EARTH AS AN ALTERNATIVE INDICATOR REGARDING THE ECOLOGICAL CHARACTER OF BUILDING MATERIALS

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Abstract

Climate change is a reality proven by the scientific community – the last 4 years have recorded the highest temperatures since the beginning of the climate analysis. The construction sector produces around 30% of CO_2 emissions, but the question remains how to build at affordable prices while considering a sustainable development. Life cycle assessment (LCA) is a method that is increasingly used to evaluate the potential for environmental impact of products and services and the consumption of resources in achieving them. LCA is used in the construction sector, where it is a crucial part of the environmental impact assessment of buildings.

Earth as a building material can be reviewed in a modern key by understanding and capitalizing on its properties in terms of heat storage capacity, regulation of the internal humidity, the lack of volatile organic compounds. Considering the ecological impact, earth has the advantage of a reduced built-in energy compared to other materials, while being adaptable to different techniques.

The case study presents a comparison regarding the life cycle assessment using the "cradle to gate" method between 2 wall stratifications that have similar properties in terms of thermal comfort, but represent 2 different approaches. The first one is made out of conventional ceramic blocks with hollows insulated with mineral wool and the other one is composed out of modern adobe bricks and wood fibers.

As for the future of earth constructions, the material itself leads to a new conception of architecture in the era of climate change. Quality of space needs to be adressed in terms of environmental benefits and comfort by refering to ecological criteria. Therefore, the potential of earth as a building material is to respond to these contemporary challenges in a natural, sustainable way.

Keywords: Sustainability, life cycle assessment, earth constructions, ecology.

1. INTRODUCTION

90% of the scientific community has concluded that climate change is due to human activity, especially through the burning of fossil fuels. (P.J.Smith, 2001, pp.1). Once this is understood and aknowledged, then human action can stop the progress of global warming and the adverse consequences for the environment. The first solution contemplated is to make a commitment to use renewable energy resources, respectively to adopt a sustainable development strategies as an imperative measure in the construction industry.

Life cycle analysis introduces greater significance for formulating strategies of reducing primary energy. Therefore, there is a potential to reduce the energy consumption incorporated by using materials that consume less energy during the manufacturing process. In this context, earth constructions are characterized by a low embodied energy which represents an advantage compared to conventional construction materials and techniques.

The presented case study follows an analysis of the built fund in the Banat region, Romania, carried out by the authors of this article. Earth was one of the building materials used, especially in the form of unburnt bricks. The physical properties of the local soil confirm that the material is suitable for this technique by comparing the composition with the reference values proposed by the CRAterre Institute and the German Dachwerband Lehm regulations. (E.R.Florescu, S.M, Bica, 2018, pp.25). Unfortunately, this constructive technique is no longer used in the territory due to more available materials. However, it is important to review some of the qualities that promote this material and this technique, as evidenced by the interest in research in the last period on earth constructions.

2. SUSTAINABLE DEVELOPMENT

"Sustainable development is that process of development that meets current needs without jeopardizing the ability of future generations to meet their own needs. [.....] So that the desire for sustainable development can be achieved, environmental protection will be an integral part of the development process and cannot be addressed independently of it."

Source: Declaration on Environment and Development, Rio de Janeiro, 1992

Statistically speaking, 40% of the energy produced is consumed by buildings. From another point of view, about 20-30% of the total energy is consumed for the production and transport of construction materials (F.Pacheco-Torgal, S. Jalali, 2012, 512-519). For this reason, the impact of buildings on the environment is huge. From an ecological point of view, this industry represents 30% of the carbon dioxide emissions; In addition, the global construction industry consumes more raw materials than any other economic activity, which shows a clearly unsustainable industry.

The predictable growth of the world population (8.5 billion by 2030 - www.un.org), and the needs in terms of construction and other infrastructures, will require even more matter. The consumption of non-renewable materials also produces waste. Therefore, the use of more sustainable building materials and techniques is a major contribution to the ecological efficiency of the construction industry.

