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THE ECOLOGICAL FOOTPRINT OF THE ECOEARTH SANDWICH SYSTEM COMPARED TO MASONRY, RAMMED EARTH, AND DRYWALL

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Studies show that the construction industry is one of the most pollutant and energy consuming. The environmental impact of construction leads us to develop alternative and more responsible ways of building. The team of the Con Lo Que Hay 14 workshop -With what is available 14 workshop (CLQH 14), developed the *eco earth sandwich* system in a small suburban community in the Ecuadorian Andes. The ecological footprint of this alternative construction system will be compared to three traditional systems: confined masonry wall, rammed earth wall, and drywall metal stud wall; testing their environmental friendliness. The different systems are quantitatively evaluated based on a mathematical formula through which the ecological footprint of the construction materials is determines. In all the systems, adding the same footprint for the transportation. Through this method we determine that the elements that are locally obtained or even taken from the site itself, adapted and produced are most environmentally friendly.

Keywords: Produced on-site, Local materials, Environmentally friendly, Construction impact.

1 ENVIRONMENTAL IMPACT OF THE CONSTRUCTION INDUSTRY

According to (Wackernagel *et al.* 2002), the ecological footprint is the biologically productive area needed to absorb the waste generated. In construction, the ecological footprint depends on the space that will be occupied considering that the construction demands land. Therefore, it is important to concern about sustainability because in the last 40 years the increase in consumption of energy has been greater than the growth of the human population (Wackernagel *et al.* 2002). Within the industrial activities, construction activity is the largest consumer of natural resources (Alavedra *et al.* 1997) and has a direct impact on climate change. Dixon (2010) states the relationship between buildings and environmental problems: 23% of air pollution, 50% of greenhouse gas production, 40% of water pollution, and 40% of solid waste is produced by buildings. Concluding that globally, 45% of world energy and 50% of water is consumed by buildings.

2 METHODOLOGY

The *eco earth sandwich*, developed in the community of Guápulo-Ecuador by the Con Lo Que Hay -With what is available 14 workshop (CLQH 14) together with Ensusitio , seeks to be an alternative construction system (Ensusitio 2020a).

This research will compare three different methods of construction systems: the confined masonry, the rammed earth, and the drywall, with the case study of the "*eco earth sandwich*", based on the ecological footprint in hectares. To calculate the total ecological footprint of the construction, the quantity of each material used, and the time needed for travel will be specified and quantified based on complementary research of scientific and academic articles, in the case of the *eco earth sandwich*, there is more precise information, considering the data provided by Ensusitio office (Ensusitio 2020b).

3 ECOLOGICAL FOOTPRINT

Wackernagel and Kitzes (2019) states that the Ecological Footprint measure the extent to which human demands on the biosphere exceed the biosphere's capacity to meet those demands. It determines the ecological capacity of the earth to resettle itself by calculating the amount of productive land and water area required to absorb the waste and regenerate its resources.

The ecological footprint of construction materials is calculated by the mathematical formula:

$$HE_{pm} = \frac{\sum Cm_i \times Eiem_i}{PE} \times FE_b \tag{1}$$

where, $\boldsymbol{HE_{pm}}$: the weighted ecological footprint of building materials global hectars (gha), $\boldsymbol{Cm_i}$: material consume kilograms(kg), $\boldsymbol{Eiem_i}$: energy incorporated specific from material (MJ/kg), $\boldsymbol{PE}$: oil energy productivity (MJ/ha), $\boldsymbol{FE_b}$: forest equivalence factor (gha/ha).

Also, the ecological footprint of the transport was obtained on the basis that one hour of travel of a truck emits 0.18 tons of CO2 (Bellart Crevillen and Mesa Marcos 2009), and will be added to the calculation table of all the studied systems.

4 *ECO EARTH SANDWICH* ECOLOGICAL FOOTPRINT

The *eco earth sandwich* is a construction system of reinforced earth wall which has spatial and structural applications: being structurally safe, acoustic, thermal, and self-supporting.

The ratio for the terro-cement in the foundation beam is 6:3:1 and in the crowning beam a 3:1 ratio mortar. Then the wall is assembled by placing the steel panel against the faces of the concrete masonry units (CMU) base and the plastic at 45 cm deep and 1.40 m high. Later the wall is filled by placing rammed earth (rammed maximum 7 times) between the two steel panels. Raise the earth evenly throughout the system and dampen every 20 cm. See Figure 1 and 2

Figure 1. The construction process of the *eco earth sandwich* (CLQH).

