Annals of the Academy of Romanian Scientists
Series on Engineering Sciences
ISSN 2066 – 8570 Volume **7**, Number **2**/**2015**

ENVIRONMENTAL IMPACT OF FIBRE-REINFORCED POLYMER STRENGTHENING SOLUTIONS OF REINFORCED CONCRETE COLUMNS

Sebastian George MAXINEASA[1], Nicolae TARANU[2]

Rezumat. *Sectorul construcțiilor este considerat unul din factorii cheie în atingerea dimensiunilor sustenabilității. În afara influenței sale, deja incontestabile, asupra ariei economice și sociale, acest fapt este justificat, în principal, de impactul ecologic masiv. O metodă de micșorare a impactului mediului construit asupra celui natural constă în reutilizarea structurilor din beton armat existente, folosind pentru consolidarea acestora materialele compozite. Obiectivul prezentei lucrări este de a stabili dacă extinderea perioadei de exploatare a stâlpilor din beton armat prin aplicarea unor sisteme compozite bazate pe produse polimerice armate cu fibre din carbon (CPAFC) reprezintă o soluție viabilă din punct de vedere a dimensiunii ecologice a sustenabilității. Rezultatele obținute în urma studiilor Life Cycle Assessment (LCA) la soluțiile de consolidare a stâlpilor din beton armat încurajează utilizarea sistemelor compozite analizate în această lucrare pentru atingerea dimensiunii ecologice a sustenabilității în sectorul construcțiilor.*

Abstract. *The construction sector is considered by many as one of the key factors in fulfilling the three dimensions of sustainability. Notwithstanding its indisputable influence over economy and society at large, the statement above is most importantly justified by the massive impact the construction industry exerts over the environment. Strengthening existing reinforced concrete structures with composites and reusing them instead of building new ones is one of the ways by which the impact of the built environment over the natural one can be successfully decreased. This paper aims at determining if the extension of the life span of the reinforced concrete columns by applying different carbon fibre-reinforced polymer (CFRP) strengthening systems can be considered a viable solution in terms of the ecological dimension of sustainability. The results obtained after conducting Life Cycle Assessment (LCA) studies encourage the usage of the composite systems hereby analysed in the context of achieving the environmental aspect of sustainability in the construction sector.*

Keywords: CFRP, construction sector, LCA, reinforced concrete columns, sustainability

1. Introduction

At present, the volume of natural resources consumed in one year exceeds with approximately 50% the stock renewing capacity of planet Earth. It is estimated

[1]PhD student, Faculty of Civil Engineering and Building Services, "Gheorghe Asachi" Technical University, Iasi, Romania (e-mail: sebastian.maxineasa@tuiasi.ro).
[2]Professor, Faculty of Civil Engineering and Building Services, "Gheorghe Asachi" Technical University, Iasi, Romania, full member of the Academy of Romanian Scientists (nicutara@yahoo.com).

that the total amount of raw materials used in all daily activities reaches the value of 60 billion tons. What is more alarming is that more than 50% is consumed in the construction sector, which is also responsible for between 40% and 50% of the total amount of materials used around the globe; producing over 40% of the total greenhouse gas emissions; and for utilizing almost 40% of the total amount of energy produced at the global level [1-5].

Considering all of the above, one can deduce that from the all economic activities, the construction sector has the most important influence over the natural environment. Moreover, taking into account that in the near future these values are expected to reach new record levels, achieving the environmental dimension of sustainability by reducing the impact of the built environment over the Earth's ecosystem represents one of the most important tasks that civil engineers must solve in the 21 century.

From the whole life cycle of a structure (see Figure 1), the production phase of construction materials has one of the most significant influences over the environment. Besides being the most utilized material in this sector, concrete also has a tremendous ecological impact. It is known that the environmental performances of this worldwide-used traditional construction material is influenced by cement. In order to better understand the massive influence of concrete, it is necessary to remark that in order to manufacture a ton of cement, approximately a ton of carbon dioxide (CO_2) is released into the atmosphere [6]

