# Environmental and economical assessment of a more sustainable low-cost house

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ABSTRACT: Considerable environmental impacts are involved in the construction industry. In developing countries, those problems tend to be bigger due to the lack of housing and urban infrastructure, which demand a huge amount of natural resources, both materials and energy. This paper is part of a larger research study developed by NORIE (sector of the Civil Engineering Post-Graduate Programme dealing with Construction at the Federal University of Rio Grande do Su). NORIE developed the architectural design and built a prototype, which was intended to be a *more sustainable* low-income house climatically adapted to the south of Brazil climate, the Alvorada Prototype. With the present paper, the aim was to further develop the above mentioned research, through the environmental and economical assessment (evaluating the costs involved) of the Alvorada Prototype subsystems and materials.

A methodology that includes environmental assessment criteria, selected through literature research, was developed. The environmental gains were compared to the costs and each subsystem was weighted against the others. The research allowed identifying the environmental benefits and disadvantages of the adopted solutions in the design and construction phases. Concerning the costs, they were considered high when compared to those of most commonly built low-cost houses in Brazil. However, it is necessary to consider that it is a prototype and, as a prototype, its costs are higher than those of already consolidated solutions or of the ones built in large scale.

Keywords: low-income house, sustainability, environmental assessment, economical assessment, Brazil

## 1. INTRODUCTION

It is considered today that in international efforts to achieve more sustainable societies, probably no other sector of the industry has had such a fundamental role as that of construction [1].

Specifically related with the environment, a series of strategies can be adopted to evaluate the impact of buildings. Among them, the methods, instruments and tools of environmental evaluations have been the focus of academic and commercial researches in the Northern Hemisphere throughout the last decade. More recently, this area is also getting great attention in the Southern Hemisphere, with Brazil so included.

In developing countries, in addition to the problems related to the degradation of the natural environment, one observes high rates of urbanization that go hand in hand with a progressive deficit of infrastructure and urban dwellings [2]. Housing shortage in Brazil is perhaps the greatest problem, its deficit, estimated in the year 2000, already pointed to a shortage of 6.562.000 new dwellings [3].

It should be considered that the construction and allotment of dwellings do not only reflect interventions in the environment. It is determinant to the users' health and comfort, besides being related to the aspects of cost; that is to say, those of economical and social order.

In this sense, it needs to be brought to attention that poor living conditions and environmental degradation have been characteristic of the low income housing so far produced in Brazil [2]. Economic limitations have been used as the main argument to justify the lack of technical quality for the housing sector, including deficiencies in the infrastructure, as well as restrictions in the area of both dwellings and plots.

Inserted in this context and looking for alternatives that reverse the described scenario, NORIE is conducting studies on urban planning and buildings aiming at the low-income population. One of the works' main focus has been that of a low-cost house: the Alvorada Prototype (AP).

The model for the AP analysed in this article was built in the Campus do Vale, at the Federal University of Rio Grande do Sul, in the city of Porto Alegre, in the State of Rio Grande do Sul [4]. From the start, the studies focal point has been the improvement and evaluation of the proposed alternative for the housing, and it is in this context that the present research is inserted.

## 2. METHODOLOGY

### 2.1 Study objective

The objective of this work is the environmental and economical assessment of a low cost housing prototype, within the Brazilian context: the Alvorada Prototype (AP).

### 2.2 Object of study

The AP is characterised as a detached, one floor building, with a built area of 50,50 $m^2$, ,in an approximately square shape in plan and having an inclined roof facing predominantly to the South (Fig.1, 2) – that is away from the sun. The subsystems evaluated correspond to those so far implemented, that were subdivided and named:

a) Foundations: executed in granite stone blocks (partially re-used from a pre-existent structure in the site), on the top of a compacted layer of soil and cement. These were topped by beams of concrete and sealed with a asphaltic emulsion;
b) Flooring: this subsystem includes, besides a layer of ceramic tiles, a layer of gravel topped with a layer of mortar. The enamelled ceramic tiles applied in the bathroom, used an adhesive prefabricated mortar, and those not enamelled, which were applied in the remainder of the dwelling, used a cement and sand mortar;
c) Masonry: simply constituted by a layer of clay bricks, with a total thickness of 10 cm. In the walls orientated to the south and to the west a layer of cement, sand and sealing additive mortar, was also applied to increase the thermal resistance and the durability of these façades, as they are exposed to a more critical microclimatic situation;
d) Windows and doors: of several species of eucalyptus wood. They were executed according to factory standards, with some specific dimensions and details. They totalize, 7 windows and 5 doors with an approximated useful wood volume of 0,60 $m^3$. For protection against humidity and termites , an alternative treatment ,was used;
e) Roofing: the, structure is composed by beams of concrete and Cedar and Pinus wooden joists. An improvement in the thermal insulation of the subsystem is provided by, recycled aluminium sheets, obtained from off-set process. The roof is constituted of not enamelled ceramic tiles, and the ceiling is of Cedar lumber;
f) Pergolas: there are two pergolas in the dwelling, one northern orientated, and other on the west side of the construction. They use untreated eucalyptus wood of sustainably managed forests, of two species (*Eucalyptus Salignas* and *Eucalyptus Grandis*). Its foundation is of granite stones, partly re-used, and of small blocks of concrete