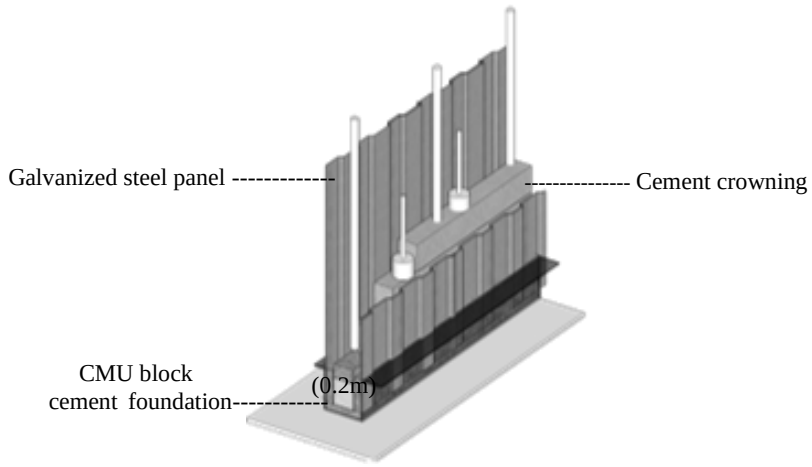

Figure 2. The construction system of the eco earth sandwich (CLQH).

Based on the mathematical formula (Eq. (1)), the ecological footprint of each material per m² of the eco earth sandwich has been determined. The ecological footprint of transport has also been considered. The results are shown in Table 1.

Table 1. The ecological footprint of materials in the eco earth sandwich (MIDUVI 2014).

Material	Amount	Footprint	Total	Extraction (+)	Total
Galvanized steel	0.8*2kg 0.0016 Ton	1.00 Ha/Ton	0.0016 Ha	0.0016 Ha	0.0032 Ha
Cement in foundation	0.5 lb 0.0002 Ton	0.05 Ha/Ton	0.0001 Ha	0.0001 Ha	0.0002 Ha
Cement in crowning	0.5 lb 0.0002 Ton	0.05 Ha/Ton	0.0001 Ha	0.0001 Ha	0.0002 Ha
				Total:	0.0036 Ha
				Transport:	0.027 Ha
			TOTAL ECOLOGICAL FOOTPRINT		**0.0306 Ha**

5 CONFINED MASONRY ECOLOGICAL FOOTPRINT

The confined masonry wall is set on a foundation of reinforced concrete with a ratio of 6:3:1, braced vertically with steel rods and confined by a reinforced concrete crowning beam. See Figure 3.

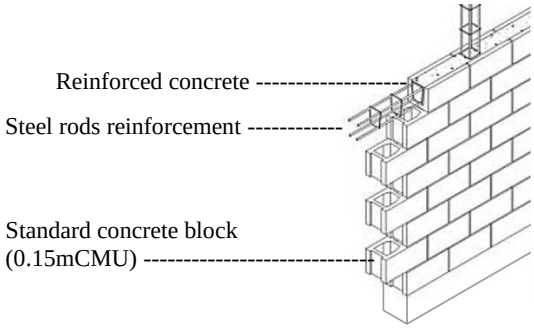

Figure 3. The construction system of the confined masonry.

Based on the mathematical formula (Eq. (1)), the ecological footprint of each material per m² of the confined masonry has been determined. The ecological footprint of transport has also been considered. The results are shown in Table 2.

Table 2. The ecological footprint of materials in the confined masonry (MIDUVI 2014).

Material	Amount	Footprint	Total	Extraction (+)	Total
Concrete block	12 u	0.00064 Ha/u	0.0077 Ha	0.0077 Ha	0,0154 Ha
Mortar	0.0013 Ton	0.084 Ha/Ton	0.0001 Ha	0.0001 Ha	0.0002 Ha
Reinforced concrete	2.40 kg 0.0024 Ton	0.05 Ha/Ton	0.00012 Ha	0.00012 Ha	0.00024 Ha
				Total:	0.01584 Ha
				Transport:	0.027 Ha
		TOTAL ECOLOGICAL FOOTPRINT			**0.04284 Ha**

6 RAMMED EARTH ECOLOGICAL FOOTPRINT

The confined rammed earth wall is set on a stone and cement foundation, rammed in a reusable plywood mold, and confined by a cement crowning beam. See Figure 4.