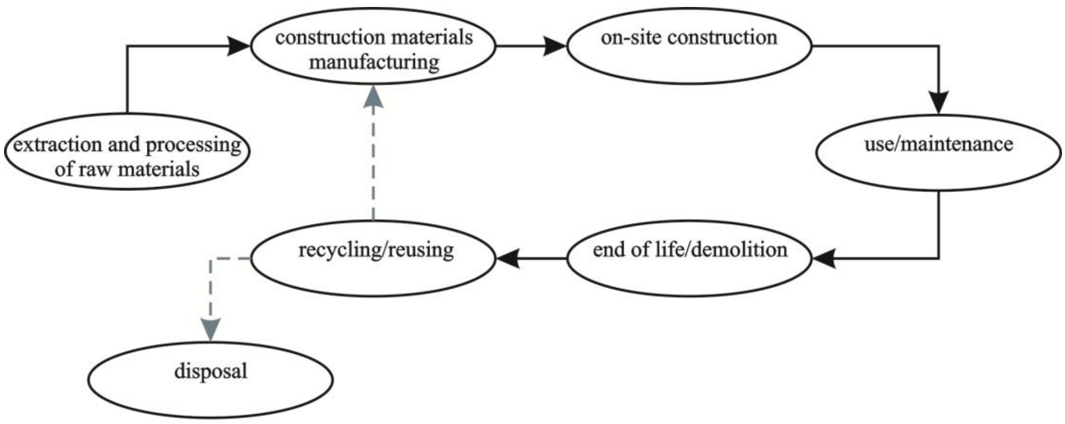

Fig. 1. Life cycle of a building [1].

A suitable answer to this complicated situation created by the massive influence the construction sector exerts over the natural environment is represented by the usage of fibre reinforced polymer (FRP) materials for strengthening and reusing the existing reinforced concrete (RC) structures which do not properly satisfy the actual structural requirements. Therefore, by using different FRP solutions, the life span of an old building can be drastically improved, thus preserving all environmental investments (i.e. environmental impact) over the pre-usage and usage stage of the existing structure and eliminating the negative influence resulted from building a new RC structure (e.g. minimizing the volume of concrete and cement used).

The objective of the present paper is to establish if the usage of FRP materials for strengthening and reusing an existing RC structural element represents a suitable solution in the context of satisfying the environmental aspect of sustainability in the construction sector. In order to reach this goal, the environmental performances of two carbon fibre reinforced polymer (CFRP) strengthening solutions of an existing RC column have been assessed and compared to the ecological impact resulted from building a new structural element. The environmental influence of the considered construction products has been evaluated with the help of Life Cycle Assessment (LCA) methodology and GaBi tm software.

2. LCA case studies

It is a fact that LCA studies are the best tools available for assessing the environmental performances of a product specific to any industrial sector [1]. The international standards ISO 14040:2006 and ISO 14044:2006 define LCA as a "compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" that can be 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" [7, 8].

There are different types of LCA studies characterized by the analyzed period from the life cycle of the evaluated product: Cradle-to-Grave, Cradle-to-Cradle, Cradle-to-Gate and Gate-to-Gate [1]. Due to the fact that the authors were interested in evaluating and comparing the environmental impact resulted only from the pre-operation stage of the assessed products, the Cradle-to-Gate LCA type of study was used by taking into consideration only the following life cycle phases:

- extraction of raw materials;
- pre-processing and processing of raw materials;
- production of construction materials;
- transportation of the construction materials from the manufacturing place to the building site;
- the assembling phase of the assessed products.

For the transportation phase of the life cycle model of the evaluated products, a Euro 5 diesel truck with 3.3 tons payload capacity has been considered. The transport distances used in the life cycle models are presented in Table 1.

Table 1. Considered transport distances

No.	*Material*	*Distance [km]*	*From → To*
1.	Fine aggregate	30	Quarry → concrete mixing plant
2.	Coarse aggregate	30	Quarry → concrete mixing plant
3.	Cement	165	Quarry → concrete mixing plant
4.	Steel reinforcement	25	Steel mill → construction site
5.	Concrete	15	Concrete mixing plant → construction site
6.	Carbon fibre fabric	1850	Manufacturing unit → construction site
7.	Epoxy resin	1850	Manufacturing unit → construction site

