The Assessment of the Impact of the Project on the Environment from the Aspect of the Embodied Carbon Footprint

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ABSTRACT

The study analyses the possibility of improving the methodology of architectural designs using the calculation of the embodied carbon as a criterion for assessing the environmental impact of the facility from construction phase. For the research needs, three models of a constructive solutions for a family housing unit, commonly used in Serbia, were developed in the energy class C. The study uses the Life Cycle Analysis Methodology (LCA), which is the basis for the Carbon Lifecycle Analysis (LCACO2), the calculation of the embodied carbon footprint. To calculate the carbon footprint ICE databases and Carbon Calculator were used, Environmental Protection Agency UK, and for the energy rating, the program URSA, Construction Physics 2, is used to make the required thermal cover sizing. The research has shown that at the design stage, a design solution with a smaller embodied carbon, or a smaller environmental impact, can be identified. The research points to the need, in addition to operational carbon, which, according to the present methodology of calculating the environmental impact of a building, should also, consider the influence of the embodied carbon of the design solution.

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1. Introduction

On the global level, the civil engineering sector is amoung the top ones regarding the consumption of resources, primary materials, energy, water, and waste generation. For this reason, an effort is made on the international scale to reduce the impact of the building construction on the environment. The measures are taken, and regulations are brought in which put a limit on the energy consumption in building exploitation phase. Classifying buildings according to energy efficiency rating per square meter has been a mandatory part of the legislation in Serbia since 2012. Designers and building constructors are obliged to do projects which are in compliance with energy rating C, which is the least acceptable energy efficiency rating of new buildings. The defined methodology for the energy rating of the project recognizes only the energy needed for the comfortable exploitation of a building (operational energy) (Directive 2002/91/EC),(Directive 2010/31/EU) and the impact created in the exploitation phase. However, the impact of a building on the environment starts with the exploitation of the raw materials used in the production of the construction materials and products, followed by transportation, processing, delivering onto the construction site and their installment, which means long before the start of the exploitation of a building. In a design phase it is possible to identify a project with the lower impact on the environment by calculating the embodied carbon as a measurement of the impact of the project on the environment from the raw materials, extracted from natural resources to the start of the building exploitation.

The need for the reduction of CO2 by 26,9% until 2020 was indicated by Kim et al. (2017). The authors such as Beak et al. (2013) concluded that the carbon footprint estimation in the design phase is crucial for the reduction of the civil engineering impact on the environment. The studies, which are often cited as example of the civil engineering impact (Abd Rashid et al., 2017), show that the use of cement accounts for 8,6% of CO2 emission worldwide (Kleijn, 2012).

The consumption of energy in civil engineering sector in Serbia in 2011 was 41% (Ministry of Mining and Energy, 2017). The production and consumption of energy is related to the production of CO2. In 2013 the national ecological footprint in Serbia was 3,02 global hectares (Global Footprint Network, 2018). More than 50 % of the ecological footprints in Serbia come from the production of CO2 (Global Footprint Network, 2018).

Methodology for energy efficiency calculation of a building in Serbia (Ministry of Construction, Transport and Infrastructure, 2016a), (Ministry of Construction, Transport and Infrastructure, 2016b) is based on building operational energy calculation (energy used for comfortable exploitation of a building), as well as EU regulations in this field.

his study suggests that there is a possibility to reduce the impact from the civil engineering sector through design phase, which involves the analysis of the impact caused by the chosen construction systems and materials when designing a building. The current methodology of energy rating of a building neglects the burdens on the environment imposed by exploitation and production of construction materials, transportation, construction, waste management, transportation of labour force and water consumption.

In the study done by Ibn-Mohammed et al. (2014), it is stated that, for mitigating climate changes, the buildings should be designed and constructed with the minimal effect on the environment.

Analyzing the operational end embodied energy of a building in Italy, Cellura et al. (2014) state that a key question is the embodied energy of a building and conclude that it is particularly important for low-energy buildings. The existing European legislations are guidance for the architects to design energy efficient buildings with zero energy consumption, with the intention of having, by 2020, all public building with zero energy.

