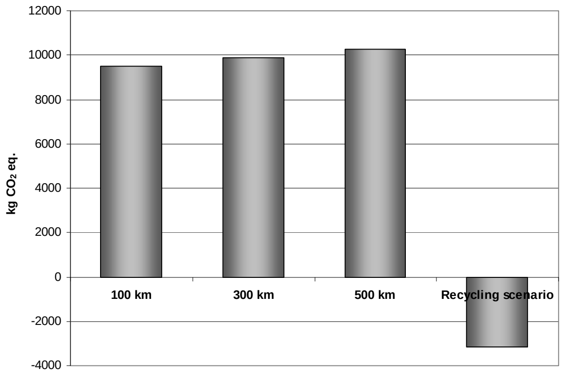

Figure 6. Environmental impact of timber (pine wood) building's construction for each transport distance to waste treatment facilities and recycling scenario

The environmental impact results obtained for the construction of the building according to each of the three distance scenarios, along with the environmental benefits of the recycling scenario -the same for each transport distance scenario- are presented in Figure 6. The environmental impact expectedly increases as the transport distance of the materials to the waste treatment facilities is increased. The differences are more noticeable in comparison to the previous analysis for the transport of the materials to the site, as the distances that are examined in this case are also longer. The impact of the 100km scenario construction is calculated at 9514kg CO_2 eq., 9898kg CO_2 eq. for the 300km distance and 10282kg CO_2 eq. for the 500km distance scenario construction. It is therefore shown that the transport distance of the retrieved construction materials from the site of the building to the various waste treatment facilities has a noticeable effect on the environmental impact of the construction of the timber building, as these distances usually quite long.

3.4 Timber materials waste treatment

The timber construction materials that are retrieved and sorted after the demolition of a building can be handled in a number of ways. There are waste treatment options that provide environmental benefits; recycling which allows for the chipping of the wood and the manufacturing of new timber products based on the wood fiber technology or reuse which utilizes the existing timber 'as is' after a set of properties inspections and few minor repair processes that may be required. On the other hand, if provisions have not been taken to handle timber waste materials this way, the wood is very likely to end up in landfills or to be incinerated.

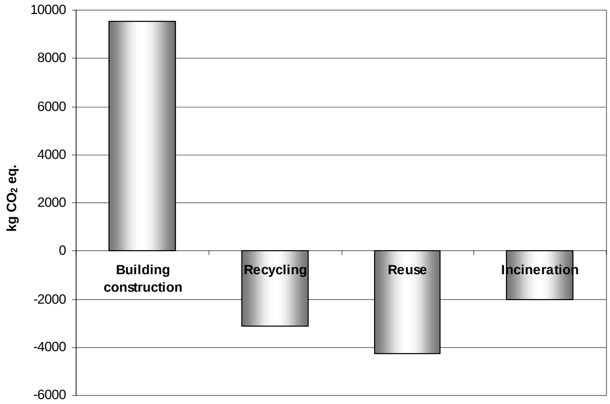

Figure 7. Environmental impact of timber(pine wood) building's construction for each transport distance to waste treatment facilities and recycling scenario

This wide range of handling options can have a significant influence on the environmental impact of a timber building's life cycle. To investigate this factor, three end-of-life scenarios are defined for the current analyses. The first is the 'recycling' scenario according to which 80% of the timber materials is successfully retrieved and sent for recycling, while the remaining 20% is considered irretrievable and is therefore disposed of in landfills. The second is the 'reuse' scenario, in which 80% of the wood is reused and 20% is again considered irretrievable and is disposed of in landfills. The third scenario is the 'incineration' scenario, according to which 100% of the timber materials are incinerated. For all three waste treatment scenarios, it is assumed that 90% of the steel materials used for the walls and roof of the building is retrieved and sent for recycling, while 10% is considered irretrievable and disposed of in landfills. In regard to the other life cycle issues, it is again assumed that pine is used for the construction of the building.

