EVALUAREA IMPACTULUI ASUPRA MEDIULUI A MATERIALELOR UTILIZATE ÎN CLĂDIRI SITUATE ÎN ZONE SEISMICE
AN ENVIRONMENTAL IMPACT ASSESSMENT OF THE MATERIALS USED IN BUILDINGS LOCATED IN SEISMIC ZONES

D.N. ISOPESCU*, **L. DUMITRESCU, I.D. ZĂPODEANU, O. NECULAI**
Department of Civil and Industrial Engineering,"Gheorghe Asachi" Technical University of Iasi, Romania
B-dul D. Mangeron nr. 1, 700050, Iași, ROMANIA

The paper findings are focused on the embodied impacts of building materials and component combinations that influence, generally, on the environment, and, particularly, the greenhouse gas emissions of a case study based on a new developed hybrid building system applicable to low-rise buildings located in seismic zones. The hybrid system has been designed as a masonry made of autoclaved aerated concrete blocks strengthened with composite frames made of rolled steel profiles embedded in concrete. The results obtained in design calculus, those obtained for global coefficient for thermal insulation, and those obtained in Life Cycle Assessment, have highlighted the good performance of the proposed hybrid system regarding its environmental impact.

Rezultatele cercetării din acest articol sunt axate pe impactul materialelor de construcții și a combinațiilor de materiale asupra mediul înconjurător, în special asupra emisiilor de gaze cu efect de seră ale unui studiu de caz bazat pe un nou sistem hibrid de construcție aplicabil la clădiri joase situate în zone seismice. Sistemul hibrid a fost conceput ca o zidărie din blocuri de beton celular autoclavizat întărit cu cadre compozite realizate din profile laminate din oţel încorporate în beton. Rezultatele obținute în calculul de proiectare, cele pentru coeficientul global de izolare termică, precum și cele în evaluarea ciclului de viață, au scos in evidenţă buna performanţă a sistemului hibrid propus în ceea ce privește impactul asupra mediului.

Keywords: *greenhouse gas emissions; Global Warming Potential; hybrid structure; Life Cycle Assessment; energy efficiency; low-rise buildings for seismic zones.*

1. Introduction

The construction sector is of vital importance for society, and it imply the development of the appropriate constructions that meets the needs of a population increasingly numerous. The buildings represent a physical division of the human habitat, and its interior serves as a place for comfort and safety. The notion of comfort should suggest creating an environment appropriate to conduct the normal life, and that of safety should suggest resistant to actions, in our case, in addition, to earthquakes. For each type of building, there are the corresponding varieties of demands, because for their interior is assigned a microclimate suitable for the purpose for which they were built.

In Europe, the energy consumption of buildings accounts for 40% of total energy consumption, of which 36% is responsible for greenhouse gas emissions. Therefore the environmental protection is and will be a real challenge to the present and future, and aims to consider the complex interrelationships of an entire ecosystem in decision making, rather than simply responding to specific issues. The topical analyses in constructions are related to structural safety, to energy saving, and to the environmental protection goals and principles. Improvements in energy efficiency of construction are generally achieved by adopting a more efficient technology or production process, or by application of commonly accepted methods to reduce energy losses. In parallel with reducing energy demand, it accomplishes two important goals of sustainable development, namely, the primary resources conservation, and the reduction of pollutant emissions into the environment.

In recent years, awareness of major environmental problems (depletion of natural resources, environmental degradation, the increased greenhouse gas emissions and global warming etc.) led to the adoption of the sustainable development as main objective of modern society. The construction sector is responsible for a high percentage of the environmental negative impacts, manifested by occupying of large areas, the high consumption of raw materials, the energy consumption and pollutant emissions, all throughout the entire life cycle of the building. As a reference example, at European Union level is estimated that about 40% of total energy consumption is due to

* Autor corespondent/*Corresponding author*,
E-mail: isopescu@ce.tuiasi.ro

consumption is due to buildings, [1]. According to European Union guidelines, [1], starting to 2021 new buildings have to comply the nZEB standards (building with nearly zero energy consumption). Due to the fact that these buildings must have a very low value of the demand in the operational energy, the constructive concept, and, also their relative impact of first stages of building life (the raw material extraction, the materials processing, the transport and the building site processes), will affect to a greater extent in terms of energy consumed and environmental impact of the entire building life cycle. Therefore, evaluating the environmental impact in stages of the materials, the components, and the whole buildings started to impose their self in the construction sector, thereby aiming to minimize the environmental impact and achieving sustainable development in the life cycle of buildings.

