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CASE STUDY COMPARISONS OF THE ECOLOGICAL FOOTPRINT ON SOCIAL HOUSING AFTER EARTHQUAKE

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This research seeks to distinguish which factors influence the ecological footprint and what types of construction have the least environmental impact in a post-disaster social housing building. The first case study is a government social housing design, built with bamboo and concrete masonry blocks, and another design by Ensusitio, a private practice approach to social housing built with bamboo and earth. These houses were granted to victims of the April 2016 earthquake in the Ecuadorian coastal region. The investigation process was carried out based on primary research, which was used to understand how Ensusitio carried out the construction process of Meche's house and also based on a secondary investigation of government social housing. With this information, a comparison is made between them to determine which of the two has the least ecological footprint.

Keywords: Local materials, Bamboo, Masonry block, Mass production, Meche’s house.

1 INTRODUCTION

Wackernagel *et al.* (2002) state that the increase in consumption of energy and materials in the last 40 years has been greater than the growth of the human population, which translates into the ecological footprint of a population that according to this author is the biologically productive area required to generate the resources used and absorb the waste generated by said population. Within the industrial activities, the construction activity is the largest consumer of natural resources (Alavedra *et al.* 1997). On the other hand, the presence of natural disasters has been a constant contribution to the deterioration of the environment and cultural memory of a place. Disasters cause displacement, uprooting of the inhabitants, breakdowns, and destruction of habitable structures and public infrastructures (Gordillo 2004). This was the case after the 7.8 earthquake that occurred in Ecuador on April 16, 2016 (IG-EPN 2016), in which 35,264 buildings were destroyed or needed repairs (Ross 2017). To this end, the National Government through the Ministry of Urban Development and Housing/MIDUVI, international organizations and the private sector, MIDUVI (2014) including Ensusitio´s project, collaborated in the partial reconstruction of the affected areas. Within the MIDUVI programs, there are bamboo and concrete block houses. Ensusitio, on the other hand, is an architecture office that works with a deep concern for the environment and incorporates a thought of coherent social conscience

(Ensusitio 2017a). After the earthquake, Ensusitio chose to help by transferring knowledge. They held a hands-on workshop about good building practices while building Meches House and the house became a model for the community (Ensusitio 2017b).

The objective of this paper is to learn about the ecological footprint of two types of houses and compare them to know which has the least impact and see how the type of construction significantly influences these results.

2 METHODOLOGY

The research will be based on the ecological footprint in hectares per house of two types of post-earthquake houses: the traditional concrete block, self-standing, pile dwelling, and Meche´s House. Based on secondary research of scientific and academic articles we will obtain the ecological footprint of the materials that were necessary to build each of these houses in order to obtain the total ecological footprint of the construction and budgets in which the quantities of each material used for its construction are detailed. The ecological footprint of the transport was obtained on the basis that one hour of travel of a truck emits 0.18 tons of CO_2 (Bellart and Mesa 2009). Hours needed for travel in each house were quantified and calculation was made based on this figure. In case of Casa de Meche, there is more precise information regarding transportation of materials, therefore the information provided by Ensusitio office was taken into account.

3 ECOLOGICAL FOOTPRINT OF THE SELF STANDING CONCRETE BLOCK PILE-DWELLING (WITHOUT FOUNDATIONS)

According to Crespo (2015), the weight of a pressed block that is 40 cm long, 20 cm high, and 15 cm thick, is 10 kg. Therefore, 10 kg of mass concrete is required for its manufacture. Based on this data, we determined that the ecological footprint of the concrete required for a pressed block is 0.00064 ha/unit. The ecological footprint of the blocks used in this house is the multiplication of the ecological footprint of 1 block and the number of blocks required for construction of the pile dwelling, which is 1,150 units, data extracted from the tender issued by the MIDUVI (2014).

