LIFE CYCLE ASSESSMENT OF TRADITIONAL VS INDIGENOUS MATERIALS

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SUMMARY

This paper is based on an accounting style life cycle assessment (LCA) that was performed comparing conventional steel and concrete block construction against the use of indigenous materials. The premise of this study is to work towards providing low-cost eco-friendly safe housing to populations in developing regions. The various parts of the LCA are described, including previous work, scope, life cycle inventory (LCI), impact assessment, and finally the improvement assessment along with conclusions and recommendations.

INTRODUCTION

In developing regions, affordable, safe housing that is eco-friendly is not readily available. The process of urbanization traditionally goes hand in hand with the improvement of economic, as well as social progress, including the improvement of education, literacy, and health. However, with the rise of rapid urbanization in these developing regions, a handful of problems, such as the development of high-density 'slum' areas inevitably occur. Housing in these areas not only suffers from unsanitary conditions leading to the proliferation of disease, but is also generally unsafe in terms of shelter from storms and seismic events. It is a huge task of governments and individual municipalities in these regions to find a balance between economics and safety for future housing projects.

It was estimated that as of 1993, only 73% of all housing structures in developing regions were permanent structures, and only 63% of all those structures were in compliance with their respective building regulations. [UNCHS (Habitat), 1998] Housing problems in developing regions have also been exacerbated by choices made that were lacking in the use of the abundant unskilled labor, the poor development of housing technology, as well as the adaptation of inappropriate housing policies and construction standards. [Moavenzadeh, 1979] Urban growth in developing regions is expected to place extraordinary strain on existing infrastructure and it is predicted that by 2020, nearly three quarters of the world's urban dwelling population will be living in developing regions. [United Nations, 1996c] Estimates on the need for housing in these regions are in the order of 35 million units annually from the year 2000 to 2010, and 39 million units annually between the years 2010 to 2020. [UNCHS (Habitat), 1999]

One obvious solution for providing safe housing is to simply import conventional construction materials such as concrete, brick and steel and construct safe housing according to acceptable building standards. However, Life Cycle Assessments of residential dwellings in the past have indicated that concrete alone can account for over fifty percent of the embodied energy of the materials used for construction [Asif et al., 2007]. Note that these assessments considered only the material themselves and didn't account for the added impacts associated with the transportation of these materials.

The use of wastes, and many indigenous building materials are still in the research phase. One such example is at the University of Central de Las Villas, in Santa Clara, Cuba, where local agricultural waste and clay has been used to produce a cheap fuel source, dubbed the Solid Fuel Brick (SFB). [Seijo et al., 2002] Not only could this technology provide a cheap energy source, but the byproduct of burning is an ash that has great potential as a cement replacement, which would reduce both cost as well as energy requirements in producing concrete, mortar, and grout.

Thus, the intent of this study was to provide an accounting style life cycle assessment (LCA) for two cases of buildings in developing regions: those using conventional materials including concrete block and steel, and those using indigenous materials, including block with indigenous cement replacement and bamboo reinforcing. Bamboo has been shown to be an effective alternative to steel reinforcement in concrete [Ghavami, 2005], and the assumption is made that it can do the same in masonry. By comparing the two cases, an indication of the potential impacts of using indigenous materials can be assessed.

PREVIOUS WORK

Over the past decade, there has been a significant increase in public awareness of the necessity for sustainability in construction projects. Mainstream approaches to 'green' building design have started to emerge, with the help of the U.S. Green Building Council (USGBC) and its Leadership in Energy and Environmental Design (LEED) program. The USGBC defines the LEED program as "promot[ing] a whole-building approach to sustainability by recognizing performance in five key areas of human and environmental health: sustainable site development, water savings, energy efficiency, materials selection, and indoor environmental quality." [USGBC, 2007]

While LEED promotes a general guideline for new buildings as well as building renovations, it does not fully take into consideration the life cycle of buildings. There is, however, an abundance of literature available to practitioners that gives guidelines on the LCA process. The Hitch Hiker's guide to LCA gives a general synopsis of life cycle assessments from all facets of environmental design. [Bauman et al., 2004] The Canada Housing and Mortgage Corporation has funded a special report guideline "Life Cycle Assessment Methods for Buildings." [CMHC, 2004] Annex 31 of this report gives direction on areas such as accounting for local impacts, maintenance scenarios, allocation problems, building related transportation, as well as in the analysis of groups of buildings.