The term sustainability is increasingly used in the design, purchase or maintenance of buildings in recent years. Although there are a number of definitions, there are few indications on how to apply the principles of sustainability in practice. For architecture, sustainability involves addressing a wider spectrum of topics, sometimes seemingly conflicting or diametrically opposed. For this reason, a holistic approach that encompasses large-scale problems, including land use, local ecology and community issues, is required.

Robert Crawfort recommends some measures of good practice in order to build in a sustainable way:

(R.H.Crawfort, pp.24-25):

1. Efficiency of resources
2. Minimizing the consumption of non-renewable resources
3. Minimizing pollution
4. Design for disassembly
5. Minimizing solid waste
6. Design for recycling
7. Design for durability
8. Design for adaptive use

The advantage of using earth as a building material is that it allows to respond to the demands stated above in a natural, efficient way, which gives it the status of being one of the most environmental friendly materials possible. However, earth buildings require a lot of raw materials and this may seem contrary to the idea of sustainable development. The material must remain simple, in order to have a small energy footprint, similar to traditional constructions. Earth constructions can be synonymous with sustainable development and a harmonious integration of buildings in the physical environment, by ensuring a low environmental impact, respectively by the social character of these constructions.

Earth constructions have a reduced impact on the environment through:

- Use of natural materials,

- Reduction of waste,

- Reduced toxic emissions.

And from a social point of view, the use of the earth has the following advantages:

- Contributes to achieving a higher quality of life due to the ecological properties;

- Integrates several social categories and levels by involving them around a common project;

- Major impact on the local community through their active participation in the construction process.

Sustainability seen from a less quantitative perspective, but rather qualitative, addresses the problems of regional and local culture. Instead of suggesting a radical change in attitude, the logic relies on a fundamental reorientation of values so as to address both environmental issues and cultural concerns.

The main problem is the authenticity and the notion that architecture must first relate to the specificity of the place. From this point of view, earth constructions are easier to implement in rural areas because they are easier to adapt to a traditional construction system, appealing to local knowledge. The authors of this article studied the evolution of constructive techniques in the Banat region, Romania. Here, the tradition of earth constructions developed from the eighteenth century when the Habsburg Empire colonized the territory. Local earth was the basic material for creating new houses and settlements. Even if earth was used before this period for various constructions, the transition to new techniques takes place gradually, starting from the available local resources and ending with a transfer of knowledge between the local population and the new settlers – Germans, French, Italians (S.M.Bica, E.R.Florescu, 2018,pp. 20).

3. LIFE CYCLE ASSESSMENT

The current approach of intensive consumption of resources is not sustainable. This becomes even more obvious, given the predictions of human population growth in the coming years. Reducing the impact associated with the design, construction, operation and management of the built environment requires a concentrated effort from many parties involved in all stages of the life cycle of the built environment.

Life cycle assessment (LCA) is a method that is increasingly used to evaluate the potential for environmental impact of products and services and the consumption of resources in achieving them. LCA is used in the construction sector, where it is a crucial part of the environmental impact assessment of buildings. An LCA-type assessment of a building typically involves an entire process. This means including all stages of the evaluation - supply of raw materials, manufacture of construction products, transport and construction process, the use, demolition, disposal and recycle stage. To evaluate the LCA of a building, the U-value of the component elements, unfortunately, is not sufficient because the environment is damaged not only by the functioning stage of a building (heating), but also by the construction itself, the production of the necessary building materials (H Birgisdóttir and F. N. Rasmussen, 2016,pp.8).

Information on the resources needed to manufacture a building material and the pollutants emitted is not always available. More and more manufacturers are publishing so-called environmental product statements while government agencies update databases with this information (the German federal government maintains the Ökobaudat database, used to conduct the case study below). An environmental statement describes the influence of the production, the use and disposal of the building material on the environment. Consideration will be given to the use of resources by calculating the energy required for production and the quantity of released greenhouse gases.

