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ENVIRONMENTAL IMPACT OF DIFFERENT CARBON FIBRE REINFORCED POLYMER STRENGTHENING SOLUTIONS OF LINEAR TIMBER ELEMENTS

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Abstract: *It is known that the significant amount of consumed building materials has a significant influence over the overall environmental impact of the construction sector. Considering that forests are Earth's most powerful tool in sustaining life conditions by maintaining the quality of the air, it can be stated that the use of timber in this industry can have a tremendous negative impact over the environment. The present study uses the Life Cycle Assessment (LCA) methodology in order to determine if reusing a timber beam, by considering different carbon fibre reinforced polymer (CFRP) strengthening solutions, can represent a suitable solution in minimising the environmental impact of the construction sector.*

Key words: *environmental impact, construction sector, LCA, timber beam, CFRP.*

1. Introduction

In the last years, the negative effects of the global climate change phenomena have influenced the general perception regarding the impact of humans' daily activities over the environment. The present consumption rates of raw materials are exceeding by approximately 60% the Earth's stock renewal capacity; it is estimated that almost 60 billion tons of natural resources are extracted worldwide each year [1], [2]. In addition to being unsustainable, the current consumption rates can endanger the chance of future generations at a proper level of development. One of the industries that is responsible for an impressive consumption of raw materials is represented by the construction sector. Annually, this economic activity leads to the consumption of almost 50% of the total amount of extracted natural resources. The construction industry is also responsible for approximately 40% of worldwide greenhouse gases emissions, and almost 25% of the total waste produced at the global scale [3-5]. Therefore, the construction sector has a far-

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reaching part in the global efforts of achieving the environmental dimension of sustainability.

Out of all materials used in the construction sector, timber is the only one that originates from a renewable resource. Forests have a significant role in maintaining life conditions, being responsible for extracting carbon dioxide (CO_2) from the atmosphere and replacing it with oxygen (O_2). It is estimated that a forest that is well managed can replace, within the photosynthesis process, almost 700 grams of CO_2 with approximately 500 grams of O_2 [6], [7]. Another important role of wood plantations in the current context of global sustainable development is represented by the fact that they are accommodating the natural habitat required by a significant part of the existing wildlife. While wood represents one of the first materials used by humans for building different structures, in the present days, it is mostly used for structural elements for buildings and short-span bridges [7].

Taking into account the above, timber can rightfully be declared as a construction material whose use can influence the impact of the built environment over the natural one. Therefore, understanding the impact of this type of material by civil engineering specialists could positively alter the overall ecological implications of the construction sector. Another consideration that will have a significant influence over the environmental impact of this industry is represented by an important part of the existing building stock that has exceeded the life span considered in the design phase. Taking into account the fact that many of the existing buildings have different timber structural elements and also that a significant number of wood structures are part of the historical built heritage, different FRP strengthening solutions can be considered for their rehabilitation.

The aim of the present paper is to determine if strengthening and reusing an existing linear timber element by utilizing FRP materials can be regarded as a solution for reducing the environmental impact of the construction sector. The study presents a series of evaluations that interpret and compare the impact of different CFRP strengthening solutions with the level of environmental burdens resulted from replacing an existing timber beam with a new one. LCA methodology and the GaBi software have been used in order to achieve the objectives of the research.

2. LCA Case Studies

LCA is defined as a “compilation and evaluation of the inputs, outputs and the potential environmental impact of a product system throughout its life cycle”, that is used for “identifying opportunities to improve the environmental performance of products at various points in their life cycle; informing decision-makers in industry, government or non-government organization; the selection of relevant indicators of environmental performance, including measurement techniques and marketing” [8], [9].

Taking into account that the present evaluation aims at determining the ecological influences over the pre-operation stage, the Cradle-to-Gate LCA type of study has been used. During the study, the following life cycle phases have been considered (Figure 1):

- extraction of raw materials;
- processing of raw materials;
- manufacturing of construction materials;
- transportation of the materials from the producing unit to the building site;

- construction phase of the considered products.

Fig. 1. *Considered life cycle phases*

The following case studies have been considered:

- **case study no. 1**: unstrengthened linear timber element with a rectangular cross-section of 50x60 mm and 1300 mm length (Figure 2a);
- **case study no**. **2**: externally bonded reinforcement (EBR) strengthening solutions which consist in applying one pultruded CFRP strip with 1100 mm in length and a cross section 1.4x14 mm cross-section (Figure 2b);
- **case study no. 3**: near surface mounted (NSM) strengthening technique developed by using one pultruded CFRP rod with a diameter of 6 mm and 1100 mm in length (Figure 2c).