Specific case study assessments in the construction industry are also widely available, some focusing on the whole building life cycle, while others focus more on specific aspects of the building. [Trust et al., 2003; Koroneos & Kottas, 2007; Hendrickson et al., 2006] Most of these

studies present accounting based LCAs where two or more material choices are compared and contrasted. In others, a specific building component is analyzed with current construction practices, such as wood components in steel and concrete structures. [Eriksson, 2003]

There are also a number of studies that have been performed solely on the life cycle of the construction materials. One such study was performed on construction materials for roads and bridges in which asphalt and reinforced concrete road surfaces were compared, as well as steel and concrete girders in bridges. [Hendrickson et al., 2006] It was found that due to the many complexities in road systems, that the results were dependent on the maintenance needed for roadways, and the eventual life span of each system. Another study focused on the environmental impacts of brick production in Greece, breaking the processes into highly specific tasks rather than taking a 'big picture' approach thereby revealing the complexities of boundaries for LCAs [Koroneos & Dompros, 2007].

In the case of residential housing, a case study of a single unit dwelling in Scotland looked at the embodied energy of the construction materials used, and found that the concrete of the building alone accounted for 65% of the total energy and a similar percentage of environmental impacts. [Asif et al., 2007] Another study comparing three different methods of construction - wood, steel and concrete - for a 2400 sq. ft (223.0 m^2) single family home, illustrated the differences and respective environmental impacts for the different methods of construction. [Trusty et al., 2003] A study done on a model house in Thessaloniki, Greece looked solely at the energy consumption of residential buildings in service. [Koroneos & Kottas, 2007]

Life cycle assessments, and the concept of 'green' buildings are relatively new concepts, and therefore there is still much debate about exactly how assessments should be conducted. It has been stated that the current green building scene is "characterized by clutter and confusion". [Trusty, 2003] The methods used to undertake the LCA presented here are valid, however, there are many ways that the same study could have been completed. The work presented here is meant to give a general idea of the impacts that would potentially be associated with the use of indigenous materials in building construction.

SCOPE OF WORK

As mentioned previously, the objective of the study presented here was to compare two different types of housing systems, considering the entire useful life of the structure. The first of these housing options is a building using conventional concrete block, and steel rebar, both of which would have to be imported to the region. The second option is to construct the house using local masonry materials and bamboo as reinforcement.

Setting the boundaries to conduct an LCA on any building or construction process is always a challenge. For the size of this study to be manageable, aspects of the construction of the non-conventional housing had to be left out and some simplifying assumptions had to be made. Only the structural skeleton of a single family housing unit and only impacts from the materials and their transportation to site were considered for this study. The assumption was made that the same details and materials would be used for the building envelope, and that the construction,

usage and demolition phases would be the same for each building. Therefore, the boundaries of this study were set so these aspects were not included in the model.

The final major boundary condition of this study was that of geography. While the purpose of this research is to aid developing regions, availability of data from these regions is scarce. To simplify this, it was decided to use data from American sources, and to assume that the place of construction would be on the island of Puerto Rico, an unincorporated territory of the United States. It was also assumed that for the case of conventional materials, that they were transported to the construction site from the State of Florida. Simplified flow diagrams of the processes within the boundary conditions for both cases of construction are shown in Figure 1.

