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Avoiding potential greenhouse emissions by using local materials in housing construction: A case study in Colombia

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Housing in Colombia, especially social housing, has been a priority issue for governments in recent years; however, it is necessary to consider building more sustainable homes with less environmental impact using local material as opposed to building with conventional materials. Based on these needs, this research aimed to evaluate the potential environmental impact of social housing by predominantly using local resources in the construction phase and surplus resources, such as rainwater and graywater, in the use phase. As a case study, a real social house in the city of Pereira (Colombia) was selected; this house was built by an institutional housing program 15 years ago. From the records of this housing project, it was possible to quantify the local resources used to build the house, which were mainly bamboo (*Guadua angustifolia* Kunth) and clay tile. Then, new social housing was modeled that used rainwater and reused graywater in non-potable uses during a life cycle of 50 years. In this scenario, we found that the use of local materials in the construction phase of housing and the combination and use of alternative water resources (rainwater, graywater) for domestic non-potable use can decrease the potential environmental impact of building and maintaining this type of housing. This decrease was equivalent to a decrease of 10.9% (Global Warming Potential [GWP] of 137 kg CO_2 eq./m^2 built) in the total potential greenhouse gas emissions for comparable conventional social housing. The use of local materials and surplus resources (rainwater and graywater) during the life cycle of low-density housing contributes to the emission of fewer greenhouse gases. Additionally, it was observed that the use of local materials for housing projects strengthens local employment options.

Key words: Life cycle analysis (LCA), graywater, rainwater, urban water, bamboo.

INTRODUCTION

As mentioned by Dixit et al. (2010), the building industry is one of the human activities with the largest energy and natural resources consumed. Housing construction based on the use of local materials contributes to reducing

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environmental impacts (Zea and Habert, 2014). According to Morales-Pinzón et al. (2014), the use of local materials, such as bamboo, brick and clay tile, and the use of surplus resources, such as rainwater, should be weighed heavily in defining sustainability standards of housing in developing countries. The inclusion of these materials and resources in public policies for social housing can be a strategy that lasts over time, beyond the limited conception of local materials, and the use of surplus stocks is a guarantee for lower-income populations.

These materials should be evaluated using techniques of environmental performance as proposed by Zea and Habert (2014) that give criteria to evaluate the potential environmental impacts of bamboo-based construction materials. The environmental benefits of using local materials in smaller residential buildings has been analyzed by Morel et al. (2001), finding decreased by up to 215% of energy used compared to a typical concrete house. Heeren et al. (2015) concluded using Monte Carlo simulation, the impacts from material input are particularly important in massive buildings, but these impacts would be reduced by using local materials.

This is very important for countries working to overcome the housing shortage. As example, Colombia housing deficits are estimated at 3.828 million households (57.9% corresponding to urban areas) (DANE, 2005). In addition, many homes were destroyed and damaged by heavy rains and floods in 2010 (2,049 homes were destroyed and 275,569 homes were damaged in 654 municipalities of Colombia) (Press National Risk Management for President of the Republic of Colombia quoted by Ministerio del Interior y de Justicia, 2010).

This context defines housing demands nationwide. In addition, there has been intensive urbanization and a lack of urban planning programs, which generate regional imbalances and increase vulnerability to natural phenomena for homes in high-risk areas, mainly homes from lower socioeconomic strata, which are magnified by human actions (Ministerio de Ambiente, Vivienda y Desarrollo Territorial, 2005). Regarding the supply of housing, the construction sector provides housing solutions to social strata with high payment capacities (strata defined as 4, 5 and 6 or areas of high urban development), which correspond to 51% of the population, whereas the number of housing solutions for “strata 1” does not reach 1% and the potential beneficiaries to obtain housing subsidies are clustered at levels 1 and 2, which satisfy the requirements of 5.1 million households nationwide (Contraloría General de la República, 2010).

The National Development Plan (2010-2014) in the Environmental Management Sector has a theme related to improving environmental quality in cities. This theme, which aims to develop tools for designing and building environmentally sustainable buildings and homes (Contraloría General de la República, 2013) or buildings and homes that prioritize the use of local materials (because these materials need only limited processing or transporting and these materials have low environmental and economic costs), renewable materials (bamboo, for example, which can be generated quickly to keep pace with how fast it is used) and recyclable materials (for example, glass, metals, and plastics) as well as the implementation of efficient systems for the consumption of water and energy, optimizing both quantity and quality (González and Pérez, 2009).