More information on the Alvorada Prototype can be found in Sattler et al. [4] and Satter & Morello [5] research.

**Figure 1:** North façade of Alvorada Prototype

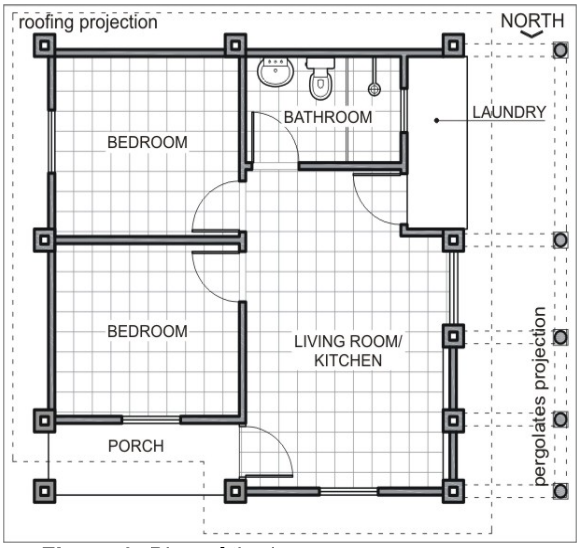


**Figure 2:** Plan of the house

### 2.3 Synthesis of the adopted procedures

A literature review was the main instrument for this work advancement. It made it possible, by means of tools from existing environmental assessment procedures, to find the basis to elaborate a methodology and to obtain sources of specific data for the evaluation. The structure of the resulting evaluation, once applied, was divided into two parts. One related to the environmental aspect, consisting of environment criteria of evaluation. And the other, related to the analysis of the materials' cost, excluding costs with labour, since the AP was conceived for self construction and was constructed partly by students. The procedures adopted, starting from the criteria selection to the final characterization, are synthetically described as follows.

2.3.1 Preliminary selection of criteria for environment evaluation

Firstly, a preliminary list of environmental criteria, pertinent to the environment evaluation of a low-cost dwelling in the Brazilian context was elaborated. The form of characterization of each selected criterion was evaluated. This occurred because we departed from the supposition that the structure of evaluation should be based on data available within the Brazilian context.

2.3.2 Surveying of data and calculation of consumption and cost of materials

The surveying of data related to the dwelling included the identification and quantification of the subsystems and materials. The physical characterization was helped by the documentation of the project and by a survey in loco. As for the information related to the construction stage, it was obtained through interviews with constructors, documents, reports and construction lay-outs.

To the actual consumption, calculated for the different materials, values related to waste were added. These numbers were obtained by comparison between the consumption estimates and the real consumption of materials registered throughout the construction stage.

The next stage was that of updating the materials cost to the month of January 2006, for the receipts of purchases presented values corresponding to the year of the AP construction: 2002. Some of the prices were updated through direct contact with the supplier of each material, as some of them are not traditionally available in the Brazilian market.

2.3.3 Definition of the criteria for evaluating and characterizing environmental impacts

The evaluation criteria here defined considers environmental loads related to the consumption of natural resources and to the emissions and residues generated. Criteria for indoor comfort are not considered since these aspects have already been discussed in a previous work [5]. The results of the negative impacts on the environment, and the form of characterizing each one is individually explained on the items that follow.

*2.3.3.1 Toxic residues emissions*

The criteria is to identify the material incorporated in the subsystems whose use or final disposal emits toxic residues. The toxic residues emitted are not specifically quantified, only the mass of materials that emits them during their life cycle.

*2.3.3.2 Energy consumption and $CO_2$ emissions related to transportation*

The consumed energy calculation is given by the product of the material mass by the energetic index for the transport by the distance of transport. To the result, in Megajoule, we apply the index of $CO_2$ emissions generated by the oil combustion due to transportation.