Besides the design requirements, and technological and economic considerations, one of the aspects taken into account, when considering the appropriateness of introducing new materials and building solutions, is their impact on the environment. Often, this is evaluated using Life Cycle Assessment (LCA) studies [2]. These studies are conducted based on provisions of ISO 14040 and 14044 standards, [3, 4], and ILCD Handbook, [5]. LCA is used to assess the environmental impacts, associated with the production, use, and disposal and recycling of products, by quantifying, on a hand, the efficiency of the resource use, and, on the another hand, the environmental emissions associated with the products used. It allows comparisons between the alternative conceptual designs and choosing the optimal solution in terms of its environmental impact, [6].

In the early days of LCA studies, calculations were very time consuming. Nowadays, there are many LCA software tools available globally, the accuracy of the results depending on the data included in the databases, [7]. LCA software uses a life cycle inventory (LCI) databases for evaluating environmental impact. There is a continuous development of LCI databases containing building product and process data, and researchers have shown an increased interest to analyse the buildings using LCA, [8 - 10], as tool to improve sustainability of the construction sector. Cabeza et al., [11], presented some of the most relevant studies regarding the LCA analyses, for selection of construction products, and for the evaluation of building systems and processes Takano et al., [12], investigated the influence of the material selection in the life cycle of the building's energy balance, concluding that the selection of the structural materials has larger effect than of the building surface and of the equipment used.

The main life cycle stages of a building product, (Figure 1), are: row materials production with extraction and processing of raw materials, materials processing which comprehends manufacturing of construction products, construction which includes transportation to the building site, and construction stage on-worksite, operation with the use and maintenance of construction, and end-of-life including the demolition and final disposal, with possible re-use or recycling of the materials. The phase with the highest environmental impact is the operation phase, representing between 62-98% of the total impacts of building in its life cycle, [13], and therefore, the emphasis is on the reducing of fluxes (energy, water and waste) during the operation phase. Currently, special emphasis is on the demolition process and the recycling of the materials.

The building concept must comply the necessary requirements for its improving, and, obviously, the structural materials selection plays the most significant role in the sustainability of the buildings, because they are responsible for the constructions strength and stability, and because they assure a high level of efficiency related to the energy consumption in buildings, or in reducing the environmental impact of built areas.

The paper findings are focused on the embodied impacts of building materials and component combinations that influence, generally, on the environment, and, particularly, the greenhouse gas emissions. The case study is based on a new developed hybrid building system applicable to low-rise buildings located in seismic zones for which the structural performances were summarised. The reference structural system used was the same building made of brick masonry framed in reinforced concrete elements. A series of simulations of the Life Cycle Assessment (LCA), in a "cradle-to-gate" manner, have been conducted to determine the environmental impact of the studied cases of constructions. The analyses have been performed for the first three stages of life cycle, and the results were estimated through the amount of CO_2-Eq emissions. The CO_2-Eq emissions were associated with the materials used in the presented structures, and also with the related transport distances in some presumed suppositions. The performed analyses allow the comparison of the Global Warming Potential (GWP) indicators of the

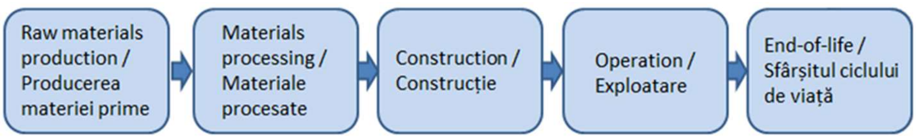


Fig. 1- Life cycle phases of building products/*Fazele ciclului de viață al clădirilor*

two structural systems, in accordance with the objectives of sustainability and environmental protection.

The aims of this study were to evaluate the environmental performance of the proposed hybrid building system, which is, already demonstrated, aligned to the energy efficiency requirements, and to determine the conditions that allow to include the presented hybrid structure in the range of building systems with reduced environmental impact.

2. Case study data

2.1. The building structures presentation

The analysed building structure systems have been chosen as strength frames filled with masonry, as they are considered proper structural systems for low-rise buildings located in seismic zones, [14].