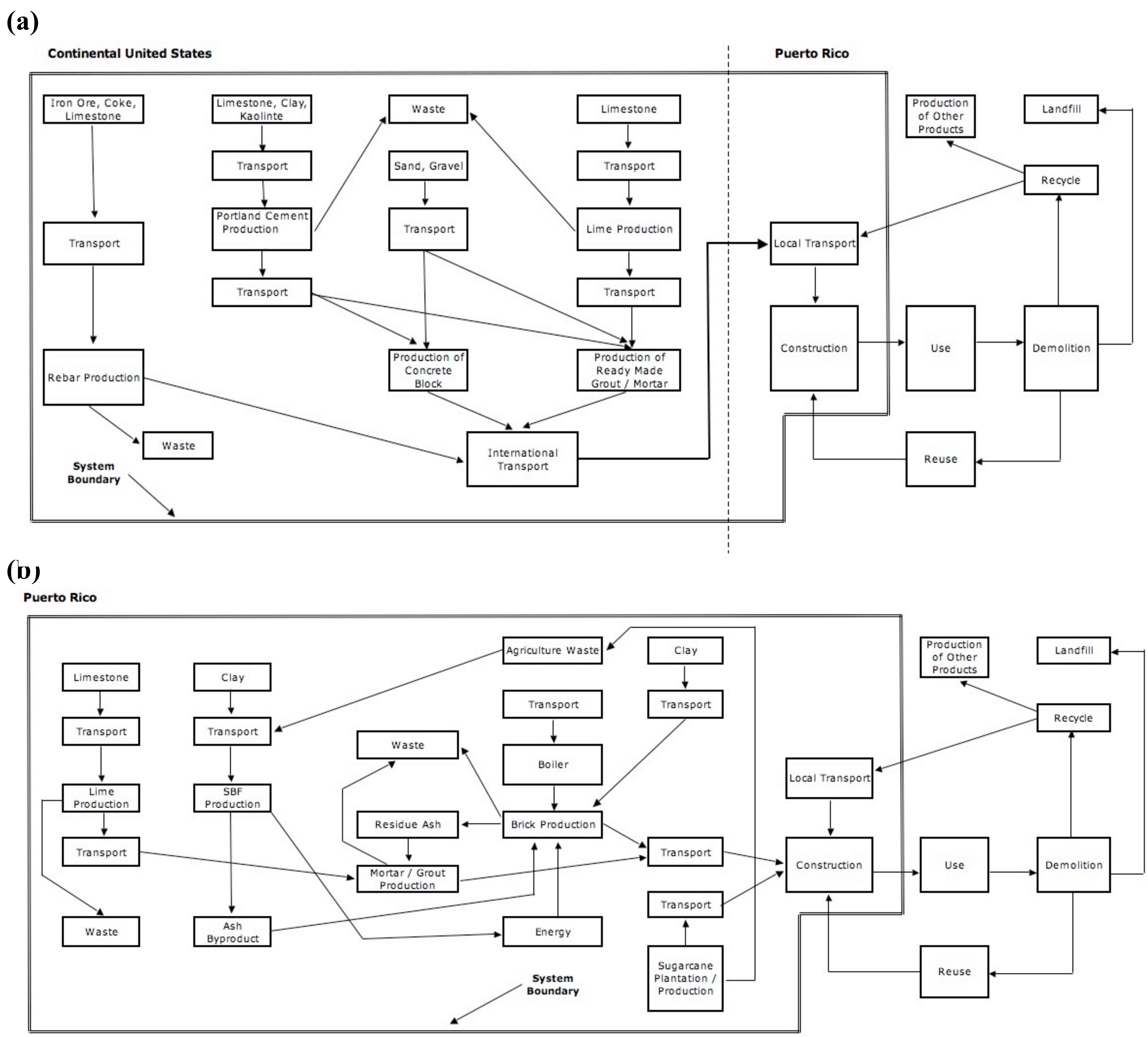

Figure 1 – Simplified Flow Diagram for: a) Conventional Material Use b) Indigenous Material Use

In order to compare the economic and environmental impacts associated with each type of construction, the quantity of building materials per each house (functional unit) was calculated. Both houses were designed to the same strength, and to all applicable building code standards. From these material quantities, and inventory of the emissions, as well as embodied energy of each house was calculated.

STRUCTURAL DESIGN

The first step in conducting this LCA was the design of a standard house. A two-storey house with a total area of 160 m^2 was designed, as shown in Figure 2.