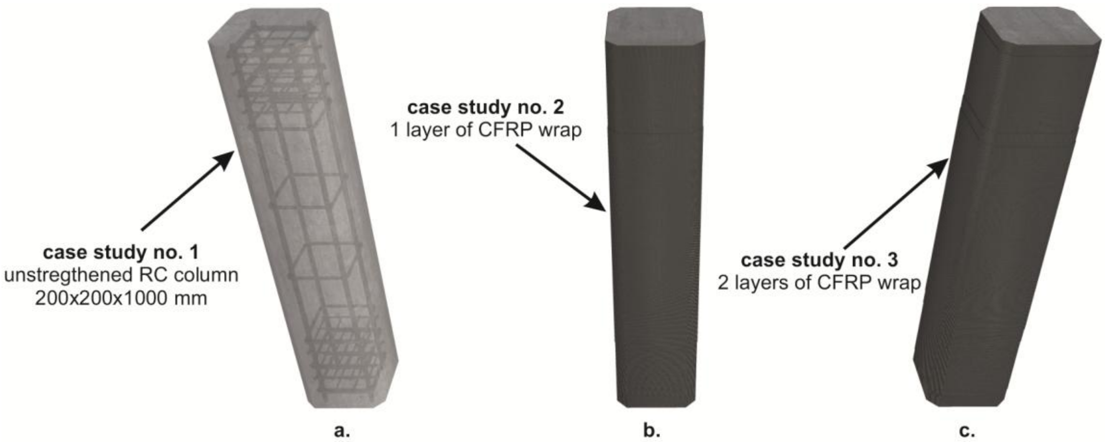

Fig. 2. Analyzed case studies. **a.** case study no.1; **b.** case study no. 2; **c.** case study no. 3.

In order to achieve the objective of the present paper, the following three case studies have been considered:

- **case study no. 1**: the unstrengthened RC column, with a length of 1000 mm and 200x200 mm cross-section (see Figure 2, a);
- **case study no. 2**: the first externally bonded reinforcement (EBR) strengthening solution, which consists of confining the RC element with one layer of carbon fibre fabric (see Figure 2, b);

- **case study no. 3**: the second EBR strengthening solution, which consists of confining the RC element with two layers of carbon fibre fabric (see Figure 2, c).

The behavior of the unstrengthened RC column and the strengthened structural element with one layer of CFRP fabric have been analyzed within an experimental program developed at the Faculty of Civil Engineering and Building Services, "Gheorghe Asachi" Technical University of Iasi, Romania. The RC element strengthened with two layers of composite fabric has also been developed in the same doctoral program, but the resulted product has not been tested yet. During the experimental program, the following values have been obtained for the ultimate strength of the considered elements: 1750 kN in the case of the unstrengthened RC element and 2750 kN in the case of the CFRP strengthened column [9].

3. Assessing the environmental impact of the considered construction products

The impact categories presented in Table 2 have been used in order to quantify the environmental impact of the analyzed products. These environmental indicators were selected from the recommended impact categories list provided by the European Commission through the Institute for Environment and Sustainability – Joint Research Centre.

Table 2. Analyzed impact categories

No.	*Impact category*	*Impact indicator (parameter)*	*Unit*
1.	Global Warming (Climate Change)	Global Warming Potential (GWP)	kg CO_2-Equiv.
2.	Human Toxicity	Human Toxicity potential, cancer effects (HTPc)	CTUh
3.	Ozone Depletion	Depletion potential of the stratospheric ozone layer (ODP)	kg CFC-11 Equiv.

3.1. Environmental impact in case study no. 1

The objective of the first case study was to assess the environmental performances of the unstrengthened RC column. The analyzed structural element has a length of 1000 mm and a rectangular cross-section of 200 mm×200 mm. The quantities of component materials used for determining the environmental merits of the considered structural element are presented in Table 3.

Table 3. Amount of component materials used in case study no. 1

No.	*Component material*	*Quantity [kg]*
1.	Fine aggregate	27.20
2.	Coarse aggregate	50.80
3.	Cement	12
4.	Water	6
5.	Steel reinforcement	6.13

The results describing the environmental impact of the construction product considered in the case study no. 1 are presented in Figures 3, 4 and 5. In the case of the first impact category, Climate Change, the total resulted value is highly influenced by the amount of cement used (see Figure 3). Also, the steel reinforcement and the mixing of concrete have an important influence over the carbon footprint of the RC column. As it can be observed in Figure 4, the steel rebar has the highest impact in the case of the HTPc parameter, followed by the mixing of concrete and the volume of diesel used in the transportations stages. As shown in Figure 5, the ODP environmental impact parameter is mostly influenced by the steel reinforcements.