*2.3.3.3 Energy consumption related to materials manufacture*

Energy consumption calculation is given by the product of the energy index of the different materials by their respective mass.

*2.3.3.4 Incorporation of non reusable resources*

The criterion is to characterize the quantity of reused resources in relation to the new ones incorporated in the construction. The materials were classified according to the type of reuse of the resources employed: either as residual materials that came from productive processes in other sectors or from preexisting constructions that did not entail a new manufacture to be incorporated into the edification; or as those requiring additional processing.

*2.3.3.5 Incorporation of resources without re-utilizing potential*

This criterion is to consider the materials weight that have low or null potential for being reused in relation to those that present medium or high potential.

*2.3.3.6 Resources waste*

The criterion is to establish the relationship between the estimated and the real consumption of resources, during the construction stage.

*2.3.3.7 Use of non-certified native lumber*

The criterion considers the relationship between the masses of native and non native wood (reforestation) employed in building construction.

## 3. ANALYSIS OF THE RESULTS

The results are shown in graphs that characterize the impacts of construction in two scales: global and by subsystems. The environmental impacts characterisation and the cost analysis are summarised in items 3.1 and 3.2. Table 1 synthesizes the mass of materials incorporated into the subsystems and their respective costs.

**Table 1**: Mass and costs of incorporated materials into AP, discriminated by subsystem

| Subsystem | Mass | | Cost | |
|---|---|---|---|---|
| | (kg) | (%) | (USS) | (%) |
| Foundations | 49.222,4 | 44,4 | 1.523,4 | 19,3 |
| Flooring | 14.169,3 | 12,8 | 801,0 | 10,1 |
| Masonry | 32.087,7 | 29,0 | 1.381,7 | 17,5 |
| Openings | 984,9 | 0,9 | 1.305,9 | 16,5 |
| Roofing | 11.891,9 | 10,7 | 2.523,2 | 31,9 |
| Pergolates | 2.453,8 | 2,2 | 362,2 | 4,6 |
| Total | 110.810,0 | | 7.897,5 | |

**3.1 Analysis of environmental impacts**

Steel and terebentine essence are the only materials responsible for toxic emissions (Fig. 1). Steel is responsible for 99,7% of the total emissions, being released during the process of manufacture. Terebentine is used to dilute linseed oil, which was used for the preservation of wooden doors and windows.

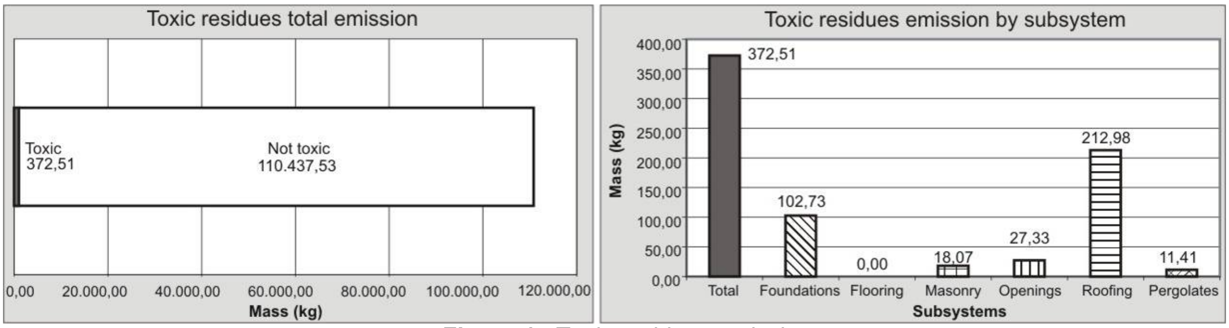


**Figure 1**: Toxic residues emissions

Energy consumption and emissions of $CO_2$ related to transportation (Fig.2, 3) are intertwined. The roofing subsystem was the one to receive the worst score, as 90,5% of energy consumption and emissions of this subsystem are due to the use of the Cedar wood, both in the making of the structure as in the making of moulds for the concrete forms. This construction material, whose manufacturing origin is the farthest from Porto Alegre, is the only one besides glass (used in small quantity) not produced in the State where the AP was implemented.

