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Environmental assessment of a constructive system for living spaces made in Mauritania

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Abstract: *An elementary living space, developed by ICHaB, is evaluated. Different solutions of ´Basic Habitability', have been constructed from it (schools, housing, medic care centres...). It consists of a structure (foundation, pillars and beams) of reinforced concrete and enclosing walls executed with different types of materials that may be local (gypsum block, adobe ...) or imported (concrete block). The cover is made as a 4 cm thick concrete catenary vault.*

The paper attempts to explore the environmental analysis of the 'module' from the perspective of sustainability assessment. Different constructive solutions are characterized with a focus on life cycle. The links with social, cultural and economic aspects have been incorporated into the analysis of different spatial solutions. The detailed inventory data from the case study project and the impact assessment focuses on resource depletion (kg, MJ, kW) and global warming (CO2eq)

Key words: LCA, environmental-impact, development cooperation, Africa

Introduction

The use of concrete as exclusive material is replacing the traditional use of local materials in latest urban developments in Africa. The concrete represents the idea of modernization in the collective unconscious of a population in need of progress, even though the traditional systems take advantage of centuries of adaptation to extreme weather conditions. The current paper aims to work on the appropriateness of the use of local materials by analyzing their impact throughout their life cycle.

The housing solution proposed for Mauritania by the Instituto de Cooperación en Habitabilidad Básica (ICHaB) of the Universidad Politécnica de Madrid, has been used to build many different buildings throughout the country by the aggregation of simple components (Image 1).

Image 1. Basic component; Dwellings at Nouakchott; Health center in Tellaba. Source: José Javier Legarra

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The construction system allows having facades of different materials depending on availability in the environment (plaster, stone, adobe ...) over a structure of pillars and roof concrete vaults (Legarra et al., 2009). This results in some environmental implications that should be studied for each case on its specific location.

Case study: El Mina school

This paper focuses on the analysis of an existing building constructed in 2008: the classrooms for El Mina school for sensory disabled children in the city of Nouakchott, in the Sahara desert.

The building is designed for a bioclimatic operation in desert climate. High ceilings are projected and solar incidence is especially controlled by surrounding circulations equipped with sunscreens that allow cross ventilation (Image 2). The impact of building enclosures for different solutions is evaluated.


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Image 2. Classroom module for El Mina school; Source: José Javier Legarra

The structure is constructed of reinforced concrete and the walls and partitions are made with gypsum blocks. The design attempted to use local low impact materials as far as possible. Imported materials were used in the structure in order to ensure structural safety according to the function of the building. Local materials were used for the enclosure: in this case the gypsum from a local factory. Nouakchott has one of the largest deposits of this material in the world, although its use in construction is limited merely to plasters and decorative elements. The blocks were hand made in the plot itself using steel moulds.

It's hard to find gravel around the sandy Nouakchott. This makes this arid be very expensive due to the cost of transport from rocky areas within the country. For this reason, the usual existing local aggregate is used: the seashells. Concrete made with this aggregate has a lower compressive strength (Revuelta et al. 2008) (Garcia et al. 2009), which requires to reinforce the structural elements with a higher amount of steel.

The data of the density and weight of the materials used for concrete production were obtained from tests performed at Instituto Eduardo Torroja in Madrid (Garcia et al. 2009) and gypsum blocks were tested at materials laboratory of Escuela Técnica Superior de Arquitectura (Villanueva, Oteiza 2002). Construction materials were imported from Mauritania to perform both studies.

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The analysis is summarized in the following chapters, taking into account the principles and guidelines of the standard ISO14040.

Goals and Scope

Being aware of the limitations of this type of analysis, the objective is not set in the accurate quantification of environmental performance. The study is aimed to raise various issues relevant to the study of impacts on this kind of projects, indicating environmental issues traditionally outside the decision-making.

The proposed methodology provides some results that allow us to evaluate solutions with local materials (gypsum, earth, stone, shells) versus imported materials (cement, steel, aggregates) in West African countries. Another aim is to understand the life cycle phases associated with higher impacts (raw material extraction, transportation, manufacturing, construction, use, maintenance and end of life).