4. PROPERTIES OF EARTH AS A BUILDING MATERIAL

Some of the properties that encourage the use of the earth as a building material are:

- Earth can serve as a significant heat reservoir due to the thermal inertia inherent in the typical massive walls of traditional constructions. The massive walls require a large and relatively long contribution of heat from the sun (radiation) and from the surrounding air (convection) before warming inwards. After the sun sets and the temperature drops, the warm wall will continue to transfer heat indoors for several hours due to the time lag effect. Thus, a wall of unburnt brick, with an appropriate thickness, is very efficient in controlling the interior temperature.

- Earth acts as a phase changing material because it exploits the change of water status as a mode of energy transfer. The water is in balance with the ambient humidity and some of this water evaporates as the outside temperature rises. In contrast, there is capillary condensation when the temperature drops. Thus, the nanostructure of the material allows the water it contains to change its state of aggregation at room temperature (L.Fontaine, R.Anger, pp.153).

- Earth regulates humidity because it can absorb / disperse moisture relatively quickly. Research from the Kassel University shows that unburnt clay blocks absorb 30 times more moisture than burnt bricks without getting wet. Thus, the relative humidity of the air of a room is kept at a constant level of about 50% and the production of fine dust is decreased (G. Minke, 2006, pp.14).

- Earth is not associated with the adverse effects of volatile organic compounds, so occupants of these buildings benefit from a higher air quality (F.Pacheco-Torgal, S.Jalali, 2012, pp.512-519).

- Earth is a good sound and vibration insulator.

- Earth is fire resistant.

- Earth is the most available material, and for each composition there is a specific construction technique. This results in a reduced impact on the environment, but may present marginal costs with the studies performed to determine the recipe and the optimal process.

- Earth preserves wood and other organic materials. Conditioned by a relative low humidity of balance, up to 6%, clay can absorb moisture from wood, keeping it permanently dry. No other material has such a good conservation property (G.Minke, pp.15).

- As a comparison, unburnt bricks are more eco-friendly, their manufacture consumes less energy (15 times less) and pollutes 8 times less than burnt brick (F.Pacheco-Torgal, S.Jalali, 2012, pp.512-519).

5. CASE STUDY: LCA COMPARISON BETWEEN COMPOSITE WALLS MADE OUT OF CERAMIC BLOCKS WITH VERTICAL HOLES AND UNBURNT BRICKS

For a better understanding of the environmental impact regarding the construction materials proposed, a life cycle assessment was made using the “cradle to gate” method. Ideally, an LCA should also include all the stages of the materials used until the disposal. In the case of composite elements, such as multilayer walls, roofs, etc., it is difficult to asses the life expectancy of each component, it is estimated to be around 30-40 years or even more.

"Cradle to gate" is an assessment of the partial life cycle for a product/material, from the extraction phase ("cradle") up to the factory gate ("gate"), before being transported to the consumer. The phase of use and the phase of elimination are omitted in this case. “Cradle to gate” ratings are sometimes baselines for environmental friendly product declarations called EPDs. "Cradle to gate" can reduce significantly the complexity of an LCA study, so that it can be analyzed more quickly, especially about the internal processes of making a product.

The case study presented in the article involves a comparative analysis of 2 wall stratifications to highlight the environmental impact of the current construction technique in the studied area, compared to an alternative, using more environmental friendly materials. It represents a interpretation of traditional construction techniques, adapted to modern comfort standards. The first stratification is composed of conventional ceramic blocks with vertical holes, insulated with mineral wool, while the second is made out of unburned bricks produced to contemporary standards, insulated with wood fibers.

At each stage of the study, elements with similar properties or optimal compatibility with the basic materials were considered. The methodological approach consisted of comparing each of the different stratifications for collecting primary data on environmental impact factors through a simulation of 2D finite elements. A free online software was used.