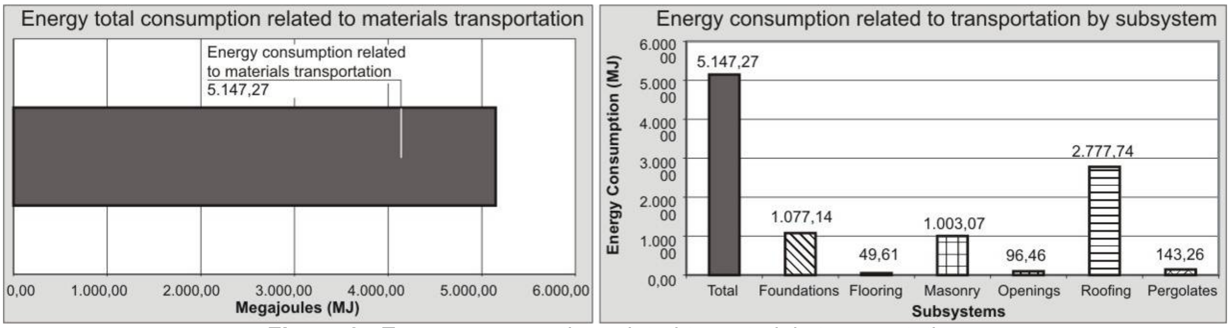


**Figure 2:** Energy consumption related to materials transportation

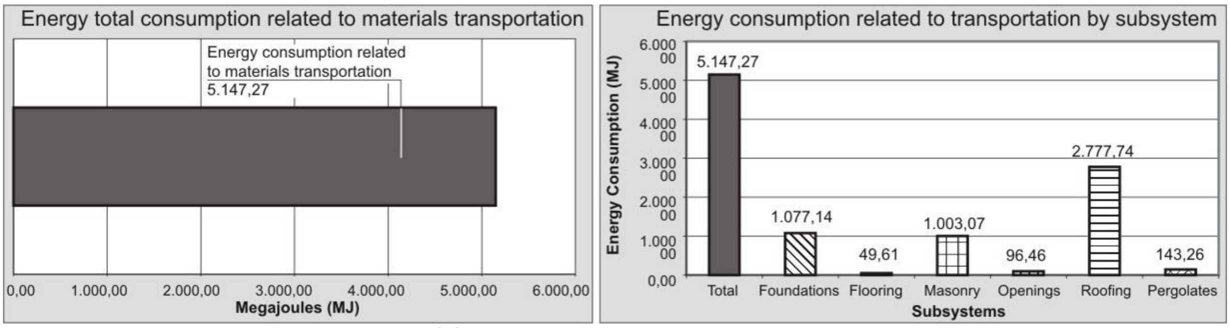


**Figure 3:** $CO_2$ emissions related to materials transportation

As for the energy consumption in the manufacturing processes, the results show that the dwelling contains more than 118.000 MJ incorporated into construction materials. This corresponds, according to results obtained by Hansen [7], to the electric energy required for 18 years of use of a similar building.

The energy consumption impact generated by the masonry and the roofing materials manufacture is shown in Fig.4. The consumption of energy, per $m^2$ of constructed area of masonry, corresponded to 1.104,90 MJ; for the roof subsystem it was equal to 811,56 MJ. These values are fairly high if compared to those obtained in other studies [6, 8], evaluating the same subsystems and similar type of dwellings in the Brazilian context.

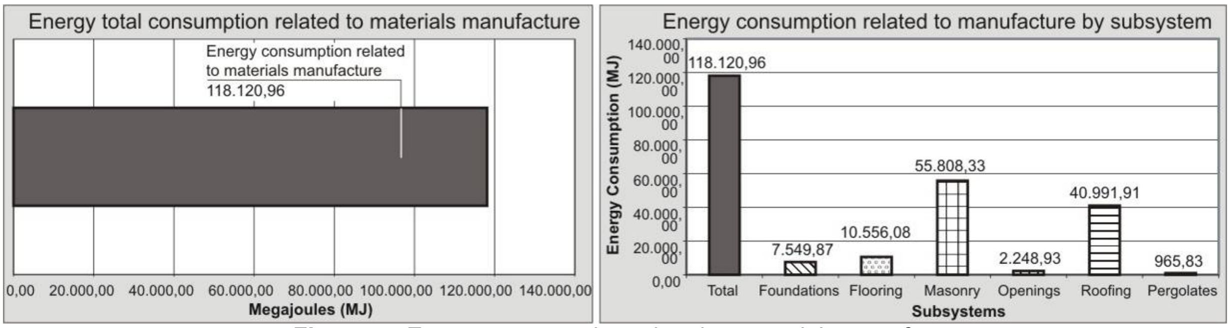


**Figure 4:** Energy consumption related to materials manufacture

The criterion of non-reusable resources incorporation (Fig.5) indicates that only a small percentage of the materials incorporated in the AP came from reuse. As the use of pre-existing structures or second hand construction materials is not a current practice in Brazil, the merit of this initiative is more a demonstration of its potential use.