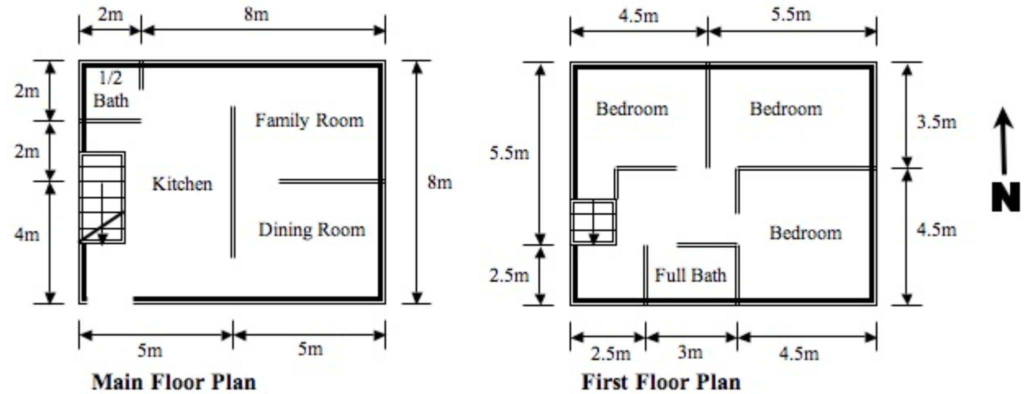

Figure 2 – Architectural Plan View

After the architectural design was finished, a structural design was completed for each set of materials. The seismic loading on the structure was calculated using the provisions of the National Building Code of Canada. [NBCC, 2005] It is standard to use lower strength materials, in the case of residential construction, as opposed to commercial construction. To simplify calculations using this fact, only one seismic design was done for both houses. The loads found were used in the structural design of both buildings. No wind loading was calculated for this study, as it was assumed that seismic loads would govern.

Once the loading for the building was determined, a structural design for each building type was performed. For the conventional steel and concrete block case, the provisions of the CSA Design of Masonry Structures Standard [CSA, 2004] were used. It was found that the conventional building required steel reinforcing of 10M bars spaced at 400 mm in the vertical direction, and 10M bars spaced at 500 mm in the horizontal direction. For the case using local masonry supplies and bamboo reinforcement, a combination of CSA Standard S304.1-04, and the work presented by Brink et al. [1966] were used. It was determined that 1” culms spaced at 100 mm on center were needed for both horizontal and vertical reinforcement.

Two separate structural designs were completed, and a quantity of materials for each of the houses was calculated. This data is the basis for the comparison and was used as input to the life cycle inventory assessment (LCI).

LCI METHOD & RESULTS

All of the data for this study comes from the Carnegie Mellon University Green Design Institute's EIO-LCA database. [GDI, 2007] While there are other databases that could be used, this gave the most complete set of data. The one downfall with this database is that it relates output to the economic cost of the input. Therefore, estimates on the cost of individual processes had to be made for the input. To verify these estimates, the outputs were compared to the outputs obtained using data from the National Renewable Energy Laboratory's (NREL) U.S. Life-Cycle Inventory Database [NREL, 2007] a mass input database. By using the data from the NREL database, the data from the EIO-LCA model was calibrated.

There is a lack of available life cycle data for local and waste materials, therefore assumptions had to be made. An allocation of agricultural farming in the EIO-LCA database was used in the production of indigenous masonry materials, as the byproduct of burning the crop is a cement replacement. Data for the production of sugarcane was assumed to apply to the production of bamboo due to lack of data for the latter. Emission data for burning of an indigenous fuel source such as the SFB, as opposed to oil resources is not directly available, therefore the amount of energy that was output by the SFB [Seijo et al., 2002], was assumed similar to the burning of wood, and an estimate was made on its emissions.

The only transportation accounted for in this model was the shipment of materials from the Continental US to the island. It was assumed that the local transportation within Puerto Rico would be the same in both cases, and this study is a relative comparison. It was decided that three modes of transportation would be used: rail transport from the respective production facilities to the coast, ship transport to the island, and finally truck transport on the island to the construction site.

Combining all of these factors together, a model was formulated which was deemed to be the best representation of the two housing cases, for the constraints of the study. Quantities of emissions were calculated for each type of building, and tabulated. The use of conventional materials showed higher quantities of energy usage, greenhouse gas emissions, as well as toxicological substance releases. The data from this inventory stage was then used to conduct the impact assessment of the LCA.