Tabel 1.2 Composition of stratification 1(up). Ceramic blocks with vertical hollows,

#		Material	λ [W/mK]	R [m²K/W]	Temp. [°C] min max		sd-value [m]	Condensate [kg/m²] [%]	Weight [kg/m²]	Heat capacity [J/(kg*K)]
		Thermal contact resistance		0,130 (0,250)	19,0	20,0				
1	0,3 cm	Lime render	0,870	0,003	19,0	19,0	0,03	-	4,2	1000
2	2 cm	Lime render	0,870	0,023	18,9	19,0	0,20	-	28,0	1000
3	36,5 cm	brick	0,120	3,042	6,7	18,9	1,83	-	237,3	1000
4	10 cm	Rockwool	0,035	2,857	-4,8	6,7	0,10	-	10,0	900
5	1 cm	Lime render	0,870	0,011	-4,8	-4,8	0,10	-	14,0	1000
6	0,3 cm	Lime Cement Render	1,000	0,003	-4,8	-4,8	0,11	-	5,4	1000
		Thermal contact resistance		0,040	-5,0	-4,8				
	50,1 cm	Whole component		6,110			2,36	-	298,9	

U-value: 0,164 W/m²K

Temperature of inside surface: 19,0 °C
Temperature of outside surface: -4,8 °C

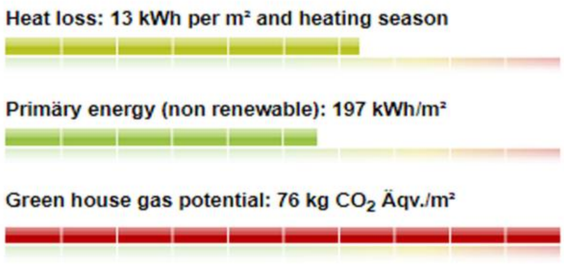
#		Material	λ [W/mK]	R [m²K/W]	Temp. [°C] min max		sd-value [m]	Condensate [kg/m²] [%]	Weight [kg/m²]	Heat capacity [J/(kg*K)]
		Thermal contact resistance		0,130 (0,250)	19,0	20,0				
1	0,3 cm	Lehmoberputz fein 06	0,910	0,003	19,0	19,0	0,02	-	5,4	1000
2	1 cm	Lehmoberputz grob mit Stroh	0,910	0,011	18,9	19,0	0,05	-	18,0	1000
3	24,5 cm	Leichtlehmsteine 2DF 700	0,210	1,167	14,2	18,9	1,23	-	171,5	1000
4	11,5 cm	Leichtlehmsteine 2DF 700	0,210	0,548	12,0	14,2	0,58	-	80,5	1000
5	16 cm	wood insulation	0,039	4,103	-4,6	12,0	0,48	-	17,6	2100
6	2 cm	Bio-Grundputz	0,400	0,050	-4,8	-4,6	0,16	-	20,6	1000
		Thermal contact resistance		0,040	-5,0	-4,8				
	55,3 cm	Whole component		6,051			2,51	-	313,6	

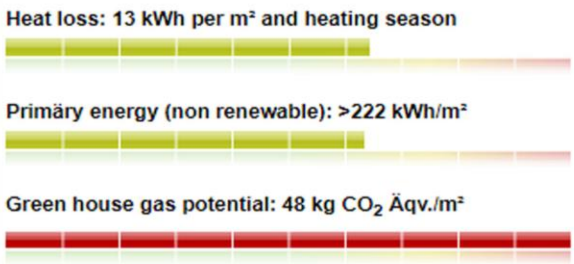
U-value: 0,165 W/m²K

Temperature of inside surface: 19,0 °C
Temperature of outside surface: -4,8 °C

Composition of stratification 2(down). Unburnt bricks.