In view of the results comparison, as a reference system, it was taken into consideration a structure designed identically with proposed hybrid building system, today used frequently, made of fired clay brick masonry (GVP bricks), and strengthened with reinforced concrete frames. For both buildings were considered a net area by 176.6 m^2 and a building regime GF + 1, with a level height of 2.80 m, (Figure 2).

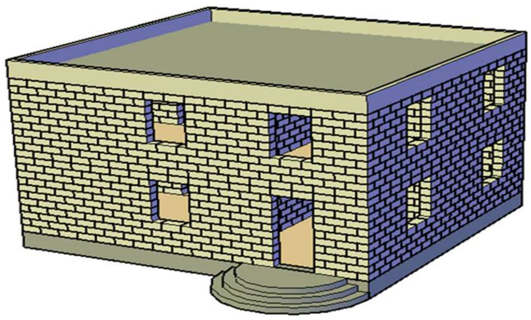


Fig. 2 - Model of the analysed structures / *Modelul structurii analizate.*

The hybrid building system applicable to low-rise buildings located in seismic zones have been presented by Isopescu & Astanei in the technical reference “Design guide for buildings with AAC elements masonry walls - A revised and supplemented edition” [15]. This structural system, designed on the basis of the technical provisions, could be used for residential buildings and presents many advantages in terms of load bearing capacity and energy efficiency. The proposed hybrid structure is made of composite frames and masonry panels with autoclaved aerated concrete blocks. The composite frames are also made of rolled steel profiles embedded in a self-compacting concrete poured into the ‘formwork’ formed by the blocks, made of autoclaved aerated concrete of type ‘O’ and ‘U’, (Figures 3 - 5), produced according to SR EN 771-4/2011, [16]. Therefore the strength structure (columns, beams, belts, lintels and sills) of the proposed building shall be considered made of steel-concrete composite elements. The masonry panels are made of normal AAC blocks and the slabs are made of reinforced concrete.

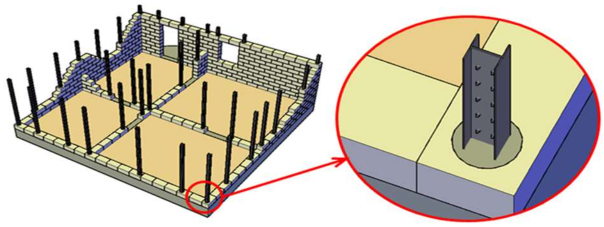


Fig. 3 - Hybrid structure for low-rise buildings / *Structură hibridă pentru clădiri joase.*

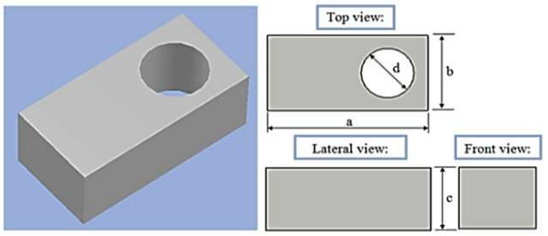
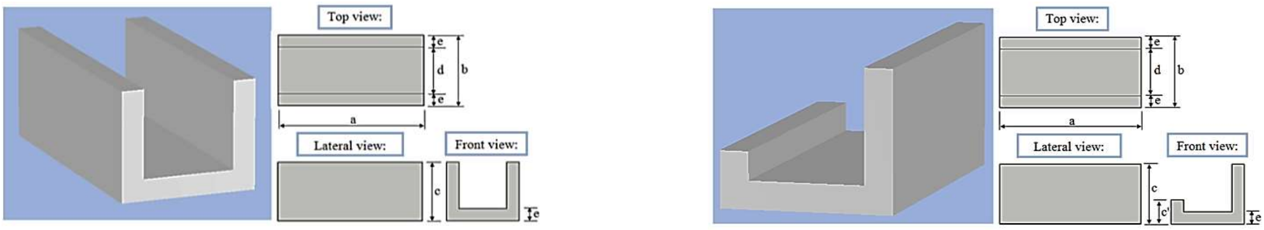


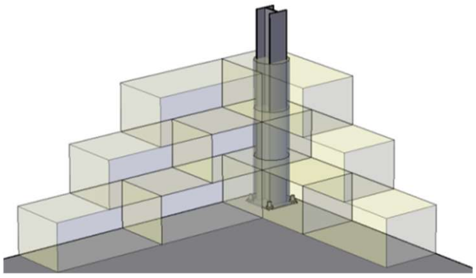
Fig. 4 - AAC block type „O” for composite column / *Blocuri BCA de tip „O” pentru stâlp compozit.*