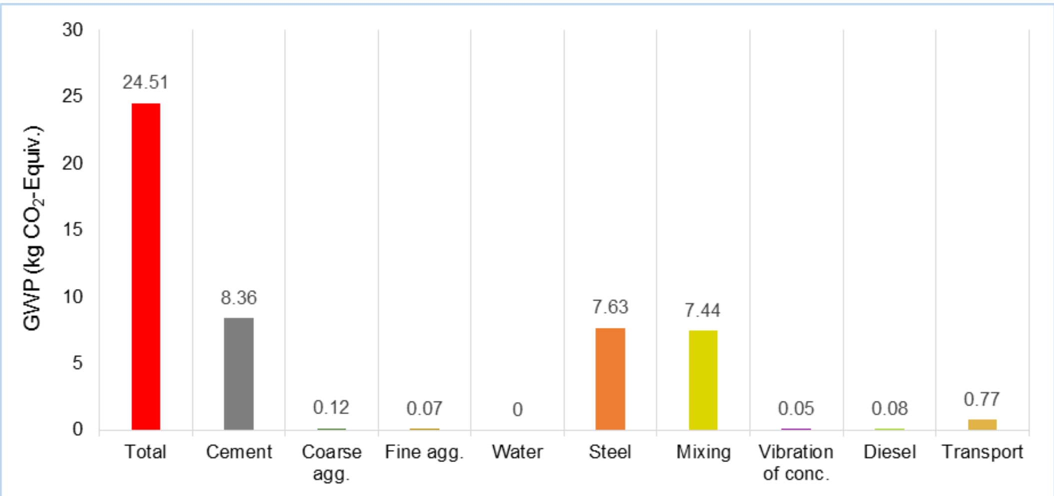

Fig. 3. Results for the GWP environmental impact indicator (case study no. 1).

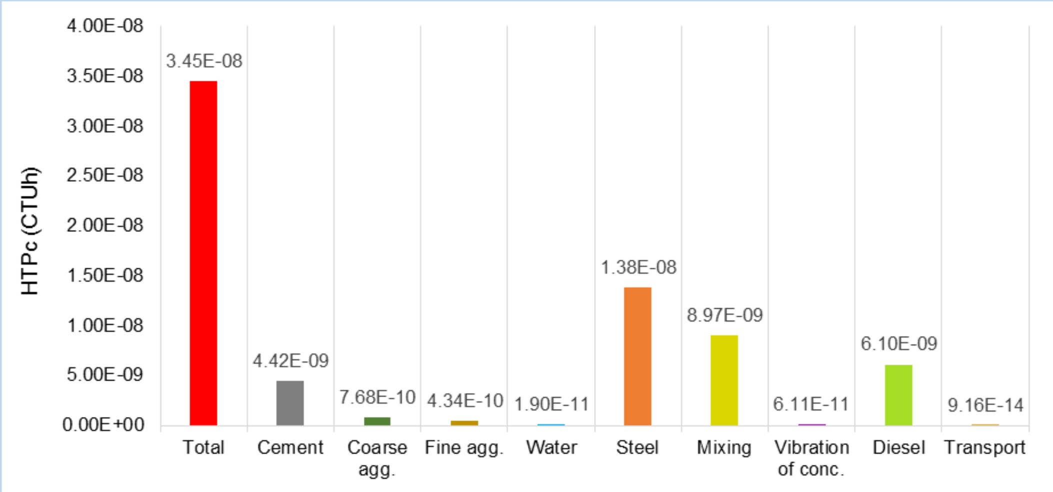

Fig. 4. Results for the HTPc environmental impact indicator (case study no. 1).

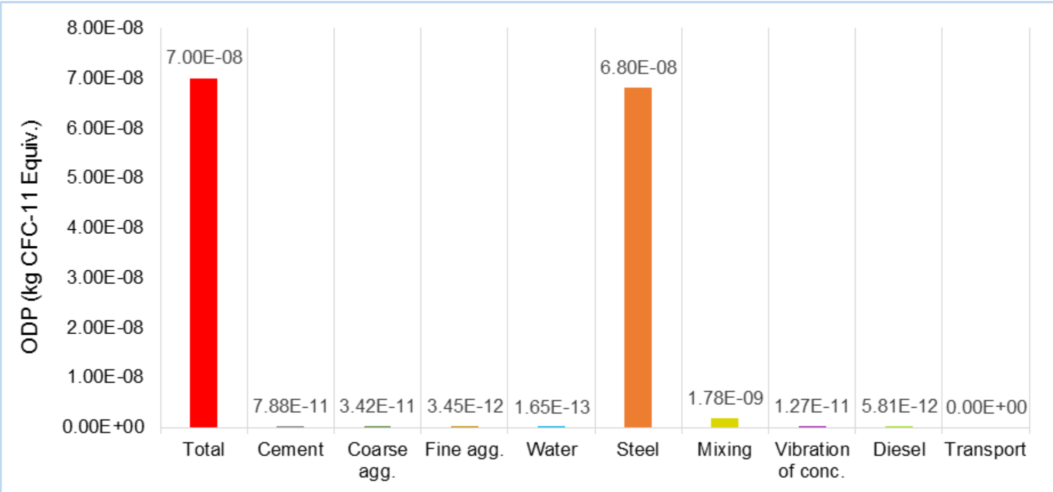

Fig. 5. Results for ODP environmental impact indicator (case study no. 1).