The functional unit corresponds to the use of a structure and envelope of a classroom block consisting of 8 modules in Nouakchott for a period of 30 years. This communication focuses on the evaluation of different solutions for the enclosure. The reduction of impacts that meant replacing conventional concrete block walls by local gypsum blocks are quantified and compared with the impact of the structure.

As system boundaries, the extraction, processing and transportation of raw materials, the placing and the stage of use and maintenance have been considered. It also outlines the end of life scenarios.

Resource depletion (kg, MJ, kW) and global warming (CO_2 eq) were taken as impact categories. The presentation is focused on CO_2 emissions.

Inventory of materials from cradle to gate

A systematic accounting of the different items from the construction of the building is made, and an estimate of the origin and mean distances of each of these materials have been calculated.

Some results are shown in the results data tables (table 1 and 2). Using data referenced by the carbon inventory developed at the University of Bath and the database Ecoinvent and ELCD. We have tried to take the data that best conform to the local reality, characterized by the following conditions:

- Both cement and steel are imported.
- As the seashell is an understudied material, equivalent aggregate data is assumed.
- Dune sand is used, very different to that commonly used in Europe
- Gypsum comes from local production
- Water is a scarce resource in the area and it is transported by tanker

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	Mass (kg)	EMBODIED ENERGY MJ/Kg	EMBODIED CARBON $KgCO_2/Kg$	EMBODIED ENERGY MJ	EMBODIED CARBON Kg CO_2	Origin	Means of transport	Dist. Km	Kg CO_2eq
Sand (general)	73.086,19	0,100	0,005	7.308,62	365,43	Nouakchott	Lorry*	2	6,62
General aggregate	50.922,50	0,100	0,005	5.092,25	254,61	Nouakchott	Lorry*	10	23,06
Portland CEMI	15.326,12	4,600	0,830	70.500,14	12.720,68	Average distance	Freight ship	3.754	1.421,1
Water	20.141,96	0,200		4.028,39	0	Idini	Lorry*	45	41,05
Gypsum (general)	10.970,33	1,800	0,120	19.746,59	1.316,44	Nouakchott	Lorry*	2	0,99
Iron (general)	3.908,00	25,000	1,910	97.700,1	7.464,29	Algeciras. Spain	Freight ship	2300	222,01

* Operation Lorry 3,5-7,5t (euro 5). Full lorry, 7t

Table 2. Inventory data summary of the main materials and transportation to the building work site. (ICE 1.6a and ECOINVENT + IPCC GWP 2007 20y)

Use stage

The benefits of thermal comfort during the use phase have been evaluated by the building energy simulation (Image 3). This allows also to evaluate the impact of energy consumption that would occur in case of installing air conditioning facilities to keep the classrooms within an acceptable thermal comfort by Western standards

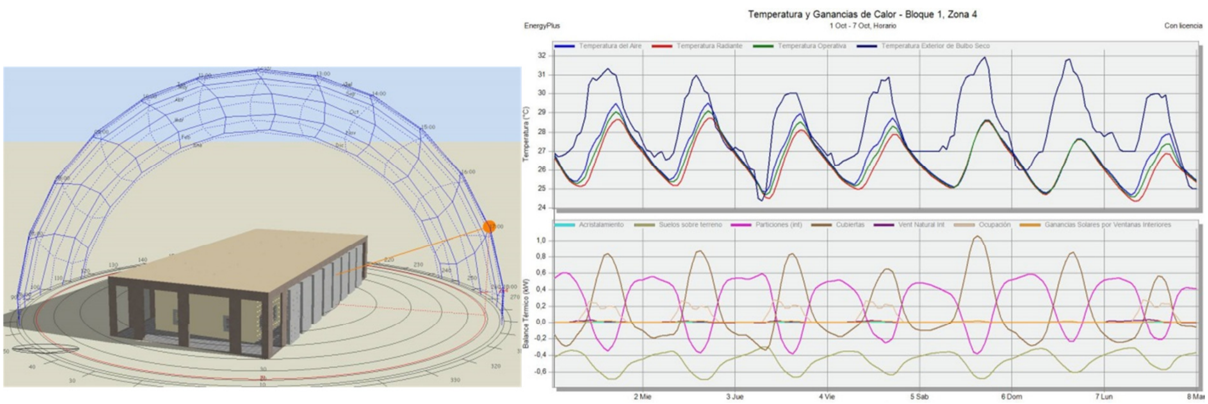

Image 3. Model and results for the energy simulation

In this case, the lack of means does not allow consumption of energy for classroom air conditioning. Therefore, the study of living space comfort based on air temperature remains interesting. The simulation allows to evaluate building elements that improve thermal comfort (such as sunscreens and ventilation), and those that worsen (roof). Building design reduces indoor temperature in the living areas an average of 3°C below the outside temperature in summer week

To avoid energy consumption in lighting, a daylighting system is designed. It is based on the inclusion of inverted tea glasses in the thickness of the concrete vaults.