IMPACT ASSESSMENT

In all impact assessments there is uncertainty in the output at the inventory assessment stage. In this study, the estimated costs could vary greatly, thereby giving unreliable results. To correct this, a sensitivity analysis was performed, to determine which elements of the model have the greatest impact on the results. The two elements that showed the greatest sensitivity in the model's output were the price of lime, and the transportation cost.

It was assumed that lime was the main binding ingredient of the local masonry. Increasing the cost of lime in the model led to increased impacts coming from the local material house.

However, when a break-even analysis was attempted, it was shown that the cost of lime would have to be increased to unrealistic values to have the same impact as the conventional materials. Therefore, in the assessment, the impacts using the original estimate of lime price as well as a 150% increase of the original value are used to give the reader a broader understanding of the values.

The same type of analysis was carried out for the transportation costs, where only the distance that materials had to be transported was varied. Once again, a break even analysis was conducted, however, even when the transport distance was set to zero for all forms of transportation, the impacts when using local materials were still lowest. Therefore, all impacts are shown for two cases: with the original distance assumed and with no transportation of conventional materials.

Finally, all the results were normalized in order to provide a general comparison of conventional versus local materials rather than to give exact amounts of releases to the environment, or of energy used. These values were normalized to the base case in which indigenous materials were used with the original cost of lime estimates.

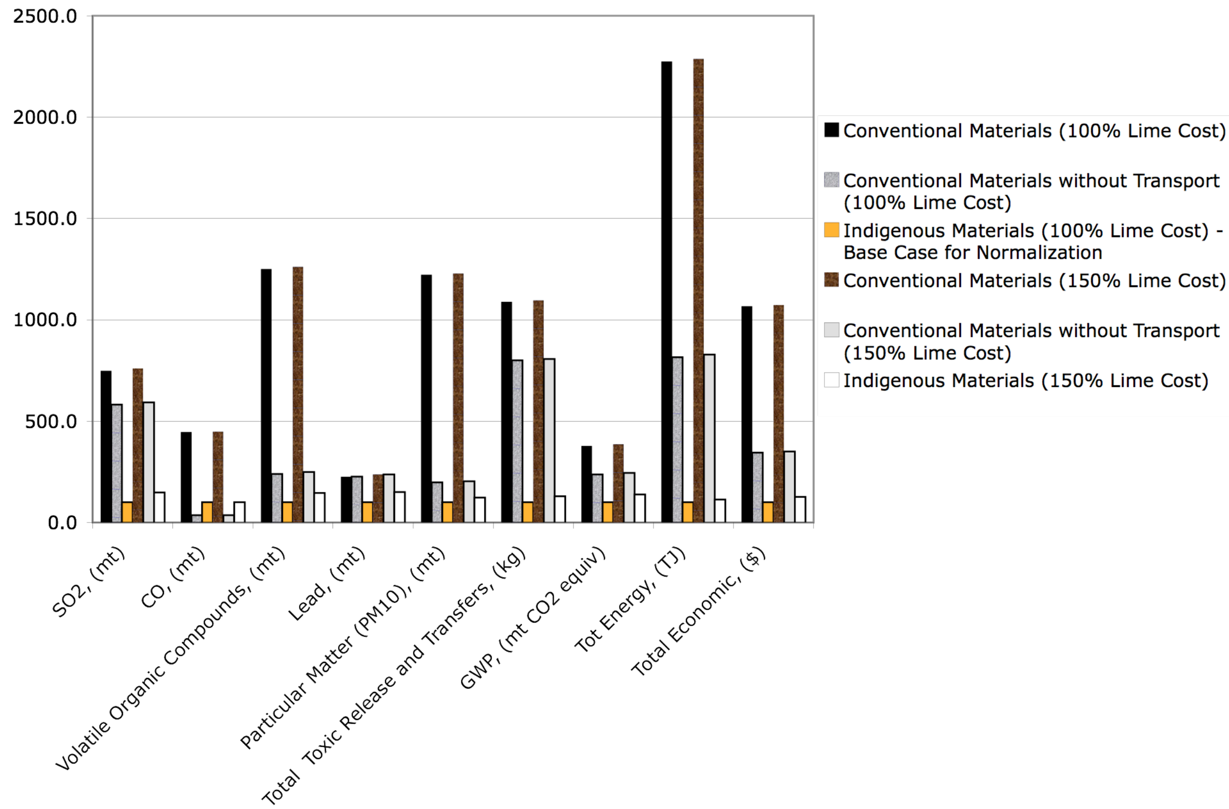

Figure 3 – Normalized Summary of Impacts

Figure 3 shows the normalized toxic releases to the environment. It may be observed that the toxic releases are not broken down into specific ecological, or human health issues. This is mainly due to the complexity of classifying the potential impacts. One source writes, “As [of]

