Bahareque as a Sustainable Construction System: Analysis of Unit Prices

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Abstract. The bahareque is a form of vernacular construction that, with the help of modern materials with adequate techniques and knowledge, constitute an alternative to provide housing solutions. Despite this, the lack of knowledge and technical processes in relation to costs, gives rise to a research problem. Thus, this document presents a set of technical strategies based on the Cost-Benefit analysis of using bahareque as a raw material and structuring a unit price analysis tool to guide construction professionals. The study had a qualitative and quantitative approach, surveys were applied to the population and professionals in the construction area that allowed to approach the reality of the construction system in the city of Cuenca-Ecuador. It is evident that people know about the construction system, but show some resistance to its application because they are unaware of the advantages and disadvantages of the vernacular technique. With the cost analyzes carried out, it is concluded that a typical house of 130 m² has a cost of $ 36,387.72 dollars; which, starts from concrete foundations, which support a reinforced masonry assembly that raises the wooden frames, associated with meshes that erect the walls with mortar and finally covered with roofs with a mixed material of wood and tile fired with clay.

1. Introduction
Sustainable development is a priority in the present and future of societies. It is transcendental for various sectors such as: industry, engineering, architecture and also for new and existing buildings that could be rehabilitated. In a global vision, particularly in the European Union (EU), it is a primary objective to promote development of cities, based on sustainability [1].

In this way, constructions, buildings, homes and other edifications are responsible of high energy consumption, which is more visible once the construction works are completed and concluded. However, it is necessary to look where the «raw material» construction systems start from, since traditional buildings are made up of blocks, bricks, prefabricated structures, cement and many other components that have chemical elements which are send off to the environment.

Facing this problem, there is a lot of raw material available in nature that has been part of ancestral buildings with great benefits. Bahareque is one of them, whose historical antecedents show that mixed construction were present with ancient civilizations, where land, water and plants elements were used as structures, giving rise to interesting infrastructures, which today are once again part of mentioned constructive systems for the advantages they present.
Studies such as the one by Laborel-Preneron et.al [2] highlight the importance of the bahareque technique, seeking to support the use of this material with other fibers and improve soil performance. Similarly, Roux [3] affirms that bahareque is an alternative to concrete as a construction material, since the characteristics of the technique, that it is born from the earth without getting burned, it can be adapted to humid climates, added to the fact that it is structured with hands by people who do not require high expertise and it is striking for builders, because it is also an issue associated with sustainability. Building techniques constitute a cluster of elements, materials and procedures, with some phases of convergence with traditional ways of construction. However, the bahareque is native from the Andean areas, especially in South America, it is formed by a continuous base of walls supporting frame in guadua wood that rests on the sills and braced, both at the base and at the top with tie beams [4]. Despite being common in the region, variation in treatment in each specific sector and empirical knowledge that are reinforced in constructivist techniques.

Despite the advantages described, bahareque is manufactured from clay, straw, sand and water, its cost and the items incurred in the application of the technique is not clear. With this background, the lack of clarity in costs, gives rise to a research problem, leading to the question: are the costs of traditional commercial constructions and Bahareque constructions, linking up people to opt for any of the construction systems?

With the exposed in the previous paragraphs, this document presents a set of technical strategies based on the cost-benefit analysis of using bahareque as a raw material and structuring a unit price analysis tool that will guide construction professionals in the “making decision”, when offering services through this construction system while they make a contribution to sustainable renovation of construction alternatives in the city of Cuenca.

2. Methodology
The present study reached a mixed investigation approach that is, quantitative, qualitative and non-experimental. The population was the set of low-income housing in the city of Cuenca, who are beneficiaries of room solutions granted by the Central Government and the Decentralized organisms. The sample was determined by taking as a reference the winners of phase 1 of “Los Capulíes” Housing Program (universe 98). When calculating the sample, a value of 78 people was obtained. A questionnaire was applied based on other studies such as the one carried out by Laestander [5] comparing the bahareque technique and traditional construction. With this, the instruments applied were adjusted to the purpose pursued by the research, which is to link techniques based on the cost-benefit analysis of using bahareque as a raw material and structuring a unit price analysis tool.

A non-probabilistic sampling was applied, for the convenience of the sample of construction professionals, addressing the following dimensions: professional data, technical information on the scope of construction systems, working experience with bahareque, in order to find the differences that help to properly structure the unit price analysis. The instrument was applied to a homeowner and to a construction professional, respectively. With this, the qualitative data allowed the investigation to be conclusive descriptive, the quantitative information, that is, the study of the prices incurred in the construction with bahareque was based on the analysis of values, indicators and data considering the following variables: hand work, materials, equipment, tools and indirect costs.

