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ECO EARTH SANDWICH CONSTRUCTION SYSTEM COST COMPARISON WITH CONFINED MASONRY, RAMMED EARTH, AND DRYWALL

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Cost and environmental efficiency are high priority facts when developing a project for communities and clients in general, one way to have cost and environmental efficient construction systems, is by using local resources, materials, and manpower. The *Con Lo Que Hay* – With what is available 14 (CLQH 14) workshop, developed the *eco earth sandwich* system in a small suburban community center, in the Ecuadorian Andes, which uses local resources and manpower to lower cost production. The use of local resources also reduces the environmental impact, however, in this study we will focus on the evaluation of the cost efficiency of this alternative construction system with industrial drywall on metal studs, semi-industrial masonry with CMU block and mortar, and handcraft developed rammed earth with the option of hired manpower and with community labor. This comparison is developed to encourage local semi-industrial construction and demonstrate that it has cost efficiency advantages.

Keywords: Industrialized materials, Local, Alternative construction, Available resources.

1 INTRODUCTION

"Traditionally, the main objective of construction was to obtain the best quality at the lowest construction cost within a limit time period" (Zhou and Lowe 2003). Industrialization can be seen as a structural means for eliminating, or at least drastically reducing, on-site activities in construction (Koskela 2003). In the other hand, handcrafted construction uses local resources as construction materials, which have the advantage of being not only renewable but also able to sequester CO_2 (Vogtländer *et al.* 2013).

Strategic choices of materials in construction will have significant impact on environmental and ecological factors (Sarkis 1995). Although this study only focuses on cost efficiency, nowadays other variables must be considered, as environmental and human cost. Resources taken from the site, help develop construction systems that could be environmental conscious and high quality.

2 METHODOLOGY

This research will compare confined masonry, rammed earth and drywall construction system with our case study: *eco earth sandwich system,* which was built in the community of Guápulo

(Quito-Ecuador) by the workshop CLQH 14 (Ensusitio 2020) together with Ensusitio (Ensusitio 2021), this project was built in 2019 by students of CLQH 14 and members of the community.

The comparison will be based on the cost efficiency of four construction systems: *eco earth sandwich* (local, industrial), confined masonry (local, industrial), rammed earth (local, handcrafted), and drywall (industrial). Based on secondary research, each constructive systems cost will be detailed. To determine each construction system cost, materials and labor (even community manpower) will be considered. It is important to clarify both handcrafted and industrial processes are part of the development in the study. Calculation will take 1sq meter (m^2) as the comparison unit and transportation is not considered because locations may vary. The construction took place in 2019, and the cost study was made on 2020 at the start of the COVID 19 pandemic.

3 COST: ECO EARTH SANDWICH

Eco earth sandwich is a construction system that has a CMU foundation, braced vertically with treated wood poles, horizontally with steel rods and rammed earth, with a steel panel envelope all confined by a reinforced concrete crowning system. See Table 1 and Figure 1.

Table 1. *Eco earth sandwich* construction system materials and total costs.

Item	U	#	Cost US$·	Total US$
Foundation				
1.1 Earth with cement	m2			0.348
1.1.2 Cement	lb	1.5	0.082	0.123
1.1.3 Gravel	lb	4.5	0.05	0.225
1.2 Plastic	m2	1	2	2
1.3 Block 20x20x40 cm	u	3	0.56	1.68
Subtotal				**4.028**

Item	U	#	Cost	Total
Crowning System				
4.1 Rod 10 mm	u	1	1.18	1.18
4.2 Sand	lb	4.5	0.03	0.135
4.3 Cement	lb	1.5	0.082	0.123
			Subtotal	**1.438**

Item	U	#	Cost	Total
2.1 Eucalyptus Pole 4 -7 m. and 10.12 -14 cmØ	m	1	1.09	2.18
2.2 Separol for wood (emulsifiable oil)	l	0.25	6.98	1.74
2.3 Pitch	l	0.25	3.48	0.87
2.4 Galvanized Wire. #18	lb	1	0.97	0.97
			Subtotal	**5.76**

Item	U	#	Cost US$	Total US$
Fill				
3.1 Rod 3/8 x 3 m	ml	1	2.28	2.74
3.2 Galvalume DRT/ALU 0.35 x 1.06 x 2.10	m2	0.8	6.91	5.528
3.3 Packing Ring	u	12	0.1	1.2
3.4 Hex Nut 3/8	u	12	0.22	2.64
Subtotal				**12.108**

Item	U	#	Cost	Total
Labor				
5.1 Builder	h	1	4.01	4.01
5.2 Laborer	h	3	3.58	10.74
Subtotal				**14.75**

FOUNDATION			4.028
FILL			12.108
CROWNING SYS			1.438
LABOR			14.75
WOOD POLE			5.76
Total US$	**m2**	**US$**	**37.834**

Figure 1. *Eco earth sandwich* construction elements.