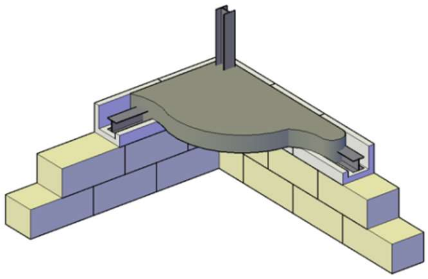
Construction elements, like the foundations, the floor slabs and the stairs are identical in both structures, and they were excluded from the LCA studies, because of their similar influences in results. Must be mentioned that the actual partition walls have been also considered unimportant because the reference evaluated parameters expressed through volume, surface or weight units may be considered relevant for conclusions so as they are, or at least they produce very little influence as not radically alter results.



a b

Fig. 5- AAC block type „U” for composite beam / *Blocuri BCA de tip „U” pentru grinda compozită*
a. normal block for beam / *bloc normal pentru grindă*; b. cut block for belts and floor slab joints / *bloc decupat pentru centuri la îmbinarea cu planşeul.*





a b

Fig. 6 - Detail of the steel-concrete composite element / *Detaliu element compozit oțel-beton*: a. vertical steel-concrete composite element (column), placed in permanent formwork of AAC blocks type „O" / *element vertical compozit oțel-beton (stâlp), situat în interiorul blocurilor de BCA de tip „O",* b. horizontal steel-concrete composite element (beams, belts), placed in permanent formwork of AAC blocks type „U" / *element orizontal compozit oțel-beton (grinzi, centuri), situat în interiorul blocurilor de BCA de tip „U".*

Figure 6 presents the construction details of the vertical and horizontal composite elements in the proposed hybrid structure.

In the design calculus of hybrid structural system it was observed a good behaviour of the steel - concrete composite elements, which were considered homogeneous elements having an equivalent section, and the material properties established by rule of mixing. The structural efficiency of the elements has been expressed as the ratio of the maximum values of internal forces and moments, developed in elements according to the rules of ultimate limit states design, (due to permanent, variable and accidental loads), and the corresponding load capacities of the elements. These ratios have had values between 0.2 and 0.7, lower than those obtained for traditional building with brick masonry, and have shown that the hybrid structure proposed is a viable structure in terms of the system strength and stability.

The proposed hybrid structure has also a much improved thermal insulation assured by the AAC blocks. According to the norms, the corrected specific thermal resistance (R') is determined using the equation $R' = 1/U'$where$U'$is the heat transfer coefficient, [W/m^{2}K], calculated based on: R = the specific unidirectional thermal resistance, [m^{2}K/W]; Ψ= factor for thermal bridges; l = the length of thermal bridges, [m]; and $A_{ext.wall}$ =the area of exterior walls, [m^2].

The specific unidirectional thermal resistances of the exterior walls (calculated for a wall without other materials applied on its surface) have values of R_{AAC} = 2.727 [m^{2}K/W] and R_{GVP} = 1.657 [m^{2}K/W]. The R_{AAC} is evaluated for the hybrid structure with wall panels made of AAC blocks, and R_{GVP} is calculated for the reference system with the wall panels traditionally made of fired clay bricks with vertical hollows, where GVP is the Romanian commercial abbreviation for fired clay bricks with vertical hollows. The minimum value imposed by standard for corrected specific thermal resistance is $R_{min} = 1.8$[m^{2}K/W]. In the studied systems the results obtained are $R'_{AAC} = 2.11 > R_{min}$ [m^{2}K/W] and $R'_{GVP} = 1.47 < R_{min}$ [m^{2}K/W], and consequently the heat transfer coefficients are $U'_{AAC} = 0.473$ [W/m^{2}K] and $U'_{GVP} = 0.676$ [W/m^{2}K]. It follows a first conclusion favourable for the proposed hybrid system, namely that it meets regulatory requirements where $U' \leq 0.56$ [W/m^{2}K], while the reference system needs additional thermal insulation works, [17].