In the studies on energy efficiency of buildings, Karimpour et al. (2014) conclude that in mild climates the embodied energy in buildings can participate with about 25% of total life cycle energy. The same authors believe the trend for designing and constructing zero-energy buildings will lead to the rise in embodied energy and the total building life cycle energy. Fay et al. (2000) conclude that the embodied energy has become important, and it is necessary to consider its impacts as well.

The importance of the impact of the applied construction materials, through the analysis of the life cycle of the materials, is also addressed by the local authors. In their papers, Slavković & Radivojević (2015) and Jovanović-Popović & Kosanović (2009), state that for the further energy saving, it is required to investigate the consumed energy in materials during their life cycle.

In that regard, the aim of the research is to calculate the value of the embodied carbon in the analyzed scenarios where three different constructive systems, common in Serbia for the residential buildings, were applied on the same project.

2. Methodology

Life cycle analysis (LCA), as a methodology for identification and intervention in the environment, and potential impact of a product or service through their life cycle, is the methodology defined by ISO standards 14040: 2006 and 1044: 2006 and is recommended by the European commission as a tool for the estimation of the impact on the environment.

The aim of this research is to assess the value of embodied carbon in one project conducted in three different constructive systems. The system boundaries are in accordance with the research goal. Materials, activities, and energy sources, which are the life cycle inventory within the system boundaries, are calculated by using The Norms and Work Standards in Civil Engineering (Mijatović, 2008). The impact assessment will be expressed through carbon footprint (embodied carbon for analyzed models and their evaluation). Accordingly, LCA is the basis for CO2 emissions calculation. The analysis of the embodied carbon footprint of a building is a methodology which relies on the principles of methodology for measuring life cycle performance of a building and the purpose of which is to calculate embodied carbon in the design stage. Due to the complexity of the construction process, great quantity of materials, activities, different energy sources, waste and exploitation of buildings, methodology scope for building LCA is classified by the Organization for Standardization in standard EN 15978:2011 (EN 15978:2011). According to that standard, the life cycle of a building is divided into four phases: production, construction, exploitation, and the life cycle end. In this research the system boundaries are from A1 to A5. The exploitation and the life cycle end are outside the system boundaries.

Databases are the sources of information to analyze inputs and outputs (LCIA) in LCA. Since Serbia does not have available public data nor national base of materials and products, the database used for this research is ICE version 2: Inventory of Carbon and Energy (Hammond et al., 2011). ICE database studies the concept of implemented materials with reference to their embodied energy and embodied carbon, in broader scope greenhouse gases (GHG), building components and transportation. Carbon calculator of the Environment Agency UK (2015) is used for analyzing carbon footprint. This software has a database of materials produced from natural raw materials (primary materials), which is one of the reasons for its use in the research. The program URSA construction physics 2 (2018) is used to calculate the building energy rating based on which the sizing of thermal cover of the building is done.

This study will show how it is possible, by calculating the embodied carbon in the design stage, to estimate the level of impact on the environment which is the result of different constructive solutions for the same project.

3. The Research Aim and Organization

The research was conducted on the project of a residential building with net area of 110m2 in the vicinity to Belgrade. For the purpose of this research, three building plans of residential houses, common in Serbia, are made: M1 (brick products and RC construction), M2 (lightweight concrete blocks and RC construction) and M3 (prefabricated wood panels). Primary materials are used as reference models for this project. This means that models M1, M2 and M3 are designed in energy rating C, in accordance with the legislative in Serbia (Ministry of Construction, Transport and Infrastructure, 2016a), (Ministry of Construction, Transport and Infrastructure, 2016b). Products and materials used for the construction are taken from the local construction industry, all transportation directions are calculated for each position as well as the types of transportation: road transportation by trucks from the factory to the construction site, and in case of smaller quantities by vans with lower payload. The engaged labour force comes from within 30 km. Construction timeframe is 15 – 16 weeks, which follows The Norms and Work Standards in Civil Engineering (Mijatović, 2008) and the calculation of the carbon footprint includes, not only the required construction materials and products, but construction activities, work force accommodation, generation of building and hard municipal waste and its disposal, water, electricity, fuel consumption for devices and machines on the building site in order to measure the impact of the analyzed models.

The program URSA 2 (2018) is used to calculate the building energy rating and measure the thermal cover, whereas ICE database (Hammond et al., 2011) (Inventory of Carbon and Energy – ICE) and the software from Environment Agency UK (2015) are used to calculate embodied carbon.