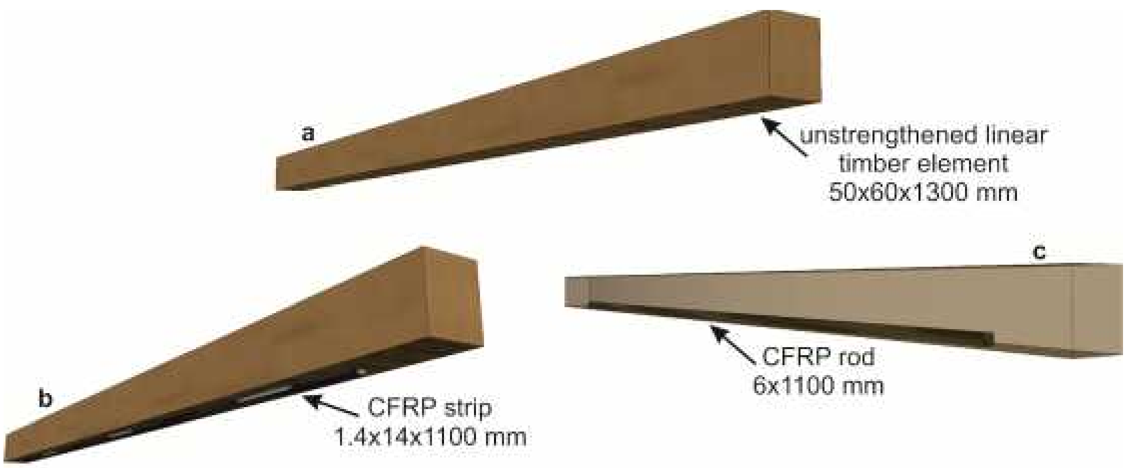

Fig. 2. *Assessed construction products. a. case study no. 1, b. case study no. 2, c. case study no. 3*

The structural behaviour of the unstrengthened and strengthened linear timber elements is currently under study at the Faculty of Civil Engineering and Building Services, "Gheorghe Asachi" Technical University of Iasi, Romania.

In order to take the transportation phase into consideration, a Euro 6 diesel truck with 3.3 tons payload capacity was used. Table 1 presents the transport distances used in the assessment. The environmental impact of the analysed construction products has been quantified by using the environmental parameters that are presented in Table 2. The pultrusion process and the surface preparation works have not been included.

Considered transport distances Table 1

Material	**Distance**	**From → To**
Timber linear element	150	sawmill → construction site
CFRP strips	1850	manufacturing unit → construction site
CFRP rods	1850	manufacturing unit → construction site
Epoxy adhesive	1850	manufacturing unit → construction site

Environmental impact categories Table 2

Impact category	**Parameter**	**Unit**
Climate Change	Global warming potential (GWP) excluding the biogenic carbon	kg CO_2-equiv.
Human Toxicity	Human toxicity potential, cancer effects (HTPc)	CTUh

2.1. Environmental Impact in Case Study no. 1

Case study no. 1 has assessed the environmental impact of an unstrengthened timber linear element with a rectangular cross section of 50x60 mm and a length of 1300 mm. The analysis has considered an amount of 1.47 kg softwood in order to determine the ecological influence of the construction element.