3.3. Environmental impact in case study no. 2

Case study no. 2 assesses the environmental performance of the first CFRP strengthening scheme, which consists of wrapping the RC column with one layer of carbon fibre fabric by using epoxy resin. The quantities used for assembling the studied composite strengthening solutions (that are considered in the life cycle model of the product) are presented in Table 4.

As shown in Figure 6, the carbon footprint of the first assessed CFRP strengthening scheme is mainly determined by the amount of epoxy resin and carbon fibres used for wrapping the RC structural element. The impact in the case of the HTPc environmental impact indicator (see Figure 7) is highly influenced by the carbon fabric. The most significant contributor to the final result obtained for the ODP parameter is represented by the epoxy resin (see Figure 8).

Table 4. Amount of component materials used in case study no. 2

No.	*Component material*	*Quantity [kg]*
1.	Carbon fibres	0.276
2.	Epoxy resin	1.16

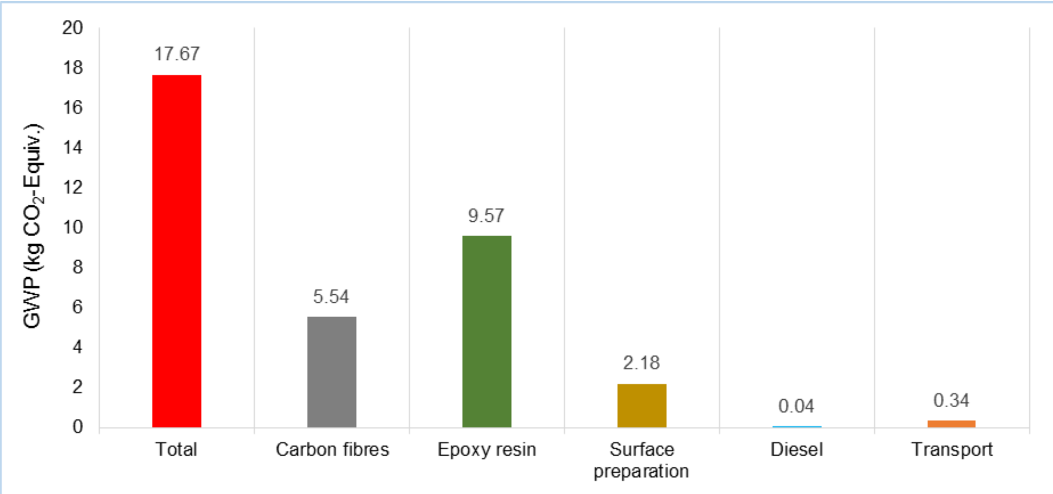

Fig. 6. Results for the GWP environmental impact indicator (case study no. 2).

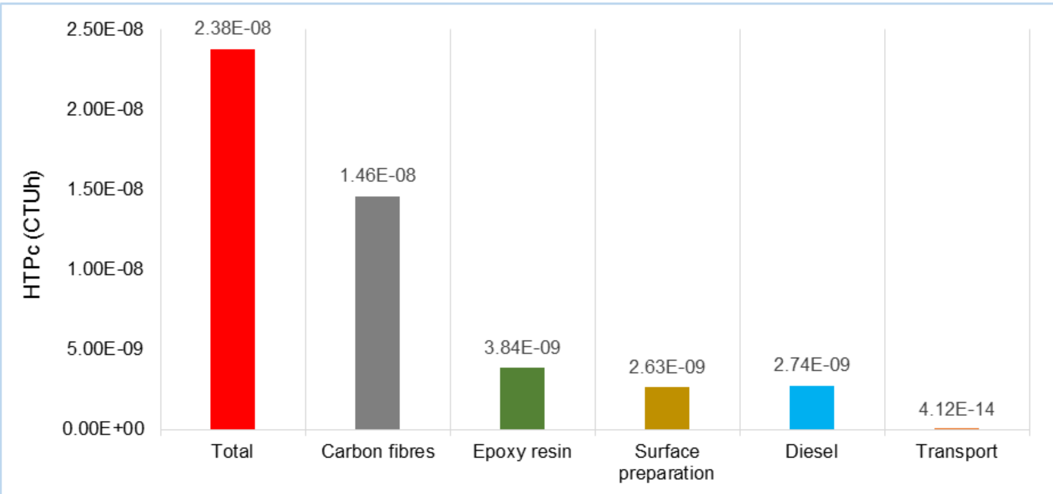

Fig. 7. Results for the HTPc environmental impact indicator (case study no. 1).