In Colombia, in addition to the research that has developed in this field, traditional domestic architecture cannot be ignored. A clear example is the type of construction defined in the culture of the Coffee Cultural Landscape (CCL), World Heritage Site by UNESCO (Ministerio de Cultura and Federación Nacional de Cafeteros, 2011), which includes approximately 143,000 hectares and a population of 80,000 inhabitants. This type of construction uses the typical amount of space, materials (rammed earth, adobe, clay tile and bamboo as carrier materials; bamboo is used in vertical, horizontal and inclined structures and constitutes one of the more representative plant species of the region), and traditional construction techniques. The rural properties of the CCL are harmoniously integrated into the landscape, where people have used traditional concepts to build homes of low density (Ministerio de Cultura and Federación Nacional de Cafeteros, 2011). In addition to coffee, housing is one of the highlights of the coffee landscape. Additionally, some urban projects can be found in cities of the CCL that involve traditional concepts of building low-density housing.

Based on these needs, the main objective of this research was to evaluate the potential environmental impact of building a social house using local materials and non-conventional water and to compare this with the impact of building a conventional house.

METHODOLOGY

According to the principles of ISO 14040 (2006), the four steps of this life cycle analysis were as follows: goal and scope definition, inventory analysis, impact assessment and interpretation.

Goal and scope definition

In this research, a functional unit equivalent was defined as a square meter of living area, and a dwelling was assumed to have a 50-year life span and four inhabitants. To compare social housing with conventional housing, a conventional house was modeled.

System boundaries

The environmental impact of the simplified dwelling life cycle was evaluated during each building phase as follows: construction, use and end-of-life. The first stage was construction and included the production of building materials, the transportation of materials to

Table 1. Materials and processes used for each dwelling of 45 m^2.

Materials	Units	Category	Suggested value
Domestic water demand	L/day	use	503
Domestic rainwater demand (laundry water use)	L/day	use	136
Domestic graywater demand (toilet water use)	L/day	use	101
Catchment surface (rainwater system)	m^2	use	45
Graywater storage capacity (1)	m^3	use	0.5
Rainwater storage capacity (1)	m^3	use	1

(1)Based on suggested values for social houses by Morales-Pinzón et al. (2014).

the building site, and the determination of the energy consumed during the construction phase (the waste generated at the building site for each of the different construction materials was not included). The use phase included operation and maintenance activities related to energy consumption and water consumption (other household maintenance activities were not considered). During the end-of-life phase, we considered collection rates for stone, metals and plastic of 60, 80 and 80%, respectively, as suggested by Ortiz-Rodríguez et al. (2010). In addition, potential rainwater and graywater use were modeled using Plugrisost software (Morales-Pinzón et al., 2015), with general parameters given in Table 1.

Inventory analysis

The inventory was conducted on one type of social urban dwelling in the city of Pereira, Colombia. This dwelling was a single-family house of 45 m^2 with one floor. This dwelling was built by a GTZ program that supported the reconstruction assistance of vulnerable families in the coffee-growing region of Colombia (GTZ, 2002).

Rainwater and graywater data were processed using Plugrisost software (Morales-Pinzón et al., 2015). The lifetime of the system was defined as 50 years according to the original proposal of Roebuck et al. (2011) (storage tanks, pipes and pumps are 50, 25 and 15 years, respectively). The quantities of materials and energy used by the system were estimated using Plugrisost software. A concrete tank, pipes of polypropylene and a stainless steel pump were selected as inputs.

Precipitation was obtained from historical records for 2008-2014, which were reported by the Red Hidroclimatológica del Departamento de Risaralda (Universidad Tecnológica de Pereira, 2014). To analyze the potential impact of social housing as described by Guinée et al. (2001), Baseline v2.04 CML was used, and the impact categories were as follows: Abiotic Depletion Potential (ADP) (kg Sb eq), Acidification Potential (AP) (kg SO_2 eq), Eutrophication Potential (kg $PO_4{}^{3-}$ eq), Global Warming Potential ([GWP] kg CO_2 eq), Ozone Depletion Potential (ODP) (kg CFC-11 eq) and Human Toxicity Potential (HT) (kg 1.4-DCB eq). The equations and models that support the technical components of Plugrisost software, which included a detailed inventory of the materials and processes for construction (collection, storage or distribution), are shown in Morales-Pinzón et al. (2015).