3. Results and discussion
Low-income housing is an alternative used by governments and municipalities to comply with political proposals or a general benefit plan, however, the manufacture of houses with brick or concrete techniques are of high cost, due to this background the proposal of building homes with the bahareque technique is an option to be considered by construction professionals.

Based on the above, a test was applied to know the level of knowledge of construction using the bahareque technique, results that are detailed:

Of the total population (13), approximately 54% of professionals have not made a bahareque-type construction, in contrast 46.2% have built using this technique. Similarly, the target group of
homeowners study reveals that 47.8% know the technique and 52.2% do not know any aspect related to the building method. The data show the ignorance of the bahareque technique in housing and the alternative it presents for the sector. According to Roux-Gutierrez [6] identifies the technique as a sustainable alternative for the use of natural construction materials, which reveals the importance of implementing this technique for the construction of social interest housing walls that presents results comparable to the brick technique if it is related to thermal inertia.

On the other hand, according to data from the Municipality of Cuenca [7], social housing in town will benefit a total of 546 families in the “Los Capulíes” project, due to the climatic conditions of the target sector, the technique is not considered by the authorities. However, in contrast to the perception that bahareque technique contributes to construction, it specifies:

The results presented in figure 2 reflect that 84.6% of professionals and 73.9% of the population consider that the bahareque technique is a feasible alternative to be implemented in low-income housing, in relation to 14.4% and 26% correspondingly, 1% believe that it is not a feasible alternative in regional construction. Hernández, Monroy, Conde and Madroñero [8] point out that the benefits of a bahareque structure is comparable to prefabricated structures and a sustainable construction alternative due to the use of natural and reusable materials.

Similarly, the ignorance about the benefits of the technique is characteristic of people that is not involved in the construction sector in the city, according to Rodríguez et al., [9] the differentiators of the technique lie in the elements used, and at the same time being friendly with the environment, easily accessible and inexpensive, considered as an alternative for the construction of social housing. Under this principle, the level of knowledge of this technique according to the data obtained is: the results reflect that the level of knowledge of the benefits of the technique is low, only 34.8% claim to know about it, and 65.2% do not know, the respondents reflect that once they know the characteristics of the technique related to the costs and permeabilization of the technique using additives, they express interest in acquiring this type of housing, the results of these questions are presented in:

The data obtained reflect a coincidence between the relationship within the knowledge of the technique prior to the acquisition of the home present in 47.8% of the respondents and in the 52.2% of the intention to change the current type of home due to costs. It was also observed that the percentage of 34.8% and 26.1% express that perhaps they would have liked to know the technique before acquiring the current one and have the intention to change of home. Based on the ideas raised, the consideration of professionals in the area is important for the analysis and correct implementation of the technique, in this context Hastings, Huerta, and Zaldívar [10] point out that the use of tools and materials are varied for the construction of bahareque-type buildings. Given this, the question of the types of tools considered for construction arises, the results are:

The result shows that the 13 professionals surveyed, choose in 30.8% to work in a manually way, an office tool present with 38.5% and other tools that are related to electronic media, hiring of experienced workers in the area is related to 30.8%, these results show the interest and the alternatives that designers have to pay for the technical work. Regarding the cost analysis Rodríguez et al., [9] identifies that economic analysis, in the same way as in any project, is essential for the objective housing process, pointing out that the main tools are in relation to cost analysis unitary (APU) and based on activities (ABC), according to the responses presented, the following data is observed:

When considering the cost analysis carried out by the professionals, it is known that 92.3% of the respondents analyze the prices through the APU, what is related with the interpro software and looking up that the construction works are small and do not require an extended analysis based on activities. On the other hand, it is considered that the workforce in construction varies according to the way of conventional construction. According to the recollected data, 100% of the people reaffirm this situation this in relation to the lack of professionals dedicated to the execution of this topic, in the same way, the influence of materials, execution time and lack of knowledge directly affects the particular conditions.

Regarding the recollected information, it is observed that 84.6% consider that natural material has an advantage in relation to materials compared to conventional construction techniques, working conditions, the terrain to be intervened should be considered, specialization of the technique, the labor,
less technological tools and the amount of hours invested. On the other hand, it is proposed that the depreciation of homes is high due to hours of use, corrosion caused by rain and general weather conditions. Regarding the hourly costs of workforce, respondents mention that the related costs are high, due to the scarce existence of qualified people, another consideration to take into account is that the price increase can rise up to 5% more, considering target machinery and equipment.

