# Embodied Energy in Wall Subsystems of More Sustainable Buildings

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*ABSTRACT: Considerable environmental impacts are caused by the building sector. Among them are those related to the high energy consumption due to the production of buildings and its materials. Hence, energy conservation is one of the main strategies to reduce environmental impacts, thus achieving more sustainable buildings. This paper attempts to characterize the embodied energy of different low impact building solutions traditionally employed in the State of Rio Grande do Sul (south Brazil) thus contributing to the decision making design process for local buildings. The research used a Centre for Regenerative Studies and Sustainability as an object of study. The methodology applied has used the calculation of the embodied energy for processes of extraction/ manufacture and transportation of the selected solutions (sandstone, basalt stone, eucalyptus wood logs, clay ceramic bricks and enxaimel). The results demonstrated that the embodied energy of the compared alternatives showed a wide variation. Among the studied technologies, sandstone masonry was the one with lowest energy requirement and the red ceramic masonry is the one with higher energy demand.*
*Keywords: embodied energy, sustainable buildings, environmental impacts, traditional buildings*

## INTRODUCTION

This paper presents the results of a study that attempts to answer the question: What is the best choice, in a compromise between environmental impacts and cost, for the materials to be used in the walls of a more sustainable building? The context for the study is the southernmost State of Brazil (30° S), more precisely the city of Feliz, where a Centre for Regenerative Studies and Sustainability - CERES (Fig. 1) is being designed by the sustainability research group at NORIE [11, 12], sector of the Civil Engineering Post-Graduate Programme, at the Federal University of Rio Grande do Sul - UFRGS.

Several locally available materials, known to determine a reduced environmental impact [2] include: stones (sandstone or basalt), wood logs (Eucalyptus), ceramic bricks and a timber-framed structure filled with adobe, known as enxaimel (brought to the region by the first German settlers, in the middle of the XVIII century). The whole study so far developed by NORIE´S team is much wider, including several other environmental impacts, but this paper concentrates on the energy consumption related to the fraction of the building life cycle related to extraction, manufacture and transportation.

Previous studies on the field of sustainable construction and in the municipality include a cooperation agreement established between NORIE and the city of Feliz that resulted in the design and construction of a more sustainable school [12]. Other studies developed by NORIE, related to more sustainable construction, include the design and assessment of a low cost house and of schools [5, 8, 14]; a low cost housing settlement [7, 9] and an education and demonstration centre [10].

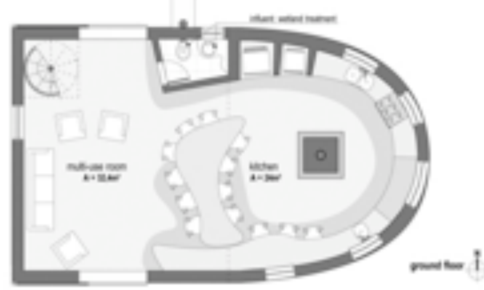

*Figure 1: Proposal for the first building of CERES.*

Any newly developed project demands efforts to conceive ways for reducing energy use, in all steps of a building life cycle. With regard to **building operational energy**, Brazilian governmental programs are under implementation. Nevertheless, there are yet no governmental programs focusing on energy reduction for building production, traditionally known as **embodied energy**. Until a few decades ago it was believed that the embodied energy was reduced, when compared to all energy spent along the building use stage [6]. The change of perception is attributed to two main factors. Firstly, to the reduction of operational energy, in cold climates, that occurred thanks to the increasing improvement on the energy performance of buildings envelopes. As the operational energy becomes gradually less significant, the material's embodied energy begins to grow in importance [4]. Secondly, the great part of the available bibliography, until recently, was related to European countries, where the energy consumption, at the stage of building use, is more significant when compared to that occurring in developing countries, such as Brazil. The reasons for this difference are: the climate challenges those countries are usually subjected to, demanding a significant amount of energy for heating; and the large number of low-income families in developing countries, resulting in reduced use of air conditioning systems, even when indoor comfort conditions are less comfortable.