In general, conventional reinforced concrete has a range of unit weights ranging from 2240 to 2400 kg/m³ (De Guzmán 2001). According to this information, we proceeded to calculate the ecological footprint of this material when obtaining the volume of reinforced concrete from the tender issued by the MIDUVI (2014) in the pile dwelling, that is, 8.62 m^3 and the weight of the concrete used in it, which is 19.82 tons and multiplying it by the ecological footprint of 1 m^3 of reinforced concrete, which is 0.05 ha/ton, according to Bellart and Mesa (2009). The amount of mortar required in a square meter of the wall is 0.045 tons (Arroyo 2010). To this was added the weight of the plaster, which is fine plaster, so that both quantities were combined; this data was multiplied by the ecological footprint of 1 ton of mortar, obtaining the ecological footprint of the total material used in the dwelling, which is 12.47 tons.

According to the volumes of work extracted from the tender issued by MIDUVI (2014) for the construction of pile dwelling, 1288.32 kg of reinforcing steel are required. This figure is multiplied by the ecological footprint of 1 ton of this material (0.58 Ha/Ton); data abstracted from the thesis on *Environmental Impact and Life Cycle of Construction Materials* (Bellart and Mesa 2009) resulted in the ecological footprint emitted by the house.

The roof of the house is made of zinc; it has a thickness of 1.2 mm (MIPSA 2017) and it is required to cover 60 m². With data obtained from the MIDUVI tender (2014), the weight was calculated with the total of the material required for the roof, which is the area to be covered multiplied by the weight of the galvanized steel 18 gauge, which is 9.79 kg/m² (MIPSA 2017). Later, the calculation of the ecological footprint was made, which consists of multiplying the weight of the cover by the ecological footprint of 1 ton of this material. This data was abstracted from the thesis on *Environmental Impact and Life Cycle of the Materials of Construction* (Bellart and Mesa 2009).

Due to the lack of data about the transport of materials, an approximation of trips made in a truck with a capacity of 12 tons is assumed. Therefore, the estimated number of trips, taking into account the number of materials used to prepare the concrete block pile dwelling, is five. According to the Itec Bedec database (2008, 2009), a truck transporting 12 tons of material emits 189.18 kg of CO_2 into the atmosphere. In our calculation, we will consider that six hours of travel are necessary. Therefore, the final emission will be 1 135.08 kg of CO_2. Taking into account that the functional unit is tons of product, the emission per ton of CO_2 is 94.59 kg.

When estimating approximately 5 truckloads, the final emission is 5675.40 kg of CO_2. According to Bellart and Mesa (2009), to weigh the impact of the greenhouse effect, a certain number of hectares or square meters of the forest is needed to counteract the CO_2 that is emitted into the atmosphere annually. Due to photosynthesis, trees absorb CO_2 from the atmosphere, and store it as carbon, expelling oxygen. Growing trees absorb more CO_2 than old trees.

The Center for Ecological Research and Forestry Applications (CREAF 2009) specifies on its website that one hectare of forest absorbs some 5,000 kg of CO_2 annually, with an approximate density of 1000 trees per hectare. Therefore, to counteract the emission of CO_2 produced by the transport of materials from Quito to the province of Esmeraldas for the construction of the block house, 1.14 hectares of forest or an approximate density of 1140 trees are required. The ecological footprint has been calculated by a unit of material. The results are shown in Table 1.

Table 1. The ecological footprint of materials in the concrete block pile dwelling. MIDUVI (2014), Crespo (2015), De Guzmán (2001), Arroyo (2010), MIPSA (2017), Bellart and Mesa (2009).

Materials	Amount	Footprint	Total	Extraction (+)	Total
Mortar	12.47 Ton/m^2	0.084Ha/Ton	0.840 Ha	0.840 Ha	1.78 Ha
Concrete block	1.150	0.064Ha/Ton	0.074 Ha	0.074 Ha	0.15 Ha
Reinforced concrete	8.62m^3	0.050Ha/Ton	0.990 Ha	0.990 Ha	1.98 Ha
Reinforcing steel	1.28832kg	0.580Ha/Ton	0.750 Ha	0.750 Ha	1.50 Ha
Galvanized steel	60m^2	1.000Ha/Ton	0.580 Ha	0.580 Ha	1.17 Ha
				Total:	6.58 Ha
				Transport:	1.14 Ha
				TOTAL ECOLOGICAL FOOTPRINT	**7.72 Ha**

4 ECOLOGICAL FOOTPRINT OF MECHE´S HOUSE

Meche´s House was designed by Ensusitio following the 2016 earthquake. Ensusitio chose to contribute by transferring knowledge and creating a workshop of good building practices and skills, while at the same time building this house. It is mostly built with local materials; however, there are some that were transported from Quito, Atacames, etc., to August 10 in Esmeraldas (Ensusitio 2017c). These materials are industrial, so the carbon footprint represents 50% of the ecological footprint (Samaniego and Schneider 2009), the extraction of the material will constitute the other 50%, which is why in some materials the Ecological Footprint is doubled.