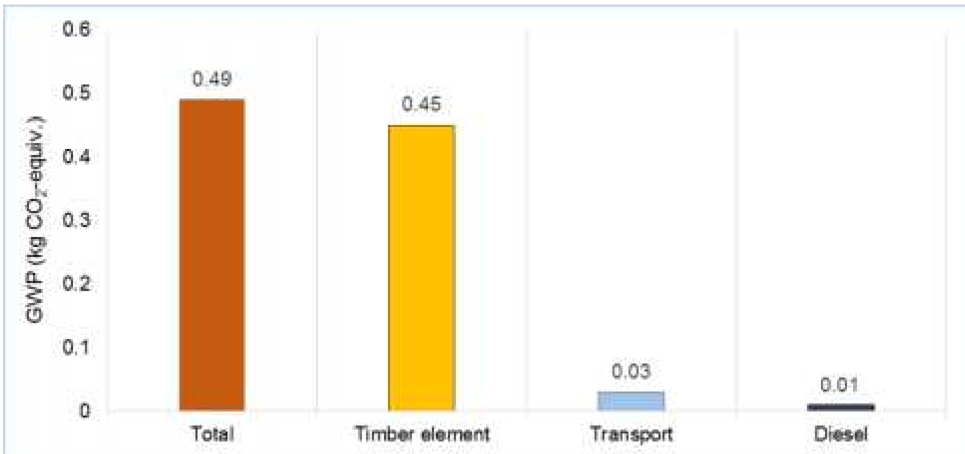

Fig. 3. *GWP environmental impact parameter results (case study no. 1)*

Figures 3 and 4 illustrate the resulted values for the considered environmental impact parameters. It can be observed that the timber linear element has the highest influence over the carbon footprint (Figure 3). The transportation phase and the amount of diesel consumed are only responsible for approximately 8% of the total volume of CO_2 equivalent emitted. In the case of the human toxicity parameter, presented in Figure 4, the linear element influences the resulted impact by almost 89%, followed by the effect caused by the manufacturing phase of the volume of consumed diesel, and by the transportation phase of the element.

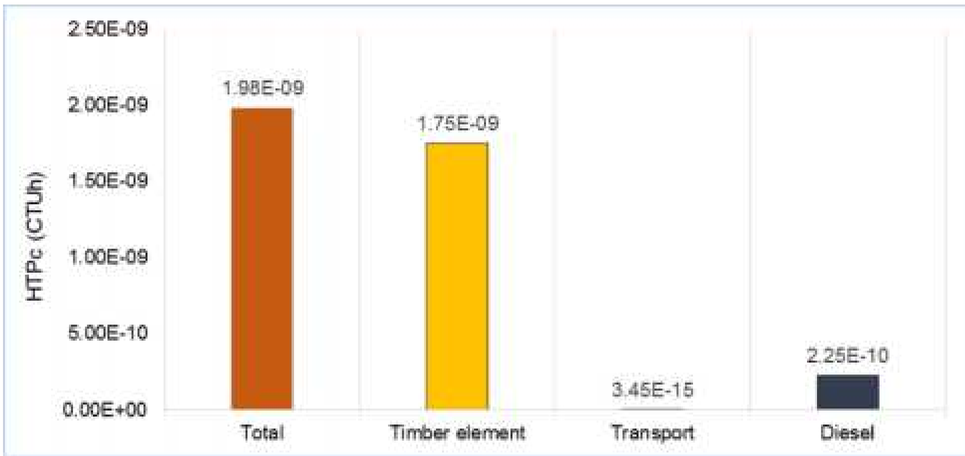

Fig. 4. *HTPc environmental impact parameter results (case study no. 1)*

2.2. Environmental Impact in Case Study no. 2

In the second evaluated case study, the environmental merits of the EBR strengthening technique have been analysed. As mentioned previously, the composite solution is formed by bonding a CFRP plate to the tension face of the timber element by using epoxy adhesive. The following amounts of component materials have been considered: 0.024 kg carbon fibres, 0.011 kg epoxy resin, and 0.054 kg epoxy adhesive.