The other advantages also identified in the conceptual design of this hybrid structure are the followings:

- The condensation on the inner surface of the walls is avoided.
- The thermal discomfort due to the radiation of cold walls is eliminated.
- The thermal bridges are fully eliminated.
- Heat consumption to ensure comfort during the cold season is lower.

2.2. Input data for the Life Cycle Assessments

The LCA analyses are performed for the first three stages of buildings: row materials production, materials processing and construction which includes transportation to the building site, and construction stage on-worksite. The analyses are using the GaBi6 software, which is a process-based model, developed at the University of Stuttgart, Germany, [18].The environmental impact is expressed by calculating the Global Warming Potential (GWP) indicator, based on the CML 2001-April 2013 methodology, [19].The global warming potential is calculated in carbon dioxide equivalent (CO_2 - Eq.), which means that the potentials of all greenhouse gas emissions (e.g. CH_4, CFCs) are given, in relation to CO_2 – Eq.

The residence time of the greenhouse gases in the atmosphere is included in the calculation, therefore the time range for the LCA-s are considered equal to 100 years. Also, as input data for transportation of materials to the building site, it is used Euro 4 diesel trucks with 3.3 t payload capacity for metal products, and with 17.3 t payload capacity for the rest of materials.

The influence of the transport distances for AAC blocks and GVP bricks, between their place of the purchase/fabrication and the site of buildings, is taken into consideration in the LCA analyses. Therefore, considering two towns, located at a distance of 300 km between them, in which are placed the factories for fabrication of the AAC

Table 1

Input data for the Life Cycle Assessments / *Date iniţiale pentru evaluarea ciclului de viață*

Material / *Materialul*	**Quantity / *Cantitatea*(kg)**	**Transport distances / *Distanța de transport*** [km]		
		Case R/*Cazul R*	**Case A/*Cazul A***	**Case B/*Cazul B***
Building 1 – hybrid structural system with AAC blocks ***Clădirea 1 – sistem structural hibrid cu blocuri de BCA***				
AAC blocks/*Blocuri BCA*	27468.2	100	15	300
Concrete/*Beton*	29392.8	100	100	100
U profiles/*Profil U*	2164.7	100	100	100
Building 2 – traditional framed masonry with GVP bricks ***Clădirea 2 – zidărie tradițională cu cărămizi GVP***				
GVP bricks/*Cărămidă GVP*	96309.1	100	300	15
Concrete/*Beton*	43423.2	100	100	100
Reinforcement/*Armătură*	2896.6	100	100	100

blocks or GVP bricks, three cases for LCA analyses were considered, namely:

- Case R (reference) : a constant distance D = 100 km between the place of the purchase/fabrication of materials and the buildings site.
- Case A: the buildings are located in the town with AAC blocks factory.
- Case B: the buildings are located in the town with GVP bricks factory.

Data on the materials quantities and transport distances for each case analysed are presented in Table 1.

3. Results and Discussion

The LCA includes analyses of carbon emission for materials production, materials processing and construction which consists of transportation to the building site, and construction stage on-worksite. The results obtained for both buildings and all case studies are presented graphically using bar chart in Figures 7 - 9.The results of the LCA analyses revealed the following:

- When transport distances are the same for the materials used in the analysed buildings (Case R,