According to Ensusitio (2017a), the material that predominates in this house is bamboo; it needed 220 canes to construct. On the other hand, 660 canes can be harvested per hectare (Tandazo 2012), which shows that the productive area needed for 220 bamboo is 0.33 Ha. The bamboo does not emit CO_2 (Rea 2012), therefore, the ecological footprint of it would be only 0.33 Ha; the extraction process is not taken into account. Ensusitio states that they had to mobilize the cane 42.7 km so that it reaches the site in a van; if a truck emits 1 ton of CO_2 in 3000 km (Medina 2010), and it takes 1 Ha of forest to absorb 5 tons of CO_2 (Bellart and Mesa 2009), then to absorb what is produced by Ensusitio truck, 0.0028 hectares of forest is necessary.

Bahareque was used for another masonry with materials obtained in the area. According to Ensusitio (2017c), the materials they used were 7 parts sand, 3 parts clay, and 7 parts coconut fiber. They mention that the clay was obtained from the site, therefore, it does not have a representative ecological footprint. The extraction of the sand was not in large proportions; therefore, its ecological footprint was not taken into account. Nevertheless, it was necessary to transport it (Ensusitio 2017d). The sand transport was 5 minutes in a van; if a truck emits 1 ton of CO_2 in 33 hours at an average speed of 90 km/h (Medina 2010), in 5 minutes it emits 0.002 ton of CO_2. To absorb 5 tons of CO_2, one hectare of forest is needed (Bellart and Mesa 2009). Therefore, 0.0004 hectares of forest are needed to absorb what the truck produced. For coconut fiber, despite being a representative product of Esmeraldas, already crushed fibers were taken from Quito in a truck. A truck emits 1 ton of CO_2 in 3000 km (Medina 2010), and it takes 1 Ha of forest to absorb 5 tons of CO_2 (Bellart and Mesa 2009). To absorb what is produced by the Ensusitio truck in the 314 km from office to location of the house, 0.02 hectares of forest is necessary. It is important to mention that this could have been avoided since coconut is a material of the area. The ecological footprint is not taken into account since the coconuts used had been already considered waste. For bahareque masonry, it was also necessary to use wire mesh (Ensusitio, 2017a). According to material tables of Ensusitio, 8.32 kg of mesh was necessary. The ecological footprint is 0.58 Ha / Ton. Therefore, the footprint is 0.004 Ha. This is doubled by the production of the material (Samaniego and Schneider 2009), giving a total of 0.004 Ha. Transportation equivalent to 0.18 Ha is added, because the material was mobilized for 5 hours in a truck with 0.18 Ton/hour CO_2 emission and 1 Ha is needed to absorb 5 Ton of CO_2. Therefore, 0.19 Ha are necessary.

Table 2. The ecological footprint of materials in the concrete block pile dwelling. MIDUVI (2014), Crespo (2015), De Guzmán (2001), Arroyo (2010), MIPSA (2017), Bellart and Mesa (2009).

Materials	**Amount**	**Footprint**	**Total**	**Extraction (+)**	**Transport**	**Total**
bamboo	220 bamboo(b)	0,0015 Ha/b	0,840 Ha	-	0.0028 Ha	1.78 Ha
clay	-	-	-	-	-	0.15 Ha
sand	-	-	-	-	0.0004 Ha	1.98 Ha
coconut fiber	-	-	-	-	0.02 Ha	1.50 Ha
metal mesh	60m^2	0.58 Ha/Ton	0.580 Ha	0.580 Ha	0.18 Ha	1.17 Ha
wood	1.51 trees	0.009 Hs/tree	0.014Ha	-	-	0.014 Ha
galvanized roofing	39.6m^2	0.58 Ha/Ton	0.39 Ha	0.39 Ha	0.019 Ha	0.79 Ha
			TOTAL ECOLOGICAL FOOTPRINT			**1.35 Ha**