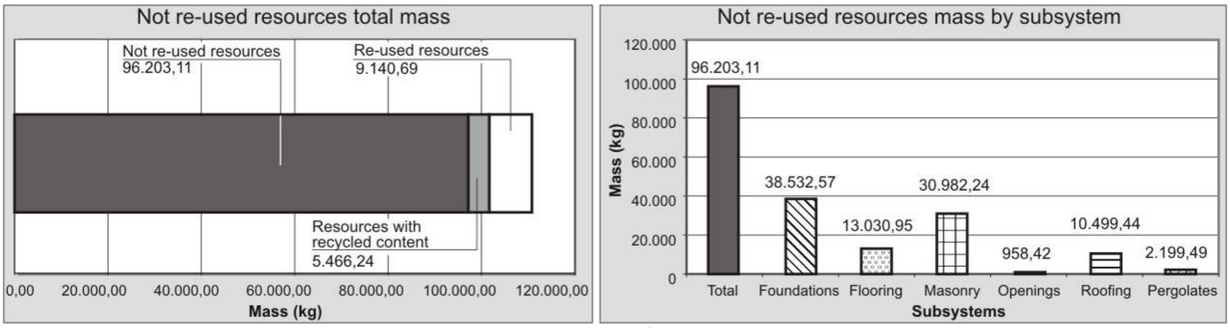


**Figure 5:** Incorporation of non re-used resources

The criterion related to the incorporation of resources without a potential for reuse (Fig. 6) reveals that the subsystems with worse performance are those that present a greater mass of incorporated resources with high potential for reuse. Thus it was found that subsystems constituted by great quantities of concrete and mortar tend to present a lower potential for re-usage.

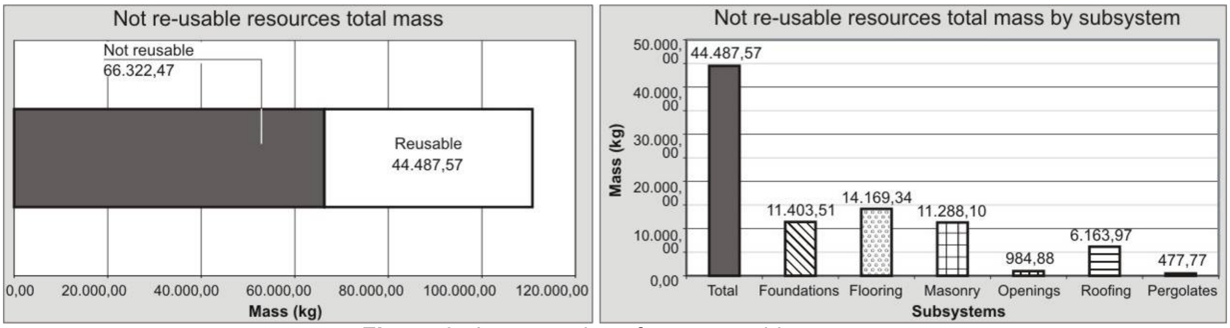


**Figure 6:** Incorporation of non re-usable resources

In relation to construction wastes (fig. 7), although those produced in the construction of AP do not differ from the average values found in Brazil, for several materials the production of wastes are in excess to those that were previously estimated or used as a reference, due to a lack of planning and control in the purchase of materials, during the construction process, thus resulting in the acquisition of materials in excess to what had to be used.