RESULTS AND DISCUSSION

From the inventory of materials with greater potential contributions (% of mass) to housing construction, it was established that the use of some materials should be reduced when local materials are used. For a non-conventional dwelling or bamboo house, the use of materials such as aluminum, brick, concrete, mortar, alkyd paint and steel decreases compared with conventional dwelling (Table 2). Nearly 90% of brick can be replaced by bamboo pole, and the use of concrete, mortar and steel should be reduced by 46, 23 and 21%, respectively (Table 2). In addition, alkyd paint should be used less because there is less mortar inside the house, and the bamboo is more visible (Table 2). However, the use of 10.2 m^3 of bamboo pole is necessary to construct a new single-family house of 45 m^2 (Table 2).

Considering the percentage of contribution, the total potential environmental impacts for dwellings of 45 m^2 built using conventional materials and local material are similar (Figure 1). The estimated GWPs were 56.2 E +03 and 50.0 E +03 kg CO_2 eq. for conventional dwellings and bamboo houses, respectively. For a conventional dwelling, the use stage has the highest potential greenhouse emissions mainly because of energy use (65%); in the construction stage, 26% of GWP results from the use of concrete (12%), steel (7%), ceramic tiles (4%) and brick (3%). For a bamboo house, total energy use is 73% and bamboo pole (2%), concrete (7%), steel (6%) and ceramic tiles (4%) are the relevant materials used in the construction stage.

The LCA shows the differences between the two systems. The dwelling built with local materials had less impact in the construction stage. The most relevant life cycle phase was the use phase for all five impacts that were analyzed. The human toxicity impact category showed a high impact in the construction stage (Figure 1). Using the impact equivalent per square meter as an indicator, the results show that the estimated GWP for the dwelling built with conventional resources was 1.25 E +03 kg CO_2 eq. • m^{-2} (29.6, 68 and 2.4% corresponded to the construction, use and end-of-life stages, respectively). However, when renewable local materials such as bamboo and non-conventional water resources were used, the GWP was reduced to 1.11 E +03 kg CO_2 eq. • m^{-2} (the construction, use and end-of-life stages corresponded to 23.7, 75.1%and 1.2%, respectively). This can be explained because energy use (being the same for both homes) has a contribution of 65.1 and

Table 2. Inventory of materials and energy for a dwelling of 45 m^2.

Materials	**Units**	**Category**	**Dwelling built with conventional materials (1)**	**Dwelling built with local materials**	**Decrease (%)**
Aluminum	kg	Covering	17.7	0.0	100.0
Ceramic tiles	kg	Covering	900.0	900.0	0.0
Glass	kg	Covering	75.0	75.0	0.0
Roof tile	kg	Covering/Roofing	1920.0	1920.0	0.0
Brick	kg	Masonry	7928.6	750.0	90.5
Mortar	kg	Masonry	3211.0	2470.0	23.1
Bamboo pole (2)	m^3	Structural material	0.0	10.2	-
Steel	kg	Metals	1767.9	1400.3	20.8
Alkyd paint	kg	Painting	7.9	6.1	22.8
PVC	kg	Pipes, wiring	141.2	141.2	0.0
Concrete	m^3	Concrete	26.0	14.1	45.8
Water use	m^3	Construction stage	285.1	160.4	43.7
Energy consumption (3)	kWh/year	Use	1560 - 1800		-

(1)Estimated from Ortiz-Rodríguez et al. (2010) and Legis (2014). (2 Adapted for local bamboo (*Guadua angustifolia* Kunth) using the life cycle inventory of *Zea Escamilla* and Habert (2014). (3)The Colombian electricity mix for 2012 is based on the data from Sistema Interconectado Nacional Colombiano (UPME, 2014).