The study used CERES as an empirical object for this paper. An attempt was made to characterize the embodied energy of different low impact building solutions traditionally employed in the State, thus contributing to the decision making design process for local buildings.

## METODOLOGY

The methodology applied in this paper is based on documentary and field research. The following stages are described below:

**Selection of the Evaluated Construction Technologies** The selection of materials was based on two main criteria:

**a) appraisal of locally available and commonly used construction materials**: the local architecture is characterized by a great number of vernacular buildings built by German first settlers and their descendents. The enxaimel technique (timber-framed structure filled with adobe) is an example of such buildings. In addition to that, derived from the Earth's crust constitution in the region, the city has a considerable number of stone quarries and ceramic industries, what explains the large adoption of quarried stones and ceramic bricks in local constructions. Another material that is widely employed in the region is wood. Traditionally, native species, which are nowadays almost extinct and protected by law, were used. Alternatively, eucalyptus from reforestation areas has been adopted. Such a reality led NORIE to elect the following materials, as options for the walls of CERES more sustainable building prototype: 50x25x12cm **basalt blocks**; 42x22x10cm **sandstone blocks**; 20x10x5cm **clay fired ceramic bricks**; **enxaimel** and **eucalyptus wood logs** (Fig. 2).

**b) suitability to local climate:** the recommendations made by the Brazilian standards on thermal performance of buildings [1] were also taken into account, when defining the alternatives to be analysed. Considering the thermal properties of the construction materials, the selected ones figure amongst the most suitable for the bioclimatic zone where the city of Feliz is inserted (bioclimatic zone 3).

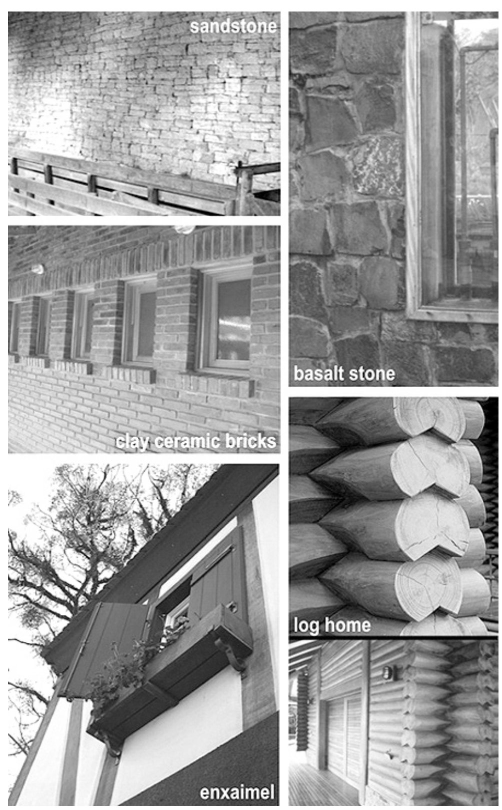


*Figure 2: The elected building solutions.*

**Functional Unit Definition and Quantification of Materials** As an important issue for any construction technology, assessment a functional unit needed to be defined. The reason for such a definition was to simplify the data analysis. When subdivided in standard units, alternative objects became more easily comparable [13].

To avoid a partial evaluation that does not consider impact transferences, the delimitation of the functional unit was made considering the impact of different solutions in other subsystems of the proposed building. For the assessment, a linear segment of one meter width of external wall was thus defined as the functional unit. The functional unit included: the foundations (designed in accordance to the loads resulting from each solution), the masonry, and, when applicable, the beams. It is important to mention that its whole height, but no openings, were considered in the wall section. After that, the materials were quantified for each solution.