The properties of materials obtained in a natural way according to Torres and Jaramillo [11] this type of housing uses natural ways of straw, mud, wood and bamboo for the foundations which have taken advantage through the use of technological resources strengthening the resistance of walls and foundations, in suitable working conditions to propose the manufacture of the house, as well as the devaluation of these works. Regarding the information, it is observed that 84.6% consider that natural materials has an advantage in relation to materials compared to conventional construction techniques, in relation to working conditions, the terrain to be intervened should be considered, specialization of the technique, the labor, less technological tools and the amount of hours invested. On the other hand, it is proposed that the depreciation of homes is high due to hours of use, corrosion caused by rain and general weather conditions. Regarding the hourly costs of labor, respondents mention that the related costs are high, due to the scarce existence of qualified labor, another consideration to take into account is that the price increase can rise up to 5% more than considering target machinery and equipment.

According to what is stipulated by Laestander [5], the working times and workers in construction bahareque systems are statistically minor than those which are required by the concrete and brick techniques, this is susceptible to comparison, however, the constant maintenance of the house guarantees life useful. According to the advantages described in the survey, 54.5% of the participants consider that the average number of workers required for the bahareque technique is less than that of concrete, in contrast, 63.6% assure that the construction time is less when compared between the second and first method. In the same way, 72.7% of people indicate the useful life of traditional concrete houses. Finally, 81.8% indicate that the working hours with the interweaving technique of natural materials are less than cement system.

In this way, the advantages of the bahareque system referring to the structural and hydro sanitary architectural system of a building with the bahareque system presents advantages and disadvantages. Based on the information collected, it is observed: The data reveal that the architectural component is the main advantage with the bahareque technique due to the presence of colonial and pre-Hispanic structures in the sector, in the opinion of Monteros [12] points out that the colonial structures established by the Catholic missions in Latin America are a precedent to modern urbanism, whose bahareque buildings persist in passing centuries and are considered part of the cultural heritage.

Similarly, respondents reveal that another related benefit is the prevalence of the structural system of buildings, which are even against concrete techniques, this population represents the 58.3% of respondents. Finally, it is pointed out that 91.7% of architects identify that the problems faced by buildings of this type are related to the plumbing systems.

In contrast, on the data about the concrete technique 100% of the respondents reflect that the architectural, structural and hydro sanitary subsystems have comparative advantages compared to other types of construction, this shows the general acceptance of the professionals of the modern cementing technique traditional and the lack of perception to implement new manufacturing techniques.

The unit price analysis took as a reference and the historical data of similar works with the experience of the researcher in the construction of houses done with bahareque, are detailed below. Being the main items: foundations, walls, mezzanine and roof.

As shown in table 1, the value of the equipment use, workforce and materials for the overrun item is $ 11.15 dollars, taking as a reference the direct, the indirect costs and the profit of 15%.

For this item analysis, unit prices of $ 1.83 are expected, it shows that the prices of manpower in relation to wages are maintained, since they are regulated by the Ministry of Labor and indicated in the table of sector payments of Ecuador, so you can reach costs flexibility in the materials. The total value of the foundation is $ 12,537 dollars.
Table 1. Unit Price Analysis of Overrun.

| Equipment Description | Unit | Quantity | Rate   | Hour Cost | Output | Total Cost |
|-----------------------|------|----------|--------|-----------|--------|------------|
| Workforce Tools 5%    | hour | 0.05     | 1.07   | 0.053305  | 0.35   | 0.01865675 |

**Equipment Subtotal**

| Workforce Description | Unit | Quantity | Wage/Hr | Cost Per Hour | Output | Total Cost |
|-----------------------|------|----------|---------|---------------|--------|------------|
| Builder               | hour | 3.00     | 3.71    | 11.13         | 0.07   | 0.78       |
| Civil Works Worker    | hour | 1.00     | 4.1     | 4.1           | 0.07   | 0.29       |

**Workforce Subtotal**

| Materials Description | Units | Quantity | Unit Value | Total Cost |
|-----------------------|-------|----------|------------|------------|
| Water                 | lt    | 5.15     | 0.015      | 0.07725    |
| Grit                  | m³    | 0.5      | 19.09      | 9.545      |
| Lime                  | Kg    | 0.3      | 1.26       | 0.378      |
| Cement                | Kg    | 5.51     | 360        | 1983.6     |
| Mounting              | Un    | 15       | 481        | 7215       |
| Sealant               | Kg    | 0.2      | 2450       | 490        |

**Materials Subtotal**

**Direct Cost Total**

**Undirects and profits (15%)**

**Total Cost of the Item**

**Offered Value**

*Note. Source: Own elaboration.*

Table 2. Unit Price Analysis of Foundation Beams.

| Equipment Description | Unit | Quantity | Rate   | Hour Cost | Output | Total Cost |
|-----------------------|------|----------|--------|-----------|--------|------------|
| Different Tools (WF) 5% | hour | 0.05     | 0.55   | 0.027335  | 0.35   | 0.00956725 |