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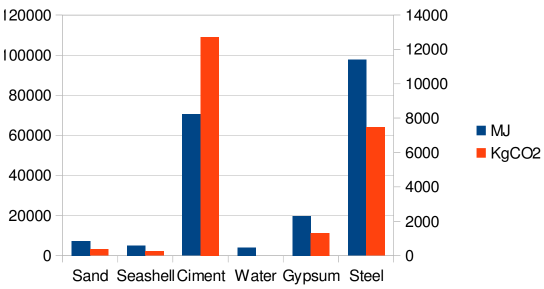
Image 4. Installation of tea glasses in the dome, view from the inside and solar protection jalousies.

It is important to correct the usual deficiencies in the maintenance of buildings in such projects. A guidance manual "Conseils pour l'Utilisation du Bâtiment et entretien" is delivered to users, and a training on general recommendations is provided to local workers in order to ensure durability of the building.

Impact assessment

The largest amount of material corresponds to the sand. The highest global warming potential and energy consumption correspond to cement and steel (Image 5). The analyze of these items in detail reveals the greatest impact is caused by materials used for the structure construction (Image 6). This impacts correspond to lean, foundations and structural concrete, as well as steel.



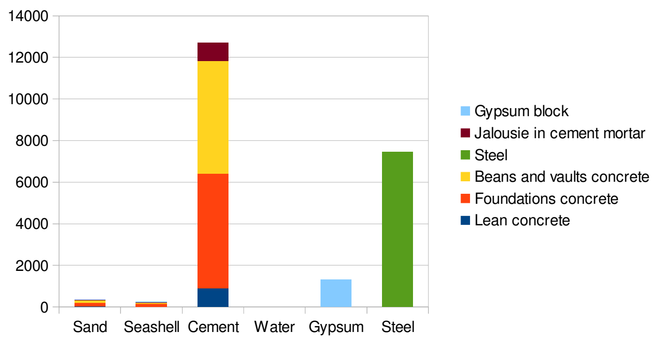


Image 5. Embodied carbon and energy of the major materials; Image 6. Embodied carbon for building elements

Regarding the transport of materials, the distances travelled by imported materials are higher, but the boat transport is more efficient than truck transport used locally.

No impacts associated to energy consumption where taken into account for the use stage.

Interpretation

Both data collection and the choice of the database to define the inventory has not been easy. Even though there are no full life cycle data of studied materials, some interesting results can be observed. Used materials are common but in most cases it was necessary to adjust the amounts and simplify processes. Most of the data found don't take into account local specific problems. As an example, used methodology tend to assume the use of machinery for mortar, concrete or plaster production, but all of these products are handmade in the case study.

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All references that have been necessary to allow traceability of data have been incorporated. The critical review of used data highlights the need for local data. Some of the references used also have a high degree of uncertainty and may lead to inconsistencies which may be taken into consideration, although they have been tested in multiple databases.

Conclusions

The collection of data needed for the analysis was not easy. There is no data available for the entire life cycle of studied materials. Although they are materials of most common use, found data are alien to local problems.

The greatest potential for global warming and higher energy consumption used in the manufacture of materials are due to cement and steel. Regarding the transport of materials, the distances traveled by imported materials are much higher, but the boat transport is more efficient than trucking used locally.

With regard to energy simulation, only climatic data from 12 of the 49 African countries are found on the 'energy plus' website. Data corresponding to Mauritania climate were not found. The climate data used are those from Dakar (Senegal). However it is found that the building's design manages to improve thermal comfort, cushioning high outside temperatures inside the classroom.

Having greater influence than energy consumption in development projects, impacts associated to materials inventory should always be taken into account.

The need for a simplified methodology for the environmental assessment, which is still under surface design is confirmed.

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