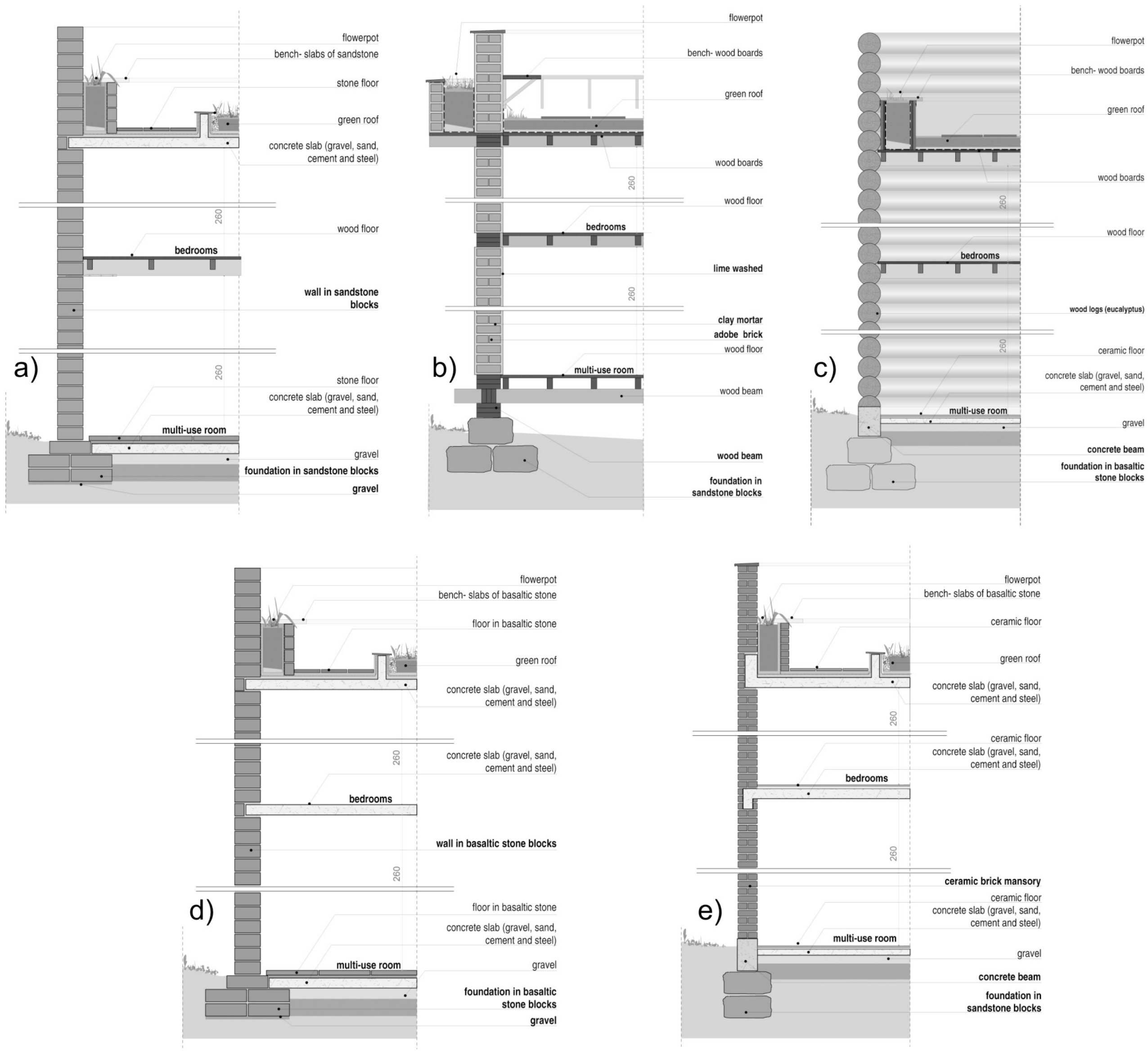


*Figure 3: Subsystems sections. a) sandstone; b) enxaimel; c) eucalyptus wood logs; d) basalt stone; e) clay fired ceramic brick*

**Calculation of the Embodied Energy due to Extraction and Manufacturing Processes** The energy consumption related to materials production was estimated by means of their respective energy index. Energy index is defined as the energy required to produce a unit of mass of a given material. The indexes adopted in this study correspond to Brazilian manufacture/extraction processes. They were found amongst the latest locally research bound figures, being, the non locally available and more specific ones, extracted from a variety of sources. It is important to state that Brazilian databases of environmental information on national processes are inexistent or unavailable. Finally, the energy content calculation is given by the product of the energy index of the different materials and their respective mass.