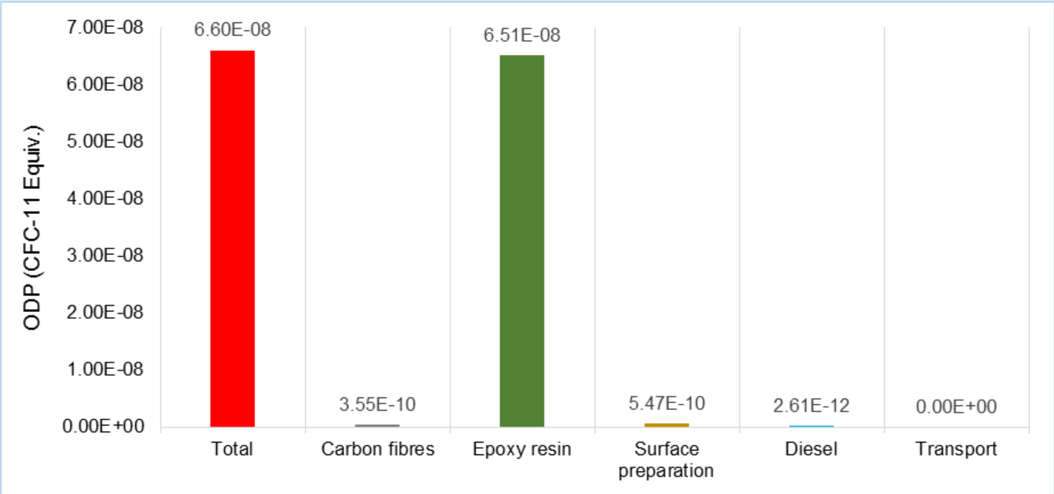

Fig.8 Results for ODP environmental impact indicator (case study no. 2)

3.3. Environmental impact in case study no. 3

The last case study evaluates the environmental merits of the second strengthening solution of the RC column. This CFRP scheme consists of wrapping the structural element with two layers of carbon fibre fabric by using epoxy resin. The quantities of component materials used for assembling the considered strengthening solution are presented in Table 5.

Figures 9, 10 and 11 show the resulted values for the considered environmental impact indicators. As it can be observed in Figure 9, the carbon footprint is highly influenced by the epoxy resin. Also, the carbon fibre fabrics have an important contribution over the total impact of the GWP parameter. In the case of the HTPc environmental indicator (see Figure 10), the carbon fibers have the most significant influence over the total impact. By analyzing Figure 11, it can be observed that the amount of epoxy resin used for setting up the assessed composite strengthening solution has a considerable influence over the ODP impact category.

Table 5. Amount of component materials used in case study no. 3

No.	*Component material*	*Quantity [kg]*
1.	Carbon fibres	0.497
2.	Epoxy resin	1.64

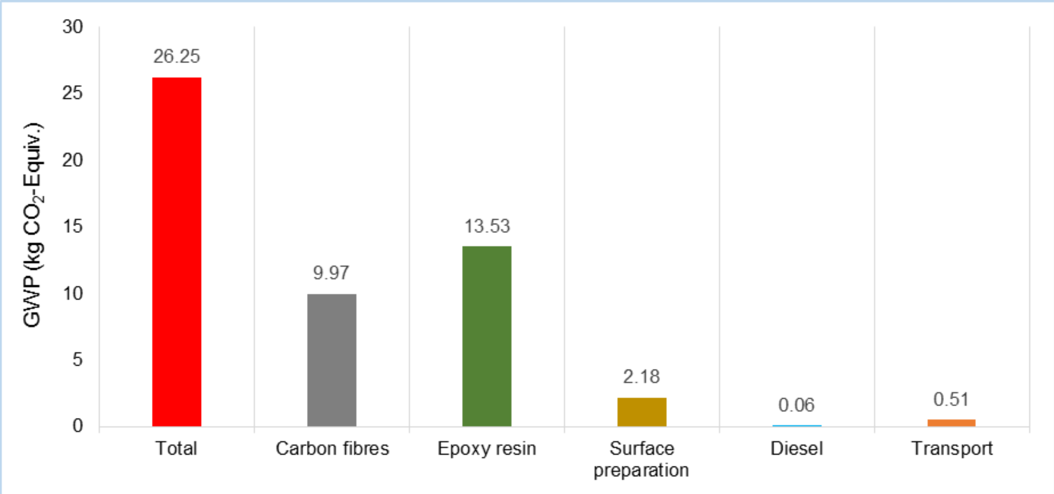

Fig. 9. Results for the GWP environmental impact indicator (case study no. 3).