The basic model 1 (M1) is a building designed in load bearing structural system. The walls are from hollow brick blocks 25 cm thick, with 12 cm of thermal insulation on the facade walls finished with decorative plaster. The interior walls are plastered. The columns are RC (reinforced concrete) both horizontal and vertical. The ceiling, LMT (easily installed), with 15 cm thick thermal insulation towards the attic. Lightweight reinforced floor slab is covered with 10 cm thick thermal insulation, cement screed and the floor finishing are in accordance with the purpose of the room. Wooden roof construction is covered with roofing tiles. Facade carpentry with the improved technical features is in accordance with the minimum requirements according to the new regulations. The timeframe for the construction is 16 weeks.

The model 2 (M2) is a building designed in light gas concrete blocks 25 cm thick, with 10 cm of thermal insulation finished with decorative plaster, and with thin layer in the interior. The columns, both horizontal and vertical, are RC. The ceiling, white Ytong with 10 cm thick thermal insulation towards the attic. Lightweight reinforced floor slab is covered with 10 cm thick thermal insulation, cement screed and the floor finishing are in accordance with the purpose of the room. Facade carpentry is with the improved technical features following the minimum requirements according to the new regulations. The timeframe for the construction is 15 weeks.

The model 3 (M3) is a building designed with the walls and ceiling made from prefabricated wood panels with 25 cm of thermal insulation on the facade walls finished with decorative plaster on the exterior and gypsum boards in the interior. Wooden roof construction is covered with roofing tiles. Lightweight reinforced floor slab is covered with 10 cm thick thermal insulation, cement screed and the floor finishing are in accordance with the purpose of the room. Facade carpentry is with the improved technical features following the minimum requirements according to the new regulations. The timeframe for the construction is 15 weeks.

4. Results and Discusion

The results of the embodied carbon footprint for the analyzed models are obtained as a sum of all analyzed components. The grouping of the materials shown in Table 1. is in accordance with UK national standard, for branches of industry and average values which are relevant for energy consumption within the industrial sector. The values of the embodied carbon footprint for the groups of materials and activities participating in the construction of the basic model M1 and analyzed models M2 and M3 are shown in Table 1. To get the results of the carbon footprint CO2e (embodied carbon) the operational phase (operational carbon) is not included in the calculation as it is outside system boundaries in this research.

The model with the highest total values of the embodied carbon is M1 which is 148,20 tons CO2e. The highest value of embodied carbon in the model M1 belongs to the group of materials that come from soil - 44,40 tons CO2e, which results from the use of brick products, bricks, roofing tiles, ceiling, and stone aggregate. Another group of materials with high embodied carbon includes concerts, plasters, and cement with 28,40 tons CO2e., as well as metals with 23,90 tons CO2e. The chosen constructive system and the implemented materials make the emissions from this group of materials considerable. Any savings in the quantity of these components and optimization can lower the emissions coming from this group of materials and of total embodied carbon. The transportation of the laborers in this model is higher compared with the other two models, because it takes more time to construct model M1 then models M2 and M3.

The value of the embodied carbon footprint in the model M2 is 112,50 tons CO2e. The highest value of embodied carbon in the model M2 belongs to the group of concerts, plasters, and cement with 38,30 tons CO2e., which results from the use of light concrete blocks and ceilings. The chosen constructive system and the applied materials make the emissions from this group of materials considerable. Any savings in the quantity of these components and optimization can lower the emissions coming from this group of materials as well as total embodied carbon. Another group of materials with high embodied carbon includes metals with 15,80 tons CO2e. The value of the embodied carbon in materials coming from soil is 13,10 tons CO2e. The transportation of the laborers in this model is lower compared with the model M1 because of the shorter construction timeframe.

The value of the embodied carbon footprint in the model M3 is 102,50 tons CO2e. The highest value of embodied carbon in the model M3 belongs to wooden materials with 13,70 tons CO2e., which results from the use of prefabricated panels with wooden framing for walls and ceilings. The chosen constructive system and the applied materials make the emissions from this group of materials considerable. Any savings in the quantity of these components and optimization can lower the emissions from this group of materials and total embodied carbon. Another way of savings in this group of materials is by using timber from certified woods, which is not a common way in Serbia. The other group of materials with high embodied carbon includes concerts, plasters, and cement with 20,20 tons CO2e. The value of the embodied carbon in materials coming from soil is 13,10 tons CO2e. Transportation of the materials in this model is lower compared with models M1 and M2, but the transportation of the laborers is lower compared with the model M1 because of the shorter construction.