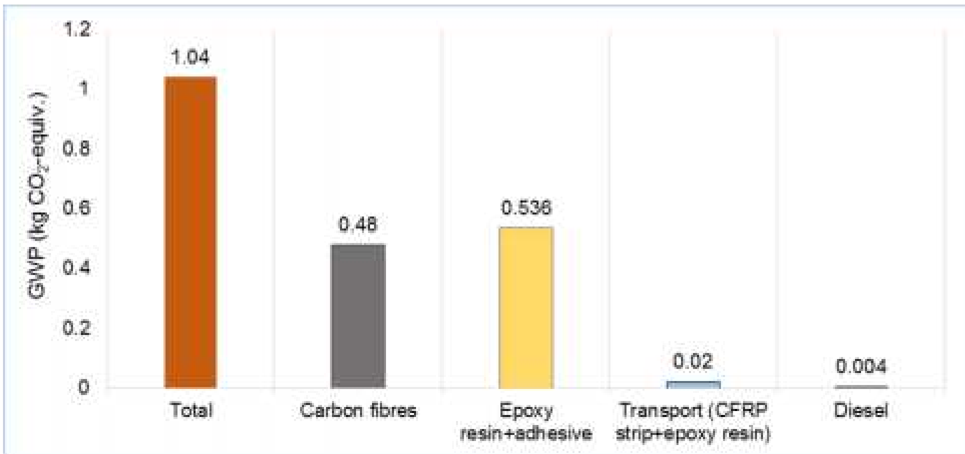

Fig. 5. *GWP environmental impact parameter results (case study no. 2)*

The resulted values for the considered environmental impact parameters are displayed in Figures 5 and 6. In the case of the first analysed indicator (Figure 5), it can be observed that the amount of epoxy resin and adhesive is responsible for more than half of the total carbon footprint of the product, closely followed by the carbon fibres. The transport phase and the amount of diesel consumed have a low influence over GWP parameter. Figure 6 shows that the carbon fibres have the most significant influence over the human health, being responsible for over 76% of the total impact. Also, the amount of epoxy resins used and the volume of diesel consumed during the transportation phase have an important negative influence.

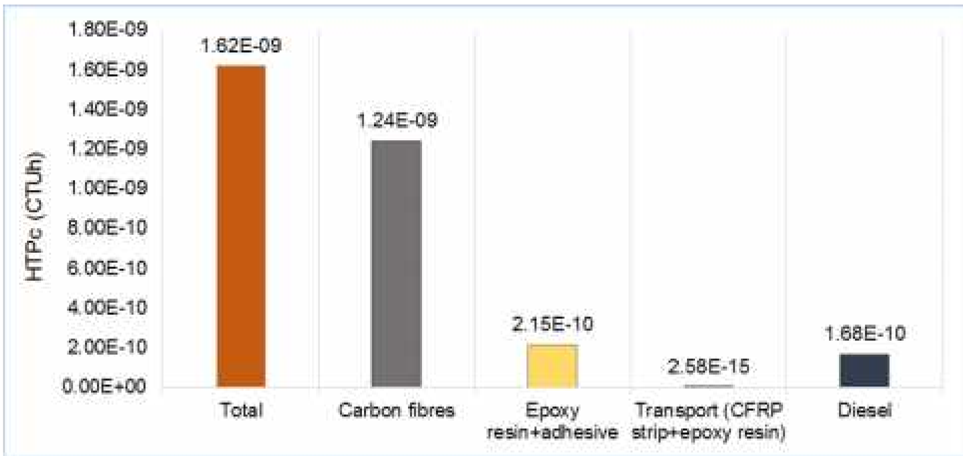

Fig. 6. *HTPc environmental impact parameter results (case study no. 2)*

2.3. Environmental Impact in Case Study no. 3

The last case study assesses the environmental impact of the NSM strengthening technique, consisting in bonding one carbon rod with a diameter of 6 mm and a length of 1100 mm in the timber element's pre-cut groove. In order to complete this assessment, there have been considered 0.034 kg carbon fibre, 0.014 kg epoxy resin, and 0.134 kg epoxy adhesive.

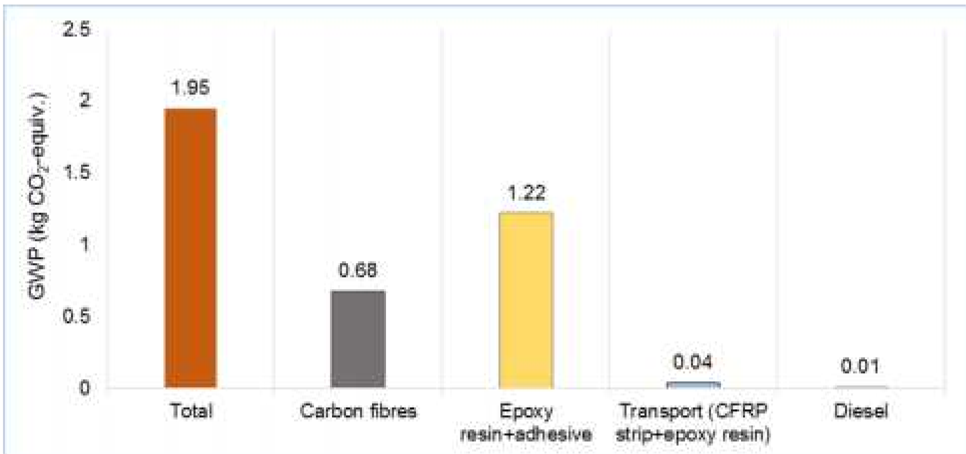

Fig. 7. *GWP environmental impact parameter results (case study no. 3)*

Figure 7 presents the carbon footprint of the considered construction product. As illustrated, the epoxy resin and adhesive and the carbon fibres have the highest influence, being responsible for 97% of the total resulted impact. In the case of the HTPc parameter, the carbon fibres have the most significant negative effect over the humans' health, followed by the epoxy resin and adhesive, the diesel volume consumed, and the transportation phase (Figure 8).