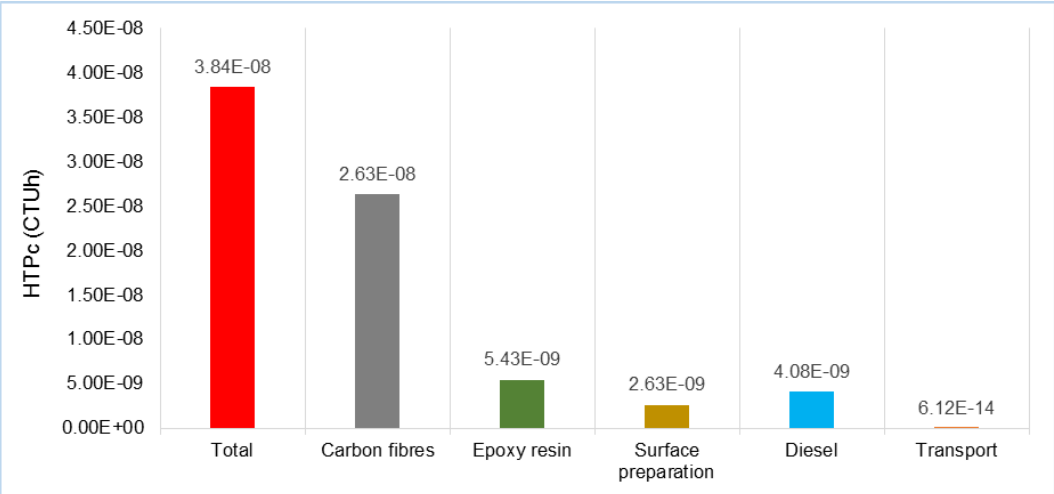

Fig. 10. Results for the HTPc environmental impact indicator (case study no. 3).

4. Conclusion

The objective of the present paper was to determine, by using the LCA studies, if strengthening and reusing an existing RC column represents a suitable solution in the current global context of achieving the environmental dimension of sustainability in the construction sector. As shown in Figure 12, the CFRP scheme considered in the second case study has a lower ecological impact compared to the impact over the natural environment resulted in the case of building a new RC column. Also, by wrapping the structural element with one layer of epoxy resin impregnated carbon fibre fabric, the value of the ultimate strength is approximately 57% higher than the one obtained in the case of the unstrengthened structural element (case study no. 1). Analyzing the same figure, it can be observed that wrapping the structural element with two layers of resin impregnated fabric (case study no. 3) leads to higher values for all environmental impact categories, in comparison with the ecological influence resulted in the first case study.

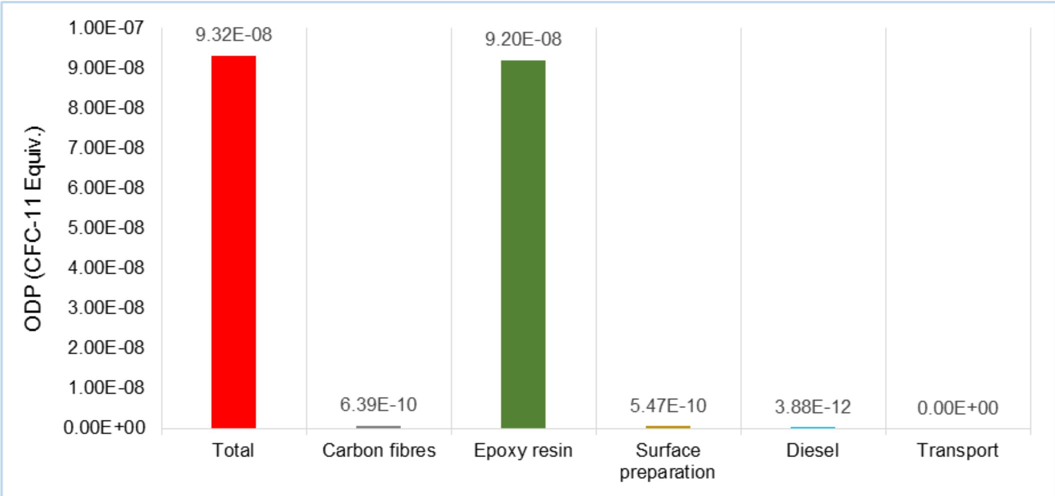

Fig. 11. Results for ODP environmental impact indicator (case study no. 3).