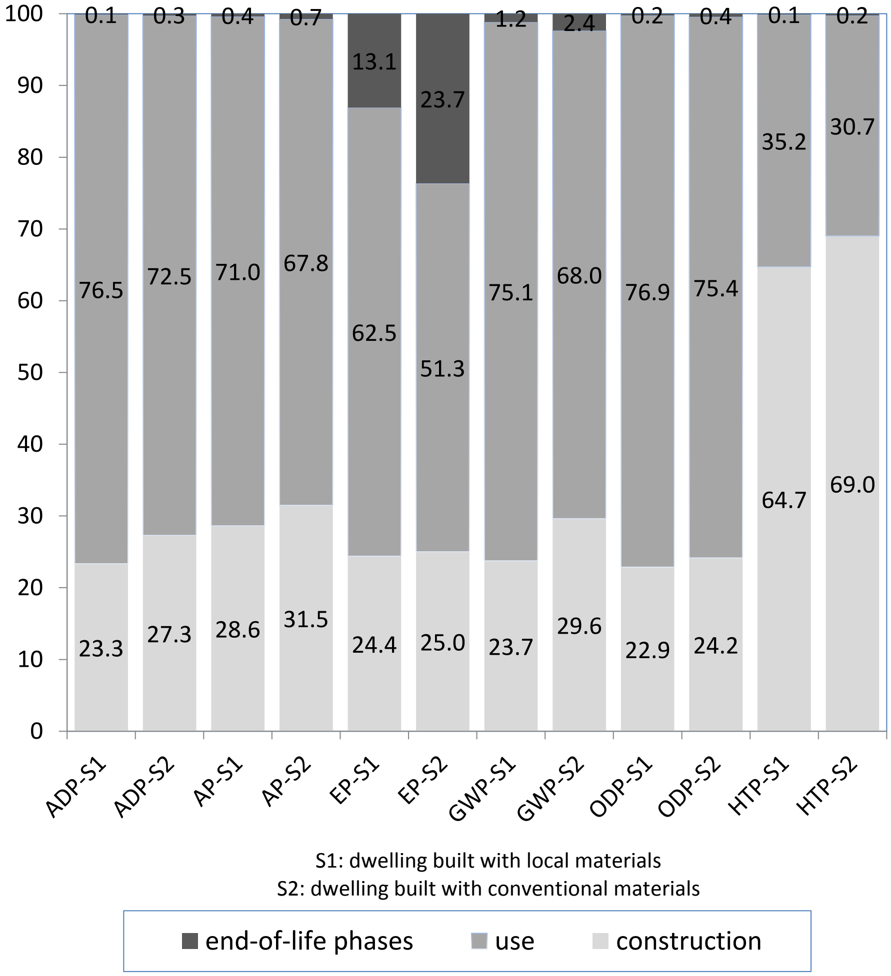

Figure 1. Potential environmental impacts of dwellings using the CML2001 method.

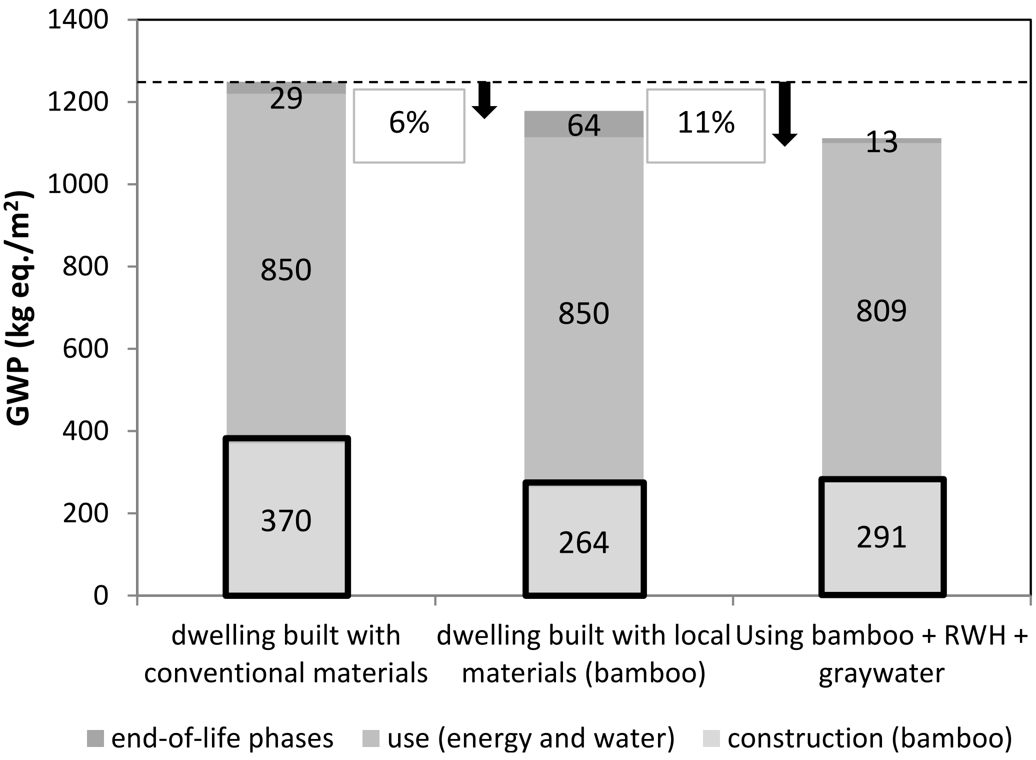

Figure 2. Global Warming Potentials of different configurations of the system using local or conventional materials.