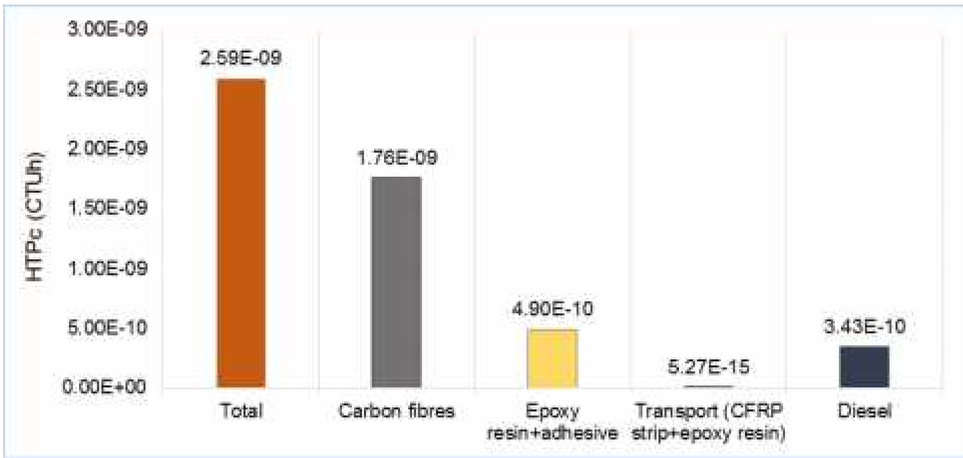

Fig. 8. *HTPc environmental impact parameter results (case study no. 3)*

3. Comparing the Resulted Environmental Effects

The goal of the paper is to determine the environmental impact resulted from replacing an existing timber linear element with a new one, and compare it with the ecological effects of different CFRP strengthening solutions. Table 3 shows the overall impact of the assessed products that are specific to the construction sector, by considering the global warming potential, excluding the biogenic carbon, and the human toxicity potential, cancer effects environmental parameters.

In the case of the GWP impact category, the new timber element has the lowest carbon footprint. A nearly double amount of CO_2 equivalent has been registered in the second case study, which assesses the EBR technique, while the last analysed strengthening solution has the highest negative impact. It must be stated though that the new timber element would have had a negative carbon footprint if biogenic carbon would have been considered in the analysis. With regards to the human toxicity category, the first analysed strengthening solution has the lowest negative effect, followed by the products considered in the first and in the last case studies.

Environmental impact results Table 3

Impact category	**Case study no. 1**	**Case study no. 2**	**Case study no. 3**
Climate Change [kg CO_2-equiv.]	0.49	1.04	1.95
Human Toxicity[CTUh]	1.98E-09	1.62E-09	2.59E-09

4. Conclusions

As stated before, the construction sector has a significant role in achieving the environmental dimension of sustainability at the global scale. The existing building stock will have an important effect over the overall performances of the industry. In the near future, the old structures, those that no longer offer users a certain level of structural safety, should either be replaced with new ones, or be strengthened and reused. Therefore, understanding the ecological impact of the materials used in this sector can have an important effect in minimising the negative effects of the built environment.

Using timber as a construction material could greatly affect the Earth's ecosystem, seeing as forests play a crucial role in supporting life conditions. As shown in the present paper, specific composite strengthening solutions could be considered in order to reuse a linear timber element with a bearable level of environmental burdens. In the case of timber historical heritage buildings, FRP materials could be a necessary solution when it comes to rehabilitating the structures. Moreover, by reusing an existing timber element, the amount of wood used in this sector will reduce. Therefore, strengthening and reusing timber structures could have an important role in both protecting the existing wood plantations and also in increasing the forested areas.

Acknowledgements

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