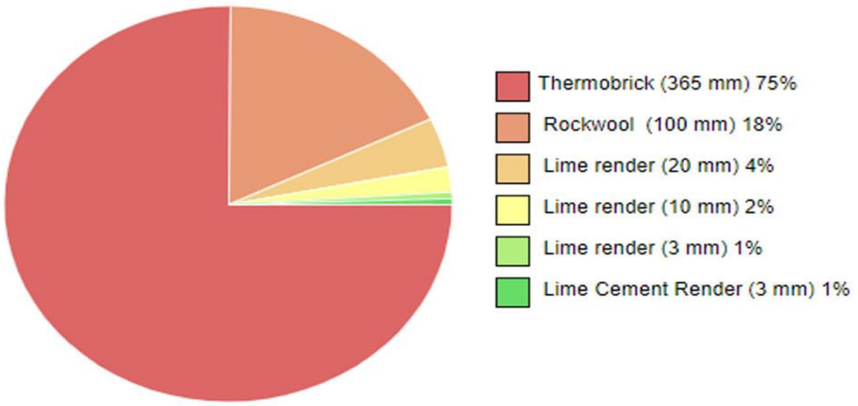
Tabel 3.4. LCA data for stratification 1 (left) and stratification 2(right).





The tables show the amount of heat that is lost through one square meter of a component in the heating period. For the validity of the test, the proposed layers are similar in terms of thermotechnical characteristics and for this reason, the value of heat loss is similar for both cases. Due to unknown solar and internal contributions, the demand for heating can only be estimated. As a result, primary energy consumption and global warming potential in the use phase are approximate. For the evaluation it was assumed that the solar and internal gains contribute with 4kWh / year / m^2 on the component surface. In terms of heat, a primary energy of 0.60kWh per 1 kWh of heat and a global warming potential of 0.16kg CO2 equivalent / m^2 per

1 kWh of heat was used. Heat source: natural gas.



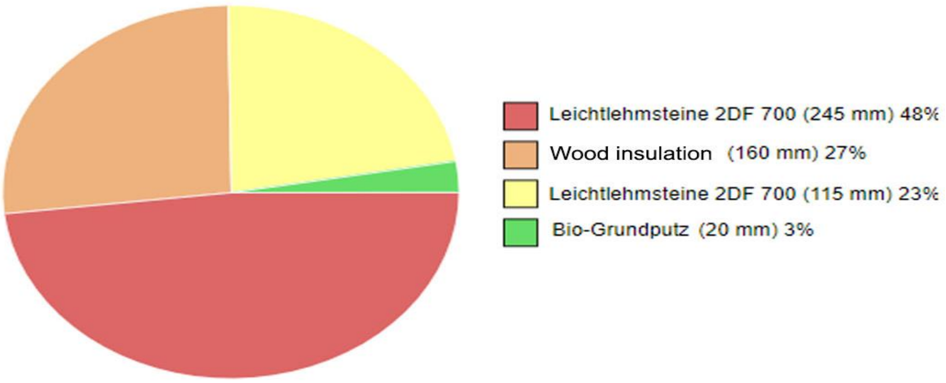


Fig 1.,2. Composition of non-renewable primary energy input for manufacturing LCA data for stratification 1 (up) and stratification 2(down).

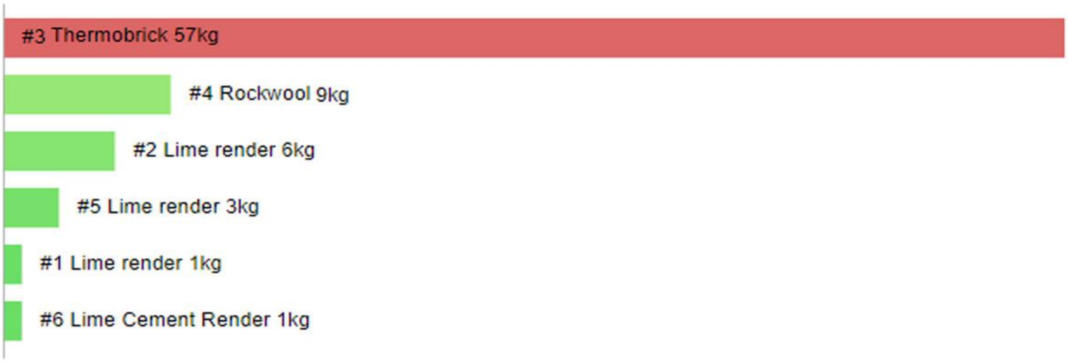


Fig 3. Composition of the global warming potential of production in kg CO2 eq/m², LCA data for stratification 1.