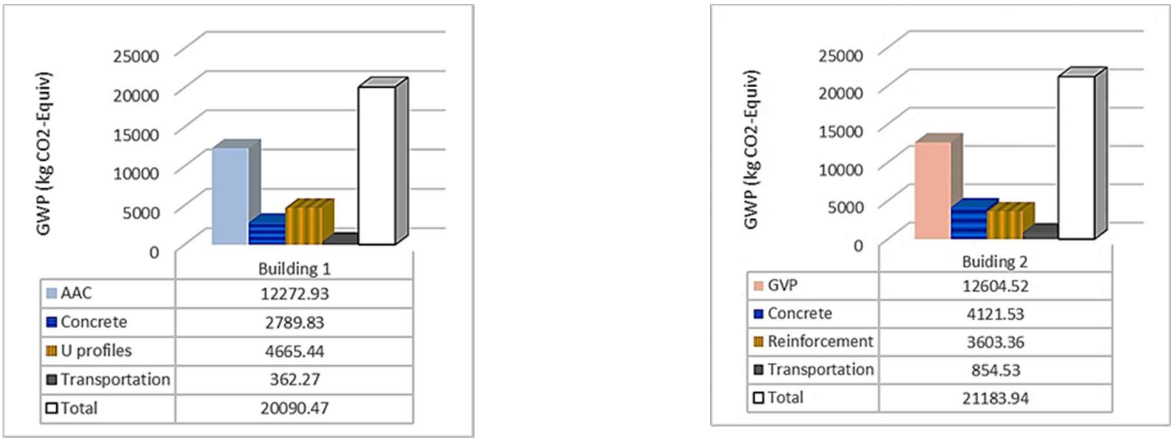


Fig. 7- GWP indicators in Case R for Building 1 and Building 2 / *Indicatorii potențialului de încălzire globală în Cazul R pentru Clădirea 1 și Clădirea 2*

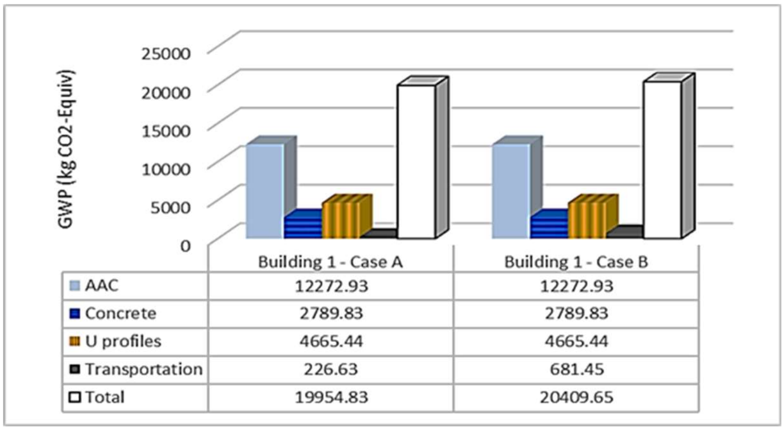


Fig. 8 - GWP indicators in Cases A and Case B for Building 1 / *Indicatorii potențialului de încălzire globală în Cazul A și Cazul B pentru Clădirea 1.*

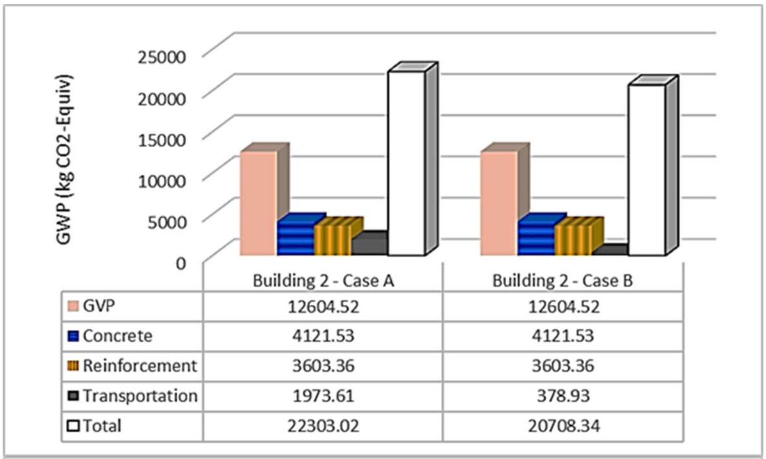


Fig. 9 - GWP indicators in Cases A and Case B for Building 2 / *Indicatorii potențialului de încălzire globală în Cazul A și Cazul B pentru Clădirea 2.*

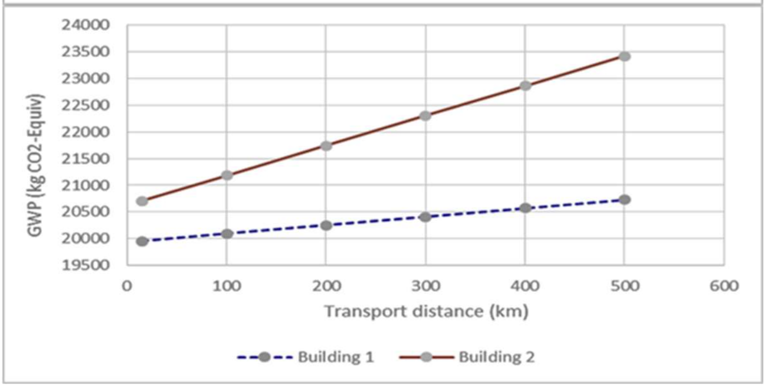


Fig. 10 - GWP indicators related to transport distance variation / *Indicatorii potențialului de încălzire globală în funcție de varița distanței de transport.*

.