**Calculation of Energy Consumption Related to Transportation** Transport, and its derived impacts, is a major issue in Brazil, due to the country's continental dimensions (with more than 8.5 million $km^2$) and considering that diesel vehicles are used both for public and goods transportation, which makes the transportation sector the second largest energy consumer in the country and the first in the consumption of oil [3].

To calculate the energy spent in the transportation of materials, a ratio was obtained from diesel fuel data and from the values of average efficiency of trucks commonly used in Brazilian highways: 0.022 l/t.km. The diesel specific mass and calorific value [3], used in the calculation correspond, respectively, to 840 $kg/m^3$ and 42,25MJ/kg. The total consumed energy is given by the product between the specific material mass (kg), the energy fuel efficiency of transport (0.78 x10-3 MJ/kg.km) and the distance between industries and construction site (km).

**Calculation of Selected Technologies Costs** The identification of costs, as far as the Brazilian social context is considered, becomes an indispensable analysis, despite the non-scientific character. In a developing country like Brazil, this is a crucial point for the decision making process involving environmental impacts.

Once the quantities of materials required for the construction of each subsystem were identified, the respective costs were calculated. The figures were obtained through surveys made with local producers and retailers, always considering the nearest supplier. The global cost of each subsystem was calculated based on its unitary cost and on the total quantities of materials.

## RESULTS

The obtained results for energy consumption are summarized in figures 4, 5 and 6. Figure 4 shows the comparison between total requirements in energy for each subsystem.

Figures 5 and 6 show the amount of energy associated to of each type of material, as required for foundation dimensions, their manufacture/ extraction and transportation, respectively.

The results show that manufacturing/extraction energy demand was significantly higher than transportation energy, in all options, but the basalt wall. Among all technologies included in the global (manufacture + transportation) assessment, red ceramic masonry is the one with highest energy demand, requiring 5 times more energy than the second – the wood logs system – and around 10 times more energy than the lowest energy consumer – the sandstone masonry system.

The red ceramic masonry also requires more energy for manufacture than the other alternatives, due to the firing process – responsible for 90.9% of total energy requirements. The wood log technology, even using 5 times less energy, if compared to ceramic bricks, is the second highest in energy demand in its manufacturing process. The wood logs processing represents 91% of its total energy content.

The enxaimel technique, in spite of the large quantities of sand and earth used in its composition (with very low embodied energy), appears as the third in energy demand, with numbers close to the wood log system. The lime (mixed with earth and used in the paint) and the wood frame structure have the highest embodied energy, representing 33% and 55% of this system's energy input, respectively.

The stone masonries, either on basalt or on sandstone, showed the lowest values in embodied energy. The different results between the two types of stone made walls were due, both to the amount of mortar needed to lay each kind of stone and to the difference in specific weight between the two types of rock. As for the transportation energy, basalt is the most demanding, due both to its weight and to the longer distance from the quarry to the building site: 116 km (third longest). However, in a global evaluation, the basalt alternative is the second lowest in energy demand, only higher than sandstone masonry.