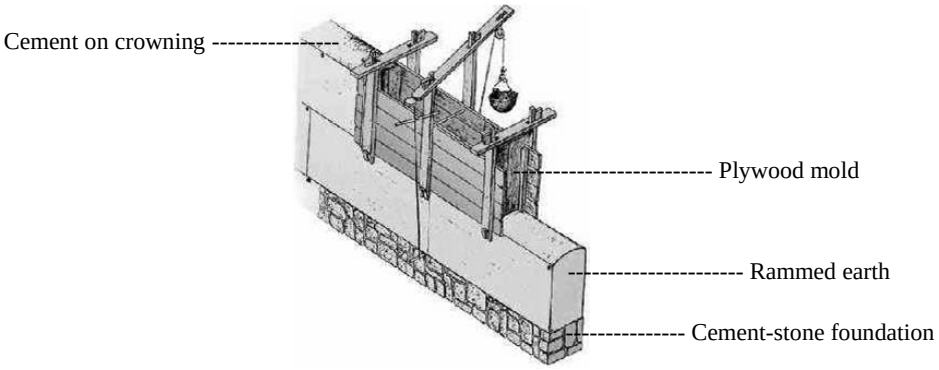

Figure 4. The construction system of the rammed earth.

Based on the mathematical formula (Eq. (1)), the ecological footprint of each material per m² of the rammed earth has been determined. The ecological footprint of transport has also been considered. The results are shown in Table 3.

Table 3. The ecological footprint of materials in the rammed earth (MIDUVI 2014).

Material	Amount	Footprint	Total	Extraction (+)	Total
Cement in foundation	0.48 kg 0.00048 Ton	0.05 Ha/Ton	0.000024 Ha	0.000024 Ha	0.000048 Ha
Cement in crowning	0.16 kg 0.00016 Ton	0.05 Ha/Ton	0.000008 Ha	0.000008 Ha	0.000016 Ha
Plywood mold	0.48 kg 0.00048 Ton	0.0009 Ha/Tree	0.0000004 Ha	-	0.0000004 Ha
				Total:	0.000064 Ha
				Transport:	0.027 Ha
		TOTAL ECOLOGICAL FOOTPRINT			**0.027064 Ha**

7 ECOLOGICAL FOOTPRINT: DRYWALL

The drywall is set on a cement foundation with a 6:3:1 ratio. Fiberglass+ Plaster + Paperboard wall is anchored on a galvanized steel structure. See Figure 5.

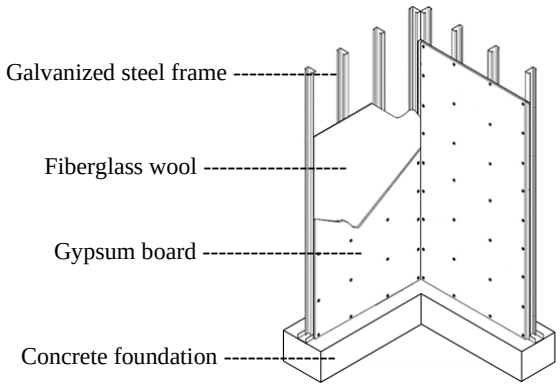

Figure 5. The construction system of the drywall.

Based on the mathematical formula (Eq. (1)), the ecological footprint of each material per m² of the drywall has been determined. The ecological footprint of transport has also been considered. The results are shown in Table 4.

Table 4. The ecological footprint of materials in dry wall construction system (MIDUVI 2014).