**Equipment Subtotal**

| Workforce Description | Units | Quantity | Wage/Hr | Cost per hour | Output | Total Cost |
|-----------------------|-------|----------|---------|---------------|--------|------------|
| Builder               | hora  | 1.00     | 3.71    | 3.71          | 0.07   | 0.26       |
| Civil Works Worker    | hora  | 1.00     | 4.1     | 4.1           | 0.07   | 0.29       |

**Workforce Subtotal**

| Materials Description | Units | Quantity | Unit Value | Total Cost |
|-----------------------|-------|----------|------------|------------|
| Concrete 3000 psi     | m³    | 1.05     | 0.015      | 0.01575    |
| Plank                 | l     | 4        | 8.6        | 34.4       |
| Steel Iron Nails      | Kg    | 9.97     | 4.8        | 47.856     |
| Bracket               | m³    | 3        | 360        | 1080       |
| Concrete Vibrator     | day   | 0.04     | 985        | 39.4       |

**Materials Subtotal**

**Direct Cost Total**

**Undirects and profits (15%)**

**Total Cost of the Item**

**Offered Value**

*Note. Source: Own elaboration.*
Table 3. Unit Price Analysis of Lattice Wall.

| Equipment Description          | Unit | Quantity | Rate | Cost per Hour | Output | Total Cost |
|-------------------------------|------|----------|------|---------------|--------|------------|
| Workforce Different Tools 5%  | hour | 0.05     | 1.33 | 0.06629       | 0.4    | 0.026516   |

**Equipment Subtotal**

| Workforce Description          | Units | Quantity | Wage/Hr | Cost per hour | Output | Total Cost |
|-------------------------------|-------|----------|---------|---------------|--------|------------|
| Worker                        | hour  | 4.00     | 3.71    | 14.84         | 0.07   | 1.04       |
| Civil Works Worker            | hour  | 1.00     | 4.1     | 4.1           | 0.07   | 0.29       |

**Workforce Subtotal**

| Materials Description        | Units | Quantity | Unit Value | Total Cost |
|-------------------------------|-------|----------|------------|------------|
| Guadua                        | M     | 5.5      | 110        | 605        |
| Enclosure                     | M     | 4        | 0.6        | 2.4        |
| Steel Iron Nails              | Kg    | 11.34    | 4.8        | 54.432     |

**Materials Subtotal**

| | Direct Cost Total | Undirects and profits (15%) | Total Cost of the Item | Offered Value |
|---|-------------------|-----------------------------|------------------------|---------------|
| | $663              | $99                         | $763                   | $763          |

\^Note. Source: Own elaboration.

With the descriptions in the preceding tables, the unit price of a bahareque wall is $8.67 dollars, considering the framework, anchoring, foundation, wood, wood boards required, meshes to put in the wood and the paneling. The cost analysis regarding to this item is $1,106, where the materials are the component and the item with the greatest weight. The unit price calculated for the cover item is $290. This shows the summary of costs generated for a typical house of 130m².

Table 4. Total, Unit Price Analysis

| Activities/Resource | Workforce | Materials | Tools | Unit Price | Units | Quantity | Total Cost |
|---------------------|-----------|-----------|-------|------------|-------|----------|------------|
| Foundation          | $ 1.61    | $ 10,900.27 | $ 0.03 | $ 10,901.91 | m³    | 1.5      | $ 16,352.87 |
| Walls               | $ 8.47    | $ 7,534.53 | $ 1.98 | $ 7,544.98 | m²    | 0.8      | $ 6,035.99  |
| Slab                | $ 0.02    | $ 0.81    | $ 0.02 | $ 0.84     | m²    | 130      | $ 109.03    |
| Roof                | $ 0.81    | $ 251.72  | $ 0.02 | $ 252.54   | m²    | 55       | $ 13,889.84 |

**Total unit cost**

**Indirects and Profits**

**Bahareque Housing Cost (130 m²)**

$ 36,387.72

\^Source: Own elaboration.

The final cost calculated for the house is $36,387.72, just applies if the bahareque construction system is used, considering that to improve this technique, reinforced soils could be joined to other fiber elements and stabilize them with cement, since the combination of they provide better stabilized soil conditions.

4. Conclusions

The construction process requires common materials such as wood, guadua, cane and mortar involvement, the first is used as a structural element of the panels. With the help of mortar, the interior and exterior of the walls are covered, isolating the wood and guadua from the environment. Other
materials are used such as iron for whips and reinforcements, which are particularly essential for joining the panels. As it was detailed in the cost analysis, the items analyzed were: foundation, wall structure, panels, lining, sanitary covering, electrical and floor finishes.

The price calculated regarding to the social housing that are built in the country, differs from the ancestral construction systems, they are economical compared to the current ones. However, the maintenance and structural work parameters required by this technique cannot be neglected, since the engineering and skilled labor are an interesting and economical option that cares for the environment and can be accessed by more families both in rural and urban sectors.

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