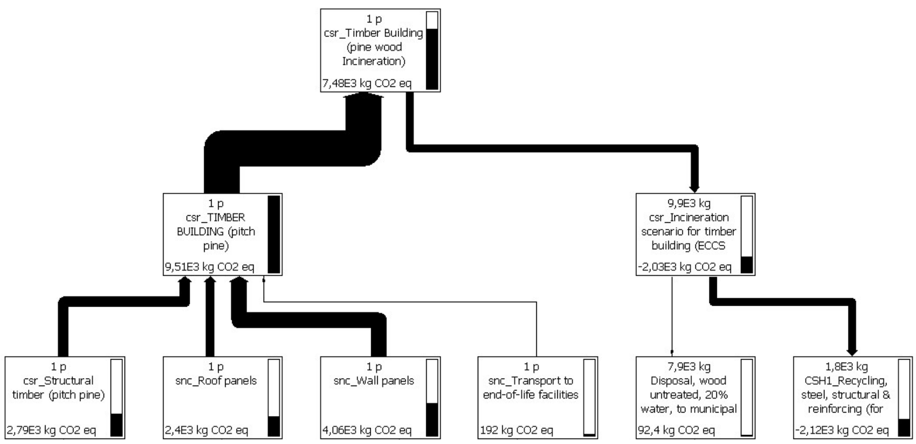

Figure 8. Environmental impact flow for the incineration scenario life cycle of the timber building

The environmental impact results for the three end-of-life scenarios and the construction of the building – which is the same for each waste scenario- are displayed in Figure 7. The recycling scenario provides noticeable benefits of 3139kg CO_2 eq. (thus reducing the environmental burden caused by the timber building's construction by a third), while reuse has an even greater positive environmental effect, providing almost 45% of the building's construction impact in environmental benefits (4255kg CO_2 eq.). As expected, the incineration scenario provides the smallest benefits among the three scenarios with 2030kg CO_2 eq. The fact that the incineration scenario provides environmental benefits rather than burden is attributed to the positive environmental effect of the recycling of the steel materials. This is also shown in Figure 8, in which the environmental impact flow of the building's life cycle is illustrated.

4 CONCLUSIONS

The purpose of the current research was to investigate the influence of certain factors and issues related to the life cycle of a timer building structure on its total environmental impact. Through the quantification of this influence on the life cycle impact of the building, key issues were identified and highlighted as the basis for future considerations regarding the optimal delivery of timber construction projects. An existing timber building was used for the calculations and the issues examined were the type of wood used, the construction materials transport distance to the site and the various waste treatment facilities, as well as three end-of-life scenarios for the timber materials after the demolition of the building.

It was found that the type of wood used in timber building projects can have a noticeable effect on the environmental impact caused by the construction of the building, the total impact of its life cycle and the potential recycling benefits at the end of the building's service life. In regard to the recycling scenario, it was also shown that the largest percentage of environmental benefits is provided by the recycling of both the timber and steel construction materials that are used.

In regard to the transport of the materials, it was found that their transport to the site across relatively short distances has a small effect on the environmental impact of the construction of the timber building. This was attributed to the fact that both structural timber elements and steel sheet panels -the main construction materials used for the timber building- are relatively light and consequently the environmental impact of their transport is not as large as it would be in the case of heavier materials such as structural steel sections or concrete. It is therefore preferable to select construction materials that cause lower environmental impacts when manufactured, even though they might be found in distant suppliers. Nevertheless, it was shown that as the transport distance increases -as is usually the case with the materials transport to the waste treatment facilities- the environmental impact of the transport processes becomes noticeable.

The recycling of the timber construction materials was found to provide noticeable environmental benefits and capable of reducing the environmental burden caused by the timber building's construction by a third, while reuse was shown to have an even greater positive environmental effect, providing almost 45% of the building's construction impact in environmental benefits. The incineration scenario provided the smallest benefits among the three scenarios, which were attributed to the positive environmental effect of the recycling of the steel materials that outbalanced the negative environmental impact caused by the incineration of the wood.

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