Material	Amount	Footprint	Total	Extraction (+)	Total
Cement in foundation	0.40 kg 0.0004 Ton	0.05 Ha/Ton	0.00002 Ha	0.00002 Ha	0.00004 Ha
Fiberglass + Plaster + Paperboard	0.036 Ton	0.04 Ha/Ton	0.00144 Ha	0.00144 Ha	0.0029 Ha
Galvanized steel	3.36 kg 0.00336 Ton	1.00 Ha/Ton	0.00336 Ha	0.00336 Ha	0.00672 Ha
				Total:	0.00966 Ha
				Transport:	0.027 Ha
			TOTAL ECOLOGICAL FOOTPRINT		**0.03666 Ha**

8 RESULTS

Based on the research carried out, it has been verified that the confined masonry has the highest environmental impact, resulting in an ecological footprint of 0.04328 Ha. Followed by the Drywall with an ecological footprint of 0.03666 Ha. The eco earth sandwich has an Ecological Footprint of 0.0306 Ha. Finally, the lowest ecological footprint is the rammed earth with 0.027064 Ha (see Table 5).

Table 5. The ecological footprint summary of all systems.

FOOTPRINT	Confined masonry	Drywall	Eco earth sandwich	Rammed earth
Without transport	0.01584 Ha	0.00966 Ha	0.0036 Ha	0.000064 Ha
Only transport	0.027 Ha	0.027 Ha	0.027 Ha	0.027 Ha
TOTAL	**0.04284 Ha**	**0.03666 Ha**	**0.0306 Ha**	**0.027064 Ha**

9 CONCLUSIONS

This study compares the ecological footprint of the confined masonry, the drywall, the eco earth sandwich, and the rammed earth; considering the same ratio of transportation for each system. The traditional confined masonry (0.04284 Ha) has the highest ecological footprint due to the industrial mass production and transportation of its materials. The drywall (0.03666 Ha) is also industrially mass-produced, but the paperboard used is recyclable, so its ecological footprint is 0. On the other hand, the eco earth sandwich (0.0306 Ha) is made mostly with local materials, which cause minimal impact and some of them avoid long-distance motorized transport. Finally, the rammed earth (0.027064 Ha) has the least ecological footprint because all of its materials could be obtained and produced on-site.

It would be difficult in current times to work with only onsite construction materials, the eco-earth sandwich system provides an alternative that uses both, local and industrialized materials providing a low footprint as well as time effective production efficiency.

10 RECOMMENDATIONS

The results of this research illustrate that an optimal way to build and to reduce the environmental impact at the same time is using materials that are locally available and produced. For further research in the eco earth sandwich construction system, it is suggested to test different filling materials and find out how the ecological footprint varies. In addition to this study, it is also recommended to develop: costs, thermal comfort comparison analysis. As the results of this study are preliminary, it is recommended to conduct a quantitative study and trace the impact of the footprint in different methods of construction.

References

Alavedra, P., Domínguez, J., Gonzalo, E., and Serra, J., *The Sustainable Construction: The State of the Issue,* Informes De La Construcción, 49(451), 41-47, 1997.

Bellart Crevillen, M., and Mesa Marcos, S., *Impacto Ambiental y Ciclo de Vida de los Materiales de Construccion*, Master's Thesis, Universitat Politècnica de Catalunya, 2009.

Dixon, W., *The Impacts of Construction and the Built Environment*, 2010. Retrieved from https://www.academia.edu/34798457/The_Impacts_of_Construction_and_the_Built_Environment /.2010 on December 10, 2019.

Ensusitio Arquitectura, *CLQH 14, Con lo Que Hay PUCE 14*, 2020a. Retrieved from http://ensusitioarq.com/clqh-puce-14.html on May 15, 2021.

Ensusitio Arquitectura. *Arquitectura y Academia*, 2020b. Retrieved from http://ensusitioarq.com/index.html /.2020 on April 8, 2022.

MIDUVI, *Strategic Planning*, Ministry of Urban Development, and Housing, 2014. Retrieved from http://www.habitatyvivienda.gob.ec/el-ministerio/.2014 on April 8, 2021.

Wackernagel, M., and Kitzes J., *Ecological Footprint*, Encyclopedia of Ecology (Second Edition) Volume 4, Pages 270-282, 2019.

Wackernagel, M., Schulz, N., Deumling, D., Linares, A. C., Jenkins, M., Kapos, V., Monfreda, C., Loh, M., Myers, N., Norgaard, R., and Randers, J., *Tracking the Ecological Overshoot of the Human Economy*, Wilson, E. O. (ed.), Proceedings of the National Academy of Sciences (PNAS), 99(14), 9266-9271, 2002.