4 COST: CONFINED MASONRY

The confined masonry wall is braced vertically with rods, settled in a foundation of reinforced concrete crowning system. See Table 2 and Figure 2.

Table 2. Confined Masonry-CMU.

Item	Unit	U	$ per unit	Cost US$
1.Confined Mansory Unit				
1.1 Standard Block, 40x20x15 cm.		12.000	0.56	6.72
1.2 Steel Rod 60 (fy=4200 kg/cm²), various Ø, accord to NTE-INEN-2167 y ASTM A 706.	Ud	0.210	1.27	0.27
1.3 Galvanized Wire, de 1,30 mm de diámetro.	kg	0.010	1.18	0.01
1.4 Horizontal Rods with epoxy resin cover diameter of 3,7 mm y 75 mm width	kg	1.000	2.62	2.62
1.5 Cement.	m	2.397	0.15	0.36
1.6 Sand.	kg	0.001	7.21	0.01
1.7 Thick Additive 12,5 mm.	m³	0.001	12.02	0.01
1.8 Quarry sand.	m³	0.011	21.69	0.24
	Subtotal			**10.24**
2.Labor				
2.1Builder	h	1.433	4.01	5.75
2.2 Laborer	h	1.433	3.58	5.13
	Subtotal			**21.12**
3. Foundation and crowning system				
3.1 Foundation 0.2*0.2*1	m^3	0.040	131.14	5.25
3.1.1 Formwork	m^3	0.040	142.45	5.70
3.2 Crowning System 0.2*0.1*1	m^3	0.020	136.14	2.72
3.2.1 Formwork	m^3	0.020	142.45	2.85
	Subtotal			**16.52**
			Total US$	**47.88**

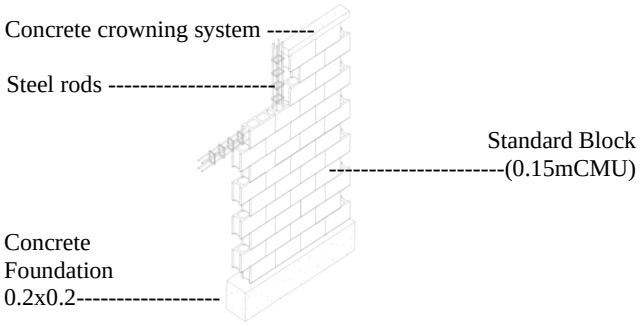

Figure 2. Confined Masonry-CMU construction system elements.

5 COST: RAMMED EARTH

The confined rammed earth wall braced with a reusable plywood mold, set on a stone foundation, and confined by concrete crowning system. See Table 3 and Figure 3.

Table 3. Rammed earth materials and total costs.

Item	Unit	Amount	Cost p/unit US$	Cost industrial US$	Cost with Community labor US$
1. Formwork					
plywood Formwork	m^2	1	7.04	7.04	**7.04**
2. Mano de obra					
2.1 Earth harvest	m^3	1	11	11	
2.2 Fill and ram	m^3	1	6.54	6.54	
			Subtotal	**17.54**	**17.54**
3. Foundation and Crowning System					
3.1 Foundation 0.80*0.6*1	m^3	0.480	99.16	47.60	0
3.2 Crowning system 0.8*0.2*1	m^3	0.160	136.14	21.78	1.2
			Subtotal	**69.38**	**1.2**
			Total US$	**93.96**	**25.78**

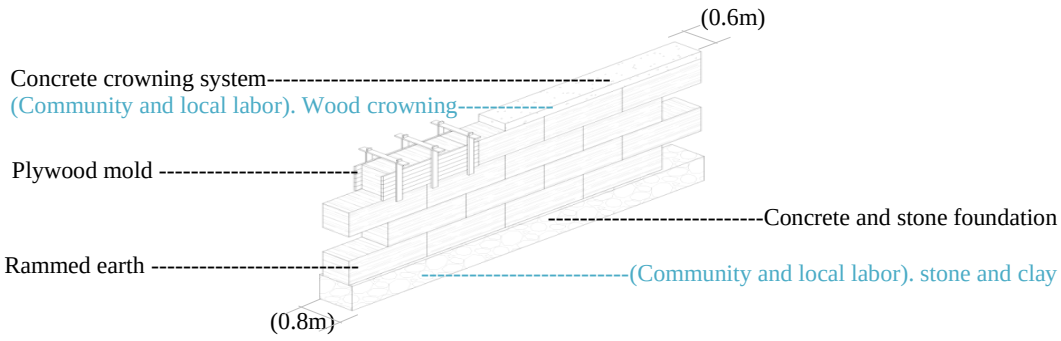

Figure 3. Rammed earth elements.

Rammed earth costs are considered with two types of construction systems, a conventional one with **industrial materials** for crowning and foundation systems, and the community process with local materials for the crowning and foundation.

6 COST: DRYWALL

Fiberglass wool and gypsum board set on a galvanized steel framing, set on a concrete foundation. See Table 4 and Figure 4.