Table 1. Values of embodied carbon and participation in analyzed models (M1, M2 and M3)

Groups of materials and activities	M1 tons CO_2e	M2 tons CO_2e	M3 tons CO_2e
Materials from soil (stone, soil)	44,40	13,10	13,10
Wooden materials	3,40	3,30	13,70
Concrete, Plaster & Cement	28,40	38,30	20,20
Metal materials	23,90	15,80	11,80
Plastic materials	5,80	5,80	5,80
Glass materials	0,90	0,90	0,90
Miscellaneous materials	9,00	9,60	12,00
Finishing, coatings & adhesives	7,10	5,60	5,50
Devices and equipment -impact	5,40	5,30	5,40
Waste removal	3,90	2,80	2,70
Labourer accommodation impact	2,00	1,90	2,00
Transportation of materials	5,60	6,30	5,20
Transportation of laborers	8,40	6,00	6,20
Total embodied carbon footprint	148,20	112,50	102,50

The benchmark values of the embodied carbon are shown in Table 2. The value of the embodied carbon in model M1 is 148,40 tons CO2e, which is the highest value among the three models. With reference to the amount of the embodied carbon, the model M1 is the least favourable regarding the environmental impact. The next model with the lower impact on the environment is the model M2 whose embodied carbon is 112,50 tons CO2e., which is 35,70 tons CO2e less than in the model M1, or by 24,09% less. The most favourable model for the environment is the model M3 whose embodied carbon is 102,50 tons CO2e., which is 45,70 tons CO2e less than in the model M1, or by 30,84% less.

The results have shown that the model M3 contains the lowest level of embodied carbon which is 102,70 tons CO2e, followed by the model M2 whose value of the embodied carbon is112,50 tons CO2e. The model M1 has the highest value of the embodied carbon, which is 148,20 tons CO2e.

Table 2. Embodied carbon benchmark for models M1, M2 and M3

Analyzed models		Embodied carbon		
		Tons of CO_2 e per building	Less tons of CO_2 e than in model (M1)	Reduction in %
1.	M1	148,20	0,00	0
2.	M2	112,50	35,70	24,09%
3.	M3	102,50	45,70	30,84%

At the start of the exploitation of the building, the model M3 is the most favourable for the environment due to the lowest level embodied carbon. The difference of 45,70 tons CO2 in embodied carbon enables the model M3 to have lower carbon footprint than the model M1. By comparing the model M1 with the model M2 it can be concluded that the model M1 has higher values of the carbon footprint than the model M2 by 35,70 tons CO2e.

Comparing the model M2 with the model M3, it can be concluded that the model M2 has higher values of embodied carbon than the model M3 by 10,00 tons CO2e.

The results show that the most favourable model, with regard to the environment in the construction phase from A1-A5, is M3 with the lowest value of embodied carbon. The increase in the embodied carbon in the construction phase, for the models M1 and M2, results from the larger quantity of soil materials, concrete, cement, and metal, which burdens the environment and makes these two models less favourable.

5. Conclusion

The results show that the construction in the model M3 has the lowest impact on the environment, then follows the model M2 with higher impact and the last is the model M1 with the highest impact on the environment within boundaries from A1 – A5.

The research indicates the necessity of including the calculation of embodied carbon in the design stage, not only operational carbon as laid down in building energy rating. The real picture about the impact of the project and its energy estimation can be conceived only by calculating the embodied carbon and adding it up to the operational carbon. The results also suggest that the savings in embodied carbon in the design stage decrease the impact on the environment caused by the civil engineering sector, but only if the methodology for the embodied carbon analysis is applied in the design stage when deciding which project is more favourable for the environment.

The research also suggests the need for introducing the national database of construction materials and products and their inventory of life cycle impact, as well as the need for the national program for carbon footprint calculation.

The study shows the need for the low-carbon construction products in the national construction industry, which will help to bridge the gap between the increasing need for the insulation materials and the necessity for CO_2 emissions decrease.

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