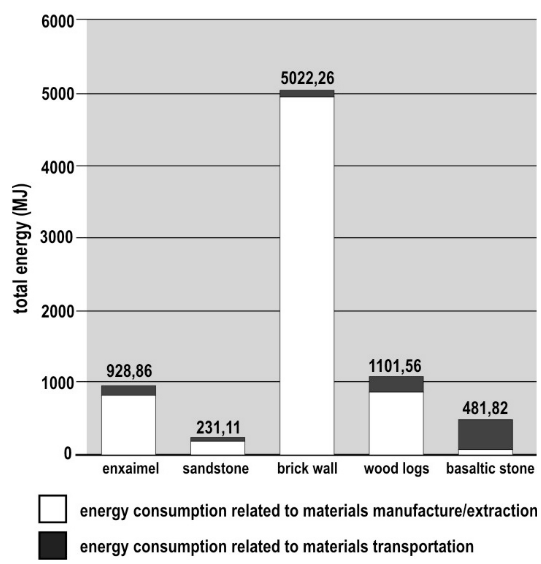

*Figure 4: Energy consumption comparison between subsystems.*

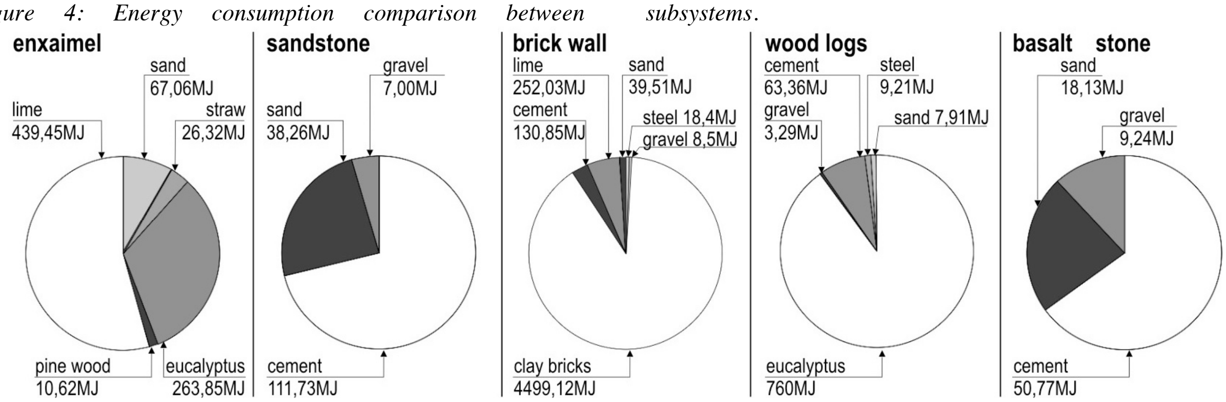


*Figure 5: energy consumption related to materials manufacture or extraction.*

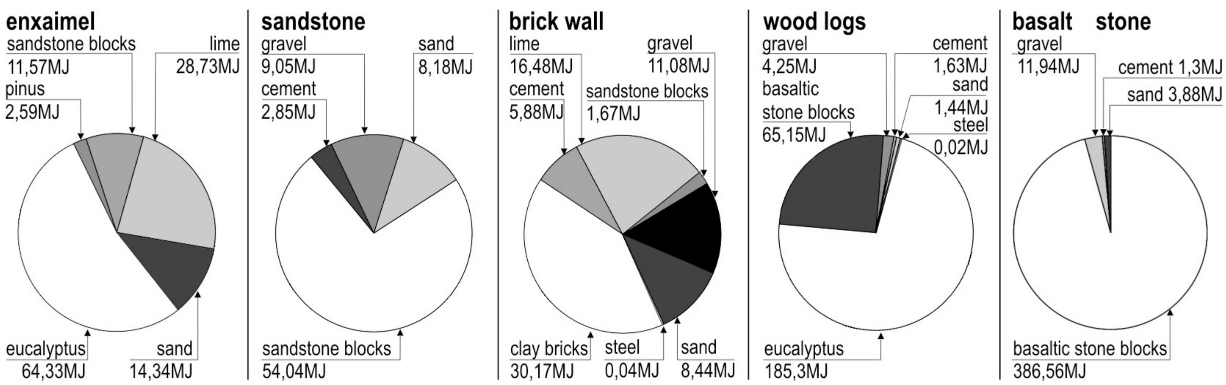


*Figure 5: energy consumption related to materials transportation.*

With regard to costs, no considerable variation was detected among most construction systems. The only exception was the cost of basalt wall, which was 2.5 times more expensive than the cheapest alternative: the enxaimel. A comparison between figures 4 and 7 shows no relation between costs and energy input, i.e., the option with highest energy requirement is not the most expensive and the alternative with the lowest energy demand is not the cheapest. For the CERES case, if adopted the lowest energy requiring solution, the execution costs would be 20% higher than the cheapest solution. Or, if the cheapest solution is applied, the embodied energy would be 25% higher than that of the lowest energy requiring solution.

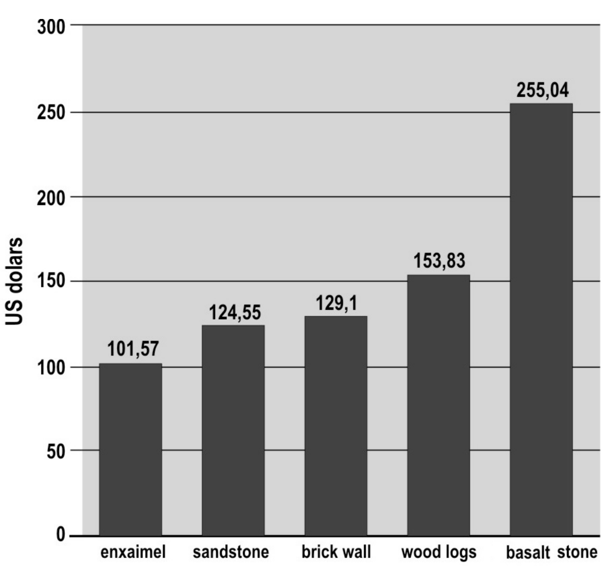


*Figure 7: Costs comparison between subsystems.*

## CONCLUSIONS

Concerning the purpose of this paper, that was to define the best choice, in terms of the material to be used in the walls of a more sustainable building, looking at energy consumption and costs, it was found that the embodied energy of the compared alternatives showed a wide variation. Among the studied technologies, sandstone masonry was the one with lowest energy requirement.

It was also verified that four of the studied subsystems presented the manufacture/extraction embodied energy significantly higher than the transportation energy. The availability of local technologies was determinant in these results. What must be kept in mind is that the found results are only valid if applied to the region of Feliz, as the transport energy demand can vary widely, depending on the availability of the studied construction materials close to the place where the construction will be built.