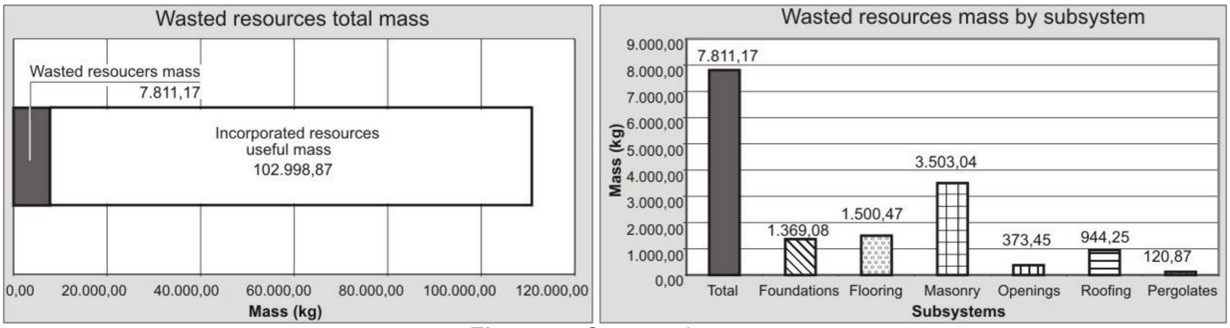


**Figure 7:** Construction wastes

In the criterion of consumption of non certified native lumber, the subsystem of roofing presented contrasting negative performance regarding the others (Fig. 8), due to the consumption of Cedar lumber. This happened in spite of the reduction of native species of lumber to almost half, due to the reuse of moulds to concrete in the structure of the roof.

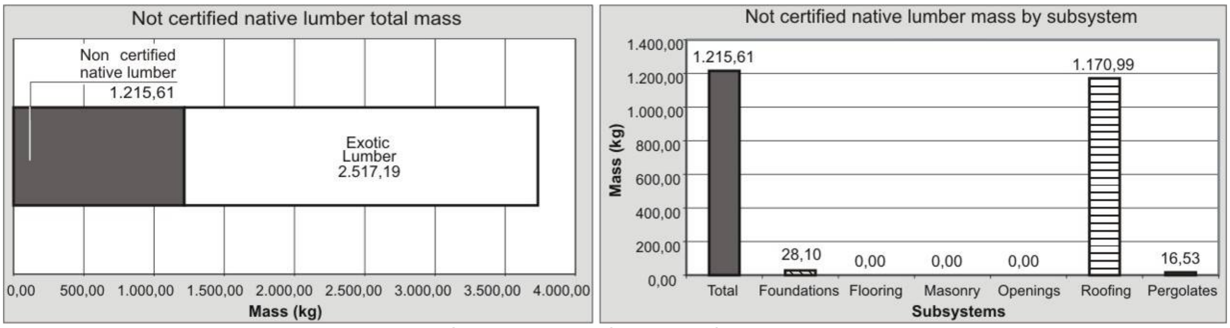


**Figure 8:** Consumption of non certified native lumber

### 3.2 Analysis of the costs associated to materials

It was verified that, in general, the solutions adopted in the design stage, in order to increase the environmental performance and habitability, did not represent significant increase in cost if compared with the alternatives for low income housing usually implemented in Porto Alegre. It was found that some issues related to the economy of resources, that have implications in both the economy and impact into the environment were neglected. Lack of planning for reuse and control in the acquisition of materials during the construction was one of those aspects observed, and they had representativeness in the total costs.

The costs of the materials were a little higher if compared to those usually used in Brazilian typologies for low income housing, with similar area. However, it has to be stressed that the figures presented here are pertinent to a prototype unit and tend to be higher than those consolidated solutions usually employed in large scale. It is necessary to consider too that some materials (of higher quality than the ones usually used in low-income housing in Brazil) were donated by partners and, in this study, it was adopted in the construction cost their actual market values. Another issue worth pointing out is that related to the foundations, that in response to the characteristics of the local soil (previously a wetland), a significantly higher cost than usual.

## 4. CONCLUSIONS

Some recurrent critical issues usually are found in studies like this [6]: a lack of data relative to Brazilian building materials that leads to uncertainty or requires the investment of considerable amounts of monetary resources and time to undertake construction evaluations like the one developed here.

However, the solution for these problems lies not only on the creation of a data bank It must be stressed that the Brazilian industries present such a heterogeneity in the production processes, that vary largely for similar products, that results in considerably different environment impacts. Thus, the selection of suppliers turns to be a critical aspect to the construction environmental performance as a whole. This issue that was prioritized in the design and construction stages of AP ended up having its benefits diluted in this evaluation due to the need of using non specific data.

Similarly critical was obtaining reference data for comparison with the AP environmental performance results. It became evident the lack of studies in Brazil related to environmental evaluations of low income housing as a whole. The existing works are limited to the analysis of isolated subsystems, and some cover only aspects related to energy consumption.

Despite the limitations pointed out, the results obtained allowed the identification of those subsystems with worst performance in relation to environmental issues and costs, and as a result the most critical environmental aspects determining them. This study may serve as reference to new propositions of low income dwellings, more sustainable and at costs more in accordance with the Brazilian reality. Additionally, it provides data for comparison with future environmental evaluations and of reference about the performance of this type of dwelling in Brazil.

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