yet, there is no coherent framework for characterizing the toxicological impacts [of] pollutants, but research and methodology development is in progress internationally [Baumann et al., 2004]." What can be concluded from this information is that in almost all cases, the use of indigenous materials cuts the released toxins into the environment by half. These results also show the amount of pollutants released into the environment that are directly associated with transportation. Therefore, through the broader use of indigenous materials, there should, in theory, be less human health and ecological issues to deal with resulting from toxins and pollutants in the atmosphere.

Other impacts shown in Figure 3 include the normalized results for a few specific emissions, total energy used, green house gas emissions as well as the total direct economic indicator. It can be noticed immediately that transportation has adverse effects on all three of the major impacts: economic, energy usage and green house gas emissions. Even with no transportation of conventional materials included, there is significant savings across all of the indicators. Specifically, there is approximately 30-50% reduction in the green house gas emissions when using indigenous construction materials. Developing regions are least likely to be able to deal with the consequences of global warming, such as rising water levels, therefore it is in their best interest to reduce greenhouse gas emissions as much as possible. From the results in Figure 3, it is also observed that there is a reduction in both energy use, and total economic impact. Not only do indigenous materials have potential to be cheaper to produce in today's economy, but they have the greatest potential to stay affordable if world energy prices continue to rise.

IMPROVEMENT ASSESSMENT

While this study gives us an idea of the relative effect of using indigenous materials rather than conventional materials on environmental impacts and economic indicators, it is far from complete and does not give any indication of the absolute effect. One of the main reasons for this is the uncertainty in the performance of housing constructed using indigenous materials. The properties of potential indigenous reinforcing materials such as bamboo and sugar cane, and the performance of structures using these materials have not yet been widely researched. While every effort has been made here to capture the actual behavior, the methods used require further research and testing in order to ensure their validity and accuracy.

Additional assumptions were made that the local construction materials could be produced on site with minimal transportation, using a de-centralized system. However, it is possible that logistically and economically, a centralized system may be more beneficial. Once this were determined, a more accurate study could be conducted.

It would also be desirable to increase the number of potential materials in future studies to include steel and other new emerging technologies such as fiber reinforced polymers (FRPs). With significantly different structural materials, there is likely to be a great difference in the building envelope system. If this were the case, it would also be necessary to increase the boundaries of the study since the differences in the use and disposal phases could have greater effect.

This study is also restricted in the fact that the output of the model was limited to the categories and output releases that were present in Carnegie Mellon's EIO-LCA database. As LCA databases are relatively new, data is not readily available covering a wide range of materials including waste and many indigenous materials. As research continues and more data becomes available, the efficacy of LCA will be greatly improved.

A final note on future improvement of this type of assessment is that this particular study is presented as a general case for developing regions. Each region may have its own unique environmental concerns that would be pertinent to include in such a study. For example, for a region that has a large amount of freshwater lakes, and is very dependant on fish resources, the environmental impact of acidification would be extremely important. With continued research on building materials, the generalized impacts could be extended to account for the specific needs and socioeconomic factors of a given region.

CONCLUSIONS

From a general viewpoint, this study shows that indigenous materials have the potential to replace conventional materials in the construction of safe, storm proof housing. This study suggests not only that the economics of using indigenous materials makes sense, but also a handful of other indicators show that the use of these materials could be preferable. Compared to the use of conventional materials such as Portland cement, and steel reinforcing, they also use less energy, contribute less to greenhouse gas emissions, and release less toxins to the environment. From this general study, it is recommended that further research be continued so that the true advantages of indigenous materials can be determined, and this construction method can eventually become a viable option for residential constructions in developing regions.

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