When considering the applicability of the findings beyond the specific studied situation, it can be stated that the obtained results of energy consumption for manufacture/extraction processes can be used as a reference for buildings of the same type in the whole of the State in Rio Grande do Sul. Nevertheless, the figures related to the transportation energy can be taken as references only for constructions to be built in Feliz. In addition, with regard to the applicability of this study to the national building sector, it must be stressed that the lack of Brazilian data on environmental performance of building materials and technologies discourage designers and final users to consider environmental impacts and requirements. In this sense, similar studies can play a significant role in encouraging more sustainable practices in the local building sector.

Clearly, embodied energy is not the only criterion to be considered, when assessing building environmental impacts, and this research only provides a partial assessment of the impacts related to the elected subsystems. Thus, there are others, not here considered, environmental loads that would allow the continuity of the present study. As such, the analyses of energy consumption and efficiency of buildings along their life span could also provide a more complete life cycle assessment, while regarding at energy.

The present paper could also be continued by analyzing the costs of operational energy related to artificial cooling and heating, estimating costs in a long term.

Considering the evaluated technologies, it is important to mention that some of them, as enxaimel for example, are normally restricted to small buildings. However, in this study, the election of the technologies was made in order to demonstrate the advantages in using traditional solutions that employ local materials, which, eventually, contributes to minimize the transportation impacts.

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