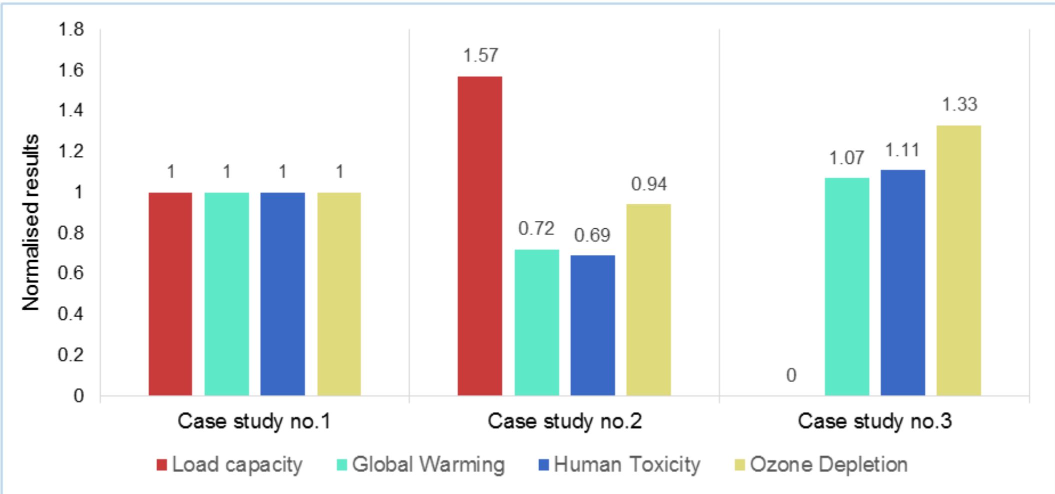

Fig. 12. Comparison between the load capacity and the environmental burdens.

By comparing the resulted environmental performances, it is easily noticeable that the CFRP strengthening solution considered in case study no. 2 represents an optimal solution that can be used for satisfying the environmental aspect of the sustainability concept. Also, taking into account the fact that the difference between the level of burdens obtained in the first and in the last case study is not significant, it can also be considered that the last studied composite solution can present a lower environmental impact after undergoing an optimization process. Therefore, the authors consider that using FRP materials for strengthening and reusing existing RC structures represents a key solution in the sustainable development of the construction sector.

R E F E R E N C E S

[1] S. G. Maxineasa, N. Taranu, L. Bejan, D. Isopescu, O. M. Banu, *Environmental Impact of Carbon Fibre-Reinforced Polymer Flexural Strengthening Solutions of Reinforced Concrete Beams*, Int J Life Cycle Assess, doi: 10.1007/s11367-015-0940-5 (**2015**).

[2] I. Z. Bribian, A. V. Capilla, A. A. Uson, *Life Cycle Assessment of Building Materials: Comparative Analysis of Energy and Environment Impacts and Evaluation of the Eco-Efficiency Improvement Potential*, Build Environ, **46**, 1133 (**2011**).

[3] F. Pacheco-Torgal, *Introduction to the Environmental Impact of Construction and Building Materials*. In: F. Pacheco-Torgal, L. F. Cabeza, J. Labrincha, A. de Magalhaes (eds.) *Eco-Efficient Construction and Building Materials. Life Cycle Assessment (LCA) Eco-Labelling and Case Studies* (Woodhead Publishing Limited, Cambridge, UK, **2014**) pp. 1-10.

[4] T. Blankendaal, P. Schuur, H. Voordijk, *Reducing the Environmental Impact of Concrete and Asphalt: A Scenatio Approach*, J Clean Prod, **66**, 27 (**2014**).

[5] A. Miller, K. Ip, *Sustainable Construction Materials*. In: R. Yao (ed.) *Design and Management of Sustainable Built Environment* (Springer-Verlag, London, UK, **2013**) pp. 341-358.

[6] A. P. Gursel, E. Masanet, A. Horvath, A. Stadel, *Life-Cycle Inventory Analysis of Concrete Production: A Critical Review*, Cement Concrete Comp, **51**, 38 (**2014**).

[7] The International Organization for Standardization, *Environmental Management – Life Cycle Assessment – Principles and Framework (ISO 14040:2006)*, (**2006**).

[8] The International Organization for Standardization, *Environmental Management – Life Cycle Assessment – Requirements and Guidelines (ISO 14044:2006)*, (**2006**).

[9] V. Munteanu, *Îmbunătățirea capacității portante a stâlpilor din beton armat folosind soluții compozite, (Improving the Load Bearing Capacity of RC Columns Using Composite Systems)*, Teză de doctorat, PhD Thesis, “Gheorghe Asachi” Technical University of Iasi, Romania, (**2008**).