75.1% for conventional and bamboo houses, respectively, and the savings are given for materials and non-conventional water use. Similar results were obtained for other indicators of conventional and bamboo houses, respectively: ADP (6.85E+00 and 6.66E+00), AP (3.01E+00 and 2.72E+00), EP (6.81E-01 and 5.43E-01), ODP (8.12E-05 and 7.43E-05), and HTP (6.26E+02 and 5.44E+02) (Figure 1).

The use of local materials can reduce some potential environmental impacts. Using bamboo, the avoided potential environmental impact was estimated to be 71 kg CO^2 eq. • m^{-2} (5.7%). When the potential use of rainwater and graywater was considered, the GWP was reduced by 137 kg CO_2 eq. • m^{-2} (10.9%) (Figure 2). These results should be included in the social aspects analyzed by Morales-Pinzón et al. (2012), who described how the social strata in Colombia affect the potentially available rainwater resources in different housing projects.

In general, the aforementioned results are comparable with those presented by Ortiz-Rodríguez et al. (2010), who estimated the GWP for different dwellings in Colombia to be 8.62E+02 kg CO_2 eq. • m^{-2} and Morales-Pinzón et al. (2014), who estimated an avoidable GWP of 3.12E+01 kg CO_2 eq. • m^{-2} using non-conventional water resources.

Using rainwater and graywater can achieve significant environmental benefits. The results of the simulation conducted for the selected dwelling estimated that a minimum storage capacity of 0.5 m^3 was sufficient to meet 100% of the demand for graywater. Considering a significant change in the slope of line from a graph, and by means of data for drinking main water (Angrill et al., 2012), each cubic meter of harvested graywater can reduce Global Warming Potential by 0.45 kg CO^2 eq. (Figure 3A). In addition, for a house with an effective surface area of 45 m^2 for collecting rainwater in the climatic conditions of the city of Pereira (annual rainfall of 2,258 mm and bimodal regime), a storage tank of 1 m^3 can reduce potential emissions by 0.14-0.71 kg CO^2 eq. • m^{-3} (an average of 0.28) of harvested rainwater (Figure 3B).

Conclusions

Dwellings built with local materials have a lower environmental impact and can last over time, even in urban areas, where the uses of conventional and new materials (no traditional or local materials) predominate. This type of dwelling will also generate benefits in environmental terms and represents an opportunity to address the shortage of social housing, because the resources needed for housing are optimized as well as an opportunity to involve families through self-management.

Local renewable materials such as bamboo and the use of non-conventional water sources such as rainwater

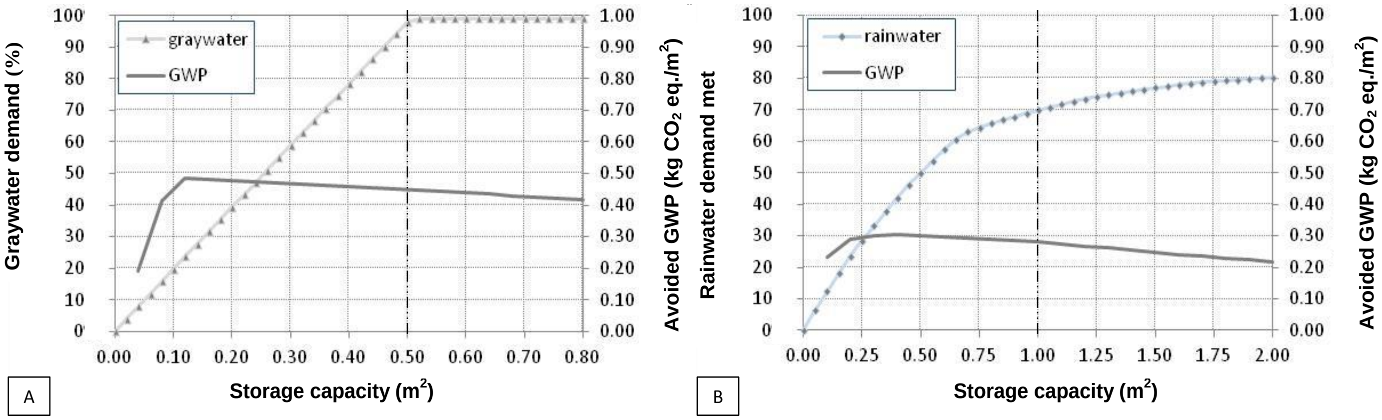

Figure 3. Simulation results of rainwater and graywater systems.

and graywater reduce the potential environmental impacts of housing. These reductions occur in all stages of building but mainly involve the construction and use phases of the life cycles of dwellings.

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Conflict of Interests

The authors have not declared any conflict of interests.

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