Figure 7), the total emissions of CO_2 - Eq. expressed by GWP indicators are: $GWP_{Total,\ 1}$ = 20090.47 kg CO_2 - Eq. and $GWP_{Total,\ 2}$ = 21183.94 kg CO_2 - Eq. The higher value is for the traditional building made of reinforced concrete frames fill with GVP bricks

- The transport distances influence the values of the indicators GWP_{Total} for both analysed buildings, (Figure 8 and Figure 9). It is observed the direct influence of the volumes of the materials and less of their weight.
- A variation of the transport distances from 15 km to 300 km produces an increase with 8% of the indicator GWP_{Total} for the traditional building made of reinforced concrete frames fill with GVP bricks, and a reduced increase with only 2% for GWP_{Total} value, in case of the proposed hybrid building, (Figure 8 and Figure 9).
- The graph presented in Figure 10 shows the variation of the indicators GWP_{Total} for the two analysed buildings, and can be noticed that the hybrid structural system has lower emissions of CO_2 - Eq. when transport distance is increasing.

4. Conclusions

The case study is based on a new developed hybrid building system applicable to low-rise buildings located in seismic zones for which the structural performances were summarised. The presented study highlights the importance of full and simultaneous action of several factors converging towards achieving sustainability as main objective of modern society, and particularly, the needs of identification the complete factors involved in environmental impact of constructions.

Analysing the results, in the limits imposed for the case studies, the main conclusion is that the hybrid system has a good performance regarding its environmental impact. The proposed building system shows a reduction in carbon dioxide emissions, in the first three stages of the life of a construction, no matter how large is the transport distance.

Considering the good characteristics of the AAC blocks for thermal insulation, it is observed that over the duration of use of the hybrid constructed system proposed will exist a substantial reduction in emissions of carbon dioxide due to eliminating the use of materials for additional insulation as in case of traditional buildings, or by reducing conventional energy consumption.

Beside these, the following conclusions can be drawn:

- In the long term, in order to implement the EU decarbonisation targets, besides energy efficiency, in the design processes of constructions, it is necessary to use performance indicators concerning environmental impact. These indicators will lead to improved building design by developing methodologies and analysis tools that will ensure reaching the threshold of CO_2 emissions envisaged.
- Although the construction products used for the proposed hybrid structure are suspected of having CO_2 emissions much higher than the products used for the classical building, the results, for the GWP_{Total} indicator and the heat transfer

coefficients, classify the proposed structure as comparable, even more performing in terms of CO_2 emissions reduction. The results obtained in LCA case studies show that information on environmental impacts of materials can help consumers and code officials to make more informed choices, and this is the way through which the designers and builders must strive to improve energy efficiency, durability and environmental performance of buildings.

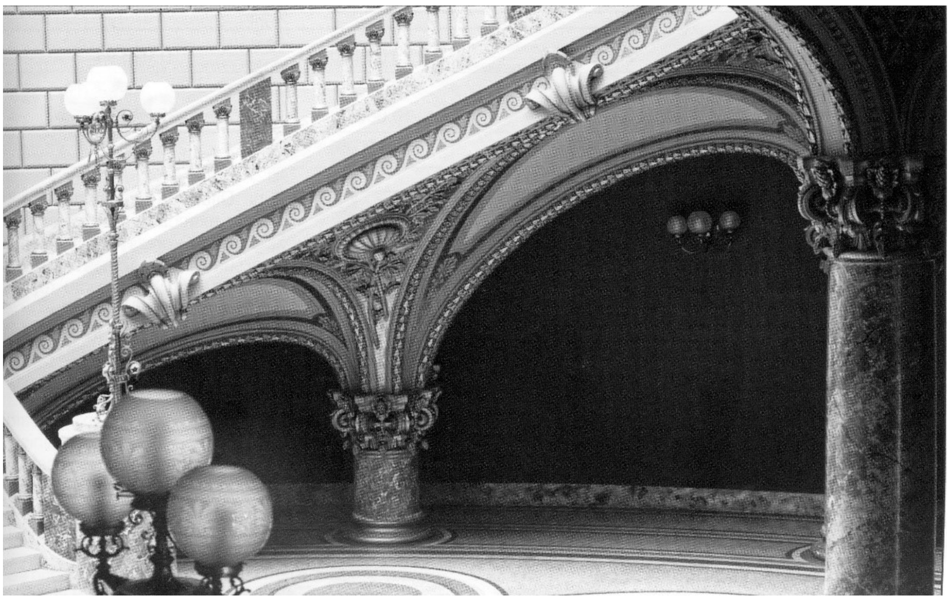
Acknowledgments

The authors would like to thank to MACON SRL Company for their support and contribution in developing the hybrid system.