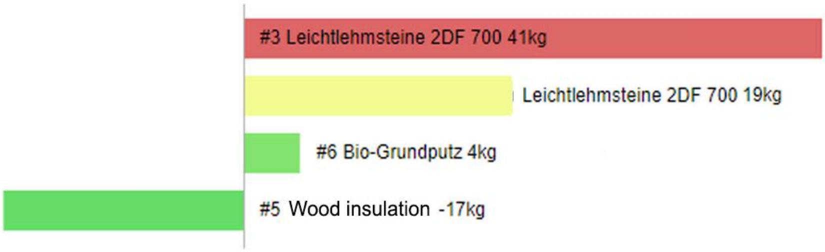


Fig 4. Composition of the global warming potential of production in kg CO2 eq/m², LCA data for stratification 2.

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Tabel 2. Comparison between ecological indicators of the 2 stratifications.

	Stratification 1. Ceramic block with vertical holes	Stratification 2. Unburnt brick
1.	Global warming potential in kg CO_2 eq./m^2	
	77 kg	47kg
2.	Quantity of released greenhouse gases in the production of building materials used	
	57 kg CO2 echivalent/m2	48 kg CO2 echivalent/m2
3.	Heat loss per m^2	
	13 kWh	13 kWh
4.	Primary energy non-renewable	
	197kWh/m^2	>222kWh/m^2
5.	Summer smog (POCP)	
	0.0089 Ethen – eq./kg	0,0085 kg Ethen – eq./kg
6.	Acidification potential (AP)	
	0,15 kg SO_2 –eq./kg	0,11 kg SO_2 –eq./kg
7.	Eutrophication potential (EP)	
	0,020 kg Phosphat-eq./kg	0,013 kg Phosphat-eq./kg
8.	Ozone depletion potential (ODP)	
	0.00000033kg R11-eq./kg	0.00000000073kg R11-eq./kg

According to the results presented in the table above, the low environmental impact of the stratification based on unburnt bricks and wood fibers is highlighted in comparison with the ceramic blocks with vertical holes. The non-renewable primary energy factor has a higher value in the case of unburnt bricks due to the wood fibers, but the wooden material has a negative global warming potential (Table 8, green bar on the left, thermal insulation), which means that more greenhouse gases have been extracted from the atmosphere than those produced by the growth of renewable raw materials. Therefore, in the overall analysis, the non-renewable primary energy factor for the unburnt brick stratitification is counteracted by the global warming potential and the greenhouse gas potential.

6. CONCLUSIONS

The simulations performed in this study clearly show the low environmental impact of unburnt bricks, while adapting to current comfort requirements. Taking into account the intrinsic qualities of the material, a new perspective on energy efficiency must be outlined, in which mass can again be considered as value and not as a consumption of useless material.

In the absence of elements of economic competitiveness compared to conventional methods of construction, earth as a building material must be promoted as part of a vision that addresses environmental problems. The contribution to a larger effort should be considered, without which all the properties of the material have no sufficient support. From a more general perspective, the reintroduction of earth constructions, can be perceived as an indicator of a wider process of transformation in architecture that also includes the rethinking of the profession's relationship with nature and local communities.

As for the future of earth constructions, the material itself leads to a new conception of sustainable architecture in the era of climate change. It is possible to formulate a new paradigm in which cultural, social and environmental factors regain prevalence over economic pressure. Therefore, the potential of earth is to respond to contemporary challenges by using its natural properties in an innovative way.

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