In the case of wood, 0.697 m^2 were necessary (Ensusitio 2017c). A tree is capable of producing 0.46 m^2 of wood (Nutto and Vázquez 2004), therefore, 1.51 trees are needed to obtain the amount of wood needed for the house. Nutto and Vázquez (2004) also mention that approximately 1100 trees can be harvested per hectare, therefore, productive area needed for a tree is 0.0009 Ha. Growing wood does not emit CO_2. Therefore, the ecological footprint of it would be 0.014 Ha. Wood was obtained from the same place, (Ensusitio 2017c), so there is no ecological footprint for its transport. For the roof, Ensusitio's budget reflects that 39.6 m^2 was needed; this is equivalent to 0.38 ton since weight of 1 m^2 is 9.79 kg / m^2 (MIPSA 2017). According to Bellart and Mesa (2009), the ecological footprint of this material is 0.58 Ha / Ton. Therefore, the footprint of the roof of Casa de Meche is 0.39 Ha, this is doubled by the production of the material (Samaniego and Schneider 2009). Added to this is the transportation that is

0.0194 Ha, since one hour of travel of a truck emits 0.18 Ton of CO_2 and 1 Ha is needed to absorb 5 Ton of CO_2 (Bellart and Mesa, 2009). Total ecological footprint is 1.35 Ha (Table 2).

5 RESULTS

There are several factors to consider in the calculation of the ecological footprint, such as the conditions of the land of implantation and consequently the foundations of the house as well as the mobilization of construction materials to the site. Due to the different terrain conditions in which each house is implanted, we have decided to separate the results.

Based on the research carried out, it is verified that the house with the highest environmental impact without considering the foundations is the MIDUVI Pile Dwelling; this is due to the materials used for its construction and the transportation of the same, resulting in an ecological footprint of 7.72 Ha. The reason for such a high level of impact of the materials is the industrial production of the same, which are manufactured in high quantities for the elaboration of a greater number of houses. The foundations used for this house are plinths that are built on four piles that separate the house from the soil and its ecological footprint is 0.59 Ha, which influences the total ecological footprint of the house, raising the result to 8.31 Ha.

Meche´s House is made mostly with local materials, which cause minimal impact and some of them avoid long-distance motorized transport, however, the site required the construction of a retaining wall and a more reinforced foundation for the house. This generates a great impact on the calculation of the ecological footprint since the concrete and the rods are the materials that have the most ecological footprint. If the foundation is not considered, Meche´s House would have the least ecological footprint, if the house were set on less complex terrain, the foundation would not have such a high ecological value. See Table 3.

Table 3. Ecological footprint comparison.

FOOTPRINT	**Concrete block Pile dwelling**	**Meches house**
With out foundation	7.72 Ha	1.35 Ha
Only foundation	0.59 Ha	2.18 Ha
TOTAL	**8.31 Ha**	**3.53 Ha**

6 CONCLUSIONS

Due to the different terrain conditions in which each of the houses is implanted, different types of foundations have had to be used, which significantly influences the calculation of the final ecological footprint. The materials that cause a greater environmental impact are those that require industrialization, as well as the transportation, these measures significantly increase the ecological footprint of a home. This is the reason why the Pile Dwelling presented by the MIDUVI has a greater ecological footprint than those in which local endemic materials or those with less environmental impact are used.

While Meche´s house, has a fairly high ecological footprint, due to the construction of a reinforced concrete retaining wall, so it should consider the possibility of implementing other strategies, replace the use of industrialized materials to save slopes. A retaining wall made with tires, which reduces the environmental impact due to the reuse of scrap tires, and is used in the lifting of slopes, this is an example of a strategy that generates a less impact than the use of reinforced concrete and satisfies the same need.

The use of local materials decreases the environmental impact because transportation is avoided. This is a practice that should always be considered when planning a construction project. Search for and implement different strategies, which reduce the ecological footprint, by replacing industrialized materials, by recycling or other options, such as the use of a retaining wall made with recycled tires, replacing the reinforced concrete retaining wall; this strategy reduces the environmental impact of the concrete and in turn reduces the monetary cost of the work.

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