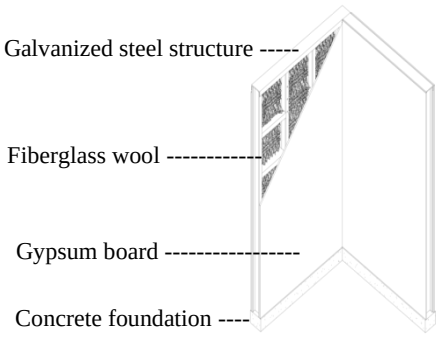

Figure 4. Drywall elements.

Table 4. Dry wall system materials and total costs.

Item	Unit	Amount	Cost per unit US$	Cost US$
1. Mansory				
gypsum wall construction 12 cm. doble face	m2	1	39.62	**39.62**
3. Foundation				
3.1 Foundation 0.2*0.2*1	m3	0.040	131.14	5.25
3.1.1 Formwork	m3	0.040	142.45	5.70
			Subtotal	**10.94**
4.Labor				
4.1 Builder	h	1.433	4.01	5.75
4.1.1 Laborer	h	1.433	3.58	5.13
			Subtotal US$	**21.82**
Total US$				**72.38**

7 RESULTS

The construction system with the highest cost in materials is rammed earth, when it is built with industrial crowning and foundation systems, although when the construction system is built with community work, it has the lowest cost in materials, the second construction system with the lowest cost in materials is the *eco earth sandwich*. See Table 5.

Table 5. Rammed earth materials and total costs.

Construction Systems					
	Eco Earth Sandwich	CMU	Rammed Earth Contract/**industrial**	Gypsum	Rammed earth Community work
Labor	14.75	21.12	17.54	21.82	17.54
Materials	23.33	26.76	69.38	50.56	8.24
Total	38.084	47.88	93.96	72.38	25.78

The construction system with the highest cost in labor is drywall, and the construction system with the lowest cost in labor is *eco earth sandwich*, the second construction system with the lowest labor cost is rammed earth. The construction system with the highest total cost is rammed earth with industrial crowning and foundation systems, the second highest is drywall. On the other hand, the construction system with the lowest total cost is rammed earth in community work, the second best is *eco earth sandwich.*

8 CONCLUSIONS

The most affordable construction system from the materials standpoint is rammed earth, because the material itself is taken from the same site of the building. The most expensive is drywall because of the number of industrial components used. Since the material comes from the same site of the building and the community as labor, our case study, *eco-earth sandwich* is the second best because it uses both local, and industrial materials.

The most affordable construction system in labor is the *eco earth sandwich*, it is the best choice because it is quick to build and does not require skilled labor. The most expensive construction system due to needed skilled labor and the more meticulous construction process is drywall, it is important to mention that the wall has a very high cost of labor because it also requires a lot of time in its development. Considering both labor and material costs, we can determine that *eco earth sandwich* is a more effective alternative, since it uses local and industrial materials, which makes the construction process fast and without the use of specialized labor. On the other hand, rammed earth, when the labor is outsourced (by contract) is the most expensive construction system because it uses industrial materials and requires a lot of labor. However, when using local materials (clay and stone for the foundation and confined with wood) it is the second most appropriate option in the study.

CMU is the most popular material in our environment, Latin America, and it requires skilled but not specialized labor and uses 100% industrial materials (cement, aggregate, sand and iron).

Drywall is a meticulous construction system that uses specialized labor and all imported industrialized materials from the framing to the boards. For this reason, it has not been in use in Ecuador as much as in other countries.

It should be noted that this study was carried out in Ecuador, a country where industrial processes are still under development; however, local non-industrial community processes are an alternative for cost efficient projects. Returning to the environmental issue, with this study we discovered that some strategies as working with local materials goes hand in hand with environmental care.

9 RECOMMENDATIONS

The cost may vary according to each region or country and time period. To complement the quantitative data, aspects related to thermal comfort, ecological food print, etc., should also be considered. For more detailed cost comparison, transportation costs should be taken into account in the specific scenario.

References

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

Ensusitio, *Ensusitio Arquitectura*, 2021. Retrieved from http://ensusitioarq.com/index.html on April 8, 2022.

Koskela, L., *Is Structural Change the Primary Solution to the Problems of Construction?*, Building Research & Information, 31(2), 85-96, 2003.

Sarkis, J., *Manufacturing Strategy and Environmental Consciousness*, Technovation, 15(2), 79–97, 1995.

Vogtländer, J. G., van der Velden, N. M., and van der Lugt, P., *Carbon Sequestration in LCA, a Proposal for a New Approach Based on the Global Carbon Cycle; Cases on Wood and on Bamboo*, International Journal of Life Cycle Assessment, 19, 13-23, 2013.

Zhou, L., and Lowe, D., *Economic Challenge of Sustainable Construction*, Proceedings of the Second International Conference on Construction in the 21st Century, Sustainability and Innovation in Management and Technology, Hong Kong, December, 10-12, 2003.