REFERENCES

1. Directive 2010/31/EU of the European Parliament and of the Council of 19May 2010 on the energy performance of buildings (recast).
2. L. Dumitrescu, S.G. Maxineasa, I.M. Simion, N. Ţăranu, R. Andrei and M. Gavrilescu, Evaluation of the environmental impact of road pavements from a life cycle perspective. Environmental Engineering & Management Journal, 2014.
3. ISO 14040:2006, Environmental management–Life cycle assessment–Principles and framework.
4. ISO 14044:2006, Environmental management–Life cycle assessment–Requirements and Guidelines
5. European Commission-Joint Research Centre-Institute for Environment and Sustainability, International Reference Life Cycle Data System (ILCD) Handbook-General Guide for Life Cycle Assessment-Detailed guidance, Ispra, Italy, 2010.
6. F. Faleschini, P. De Marzi and C.Pellegrino, Recycled concrete containing EAF slag: environmental assessment through LCA. European Journal of Environmental and Civil Engineering, 2014, **18**, 1009-1024.
7. M. Weißenberger, W. Jensch W and W.Lang, The convergence of life cycle assessment and nearly zero-energy buildings: The case of Germany. Energy and Buildings Journal, 2014, **76**, 551.
8. M. Buyle, J. Braet and A. Audenaert, Life cycle assessment in the construction sector: A review. Renewable and Sustainable Energy Reviews, 2013, **26**, 379.
9. H. Islam, M. Jollands and S. Setunge, Life cycle assessment and life cycle cost implication of residential buildings: A review. Renewable and Sustainable Energy Reviews, 2015, **42**, 129.
10. S.G. Maxineasa, N. Ţăranu, L. Bejan, D. Isopescu and O. M. Banu, Environmental impact of carbon fibre-reinforced polymer flexural strengthening solutions of reinforced concrete beams. The International Journal of Life Cycle Assessment, 2015, **20**, 1343.
11. L. F. Cabeza, L. Rincon, V. Vilarino, G. Perez and A. Castell, A Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review. Renewable and Sustainable Energy Reviews, 2014, **29**, 394.
12. A. Takano, S. K. Pal, M. Kuittinen, K. Alanne, M. Hughes, and S. Winter, The effect of material selection on life cycle energy balance: A case study on a hypothetical building model in Finland. Building and Environment Journal, 2015, **89**, 192.
13. B. Rossi, A.F. Marique, M. Glaumann and S. Reiter, Life-cycle assessment of residential buildings in three different European location, basic tool. Building and Environment Journal, 2012, **51**, 395.
14. F. Di Trapani, G. Macaluso, L. Cavaleri and M. Papia, Masonry infills and RC frames interaction: literature overview and state of the art of macromodeling approach. European Journal of Environmental and Civil Engineering, 2015, **19**, 1059.
15. D.N. Isopescu and I. Astanei, Ghid pentru proiectarea clădirilor cu pereți din zidărie cu elemente din B.C.A.-Ediție revizuită și completată [Design guide for buildings with AAC elements masonry walls - A revised and supplemented edition], Iași Politehnium Ed., 2015.
16. SR EN 771-4:2011, Specification for masonry units. Autoclaved aerated concrete masonry units. Romanian Standard Organization.
17. European Institute for Performance of Buildings Directive (BPIE), Implementation of buildings with almost zero energy consumption (nZEB) in Romania, definition and roadmap, 2012.
18. GaBi, Homepage GaBi-Software, http://www.gabi-software.com .
19. CML 2001 impact assessment method, University of Leiden, Netherlands, updated in April 2013.

****



Detaliu: coloane de susținere a scării (pg. 115 - Nicolae St.Noica - ATENEUL ROMÂN ŞI CONSTRUCTORII SĂI)