A Lifecycle Assessment of Composite Material Homes for Disaster Areas such as Haiti

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Post-disaster construction is often meant to be temporary, lasting only a few months until new homes can be built and people can move into more permanent structures. However, as demonstrated in disaster after disaster, emergency housing often remains well after a disaster has ended. To address this issue, the MIT Department of Architecture along with industry partners is designing composite material homes which can be quickly deployed and built as well as provide longer-term housing in affected areas. This study was performed in order to establish the environmental impacts of the design and to quantify them in comparison to a typical concrete-masonry home built in Haiti.

This initial analysis confirms what the MIT and Stanford teams had hoped—the use of composite materials in buildings results in less energy and material inputs and lower emissions than the closest alternative of concrete masonry. As the project develops and more information becomes available, it will be necessary to consider the full life cycle yet it will be simple to build upon this existing, preliminary analysis. This project might also benefit from other forms of analysis, such as an Environmental Impact Assessment to examine the impacts of the material on the ground at a specific site. Examining this project through the "green building" or LEED lens would also be beneficial. Finally, social aspects (e.g. is the house desirable to Haitians?) should also be considered. Although more analysis is necessary, composite housing has the potential to meet disaster housing needs in an innovative, eco-conscious way that could potentially revolutionize the building industry.

Introduction—

Background:

Post-disaster housing construction is often meant to be temporary, lasting only a few months until new homes can be built and people can move into more permanent structures. However, as demonstrated in disaster after disaster—and most notably by the thousands of FEMA trailers still parked around New Orleans since Hurricane Katrina—emergency housing often remains in place well after a disaster has ended. To address this issue, the MIT Department of Architecture along with industry partners is designing composite material homes which can be quickly deployed to affected areas and constructed on site. These designs will provide longer-term housing in addition to short-term relief.

In early 2010, Professor Mark Goulthorpe and a team of architecture students began work on assessing the design, materials, and modeling of these composite material houses. The overriding goal of the project is to develop a parametric design where one can easily input the structure's dimensions, produce the composite material onsite, and readily build a house. The composite house could be used in disaster relief situations as well as for commercial purposes. Following the example set by the boat-building industry, they hope to move the building construction industry from a segmented model to a more streamlined model where an individual or small group can design and build an entire house (enabled by the use of strong, light composite materials). In addition to creating more long-term livable housing for disaster areas, the team wanted to better understand how the design might impact the environment. In order to answer questions about the potential environmental impacts, a team at Stanford University, led by Michael Lepech has conducted this lifecycle assessment.

The Products:

In this lifecycle assessment, we analyzed an extremely simplified model of the composite house being designed by the MIT Architecture department. We assumed a design with a 20' X 8' footprint and 8' tall walls with a flat ceiling. It is essentially a box with no windows or doors. By comparing this house made out of concrete-masonry with the same house made out of the composite materials, we can better understand which components of the design contribute the most to pollution, energy consumption, and other factors of interest.

Objective and Scope:

There are two objectives for this life cycle assessment. The first is to evaluate and compare the life cycle and embodied energy of the composite material house to the concrete-masonry house to determine which is a more sustainable building option. We will be using SimaPro LCA Software to determine the net inputs and outputs for each product, including materials, energy consumption, waste, and environmental impacts. The scope of this project will cover the entire life cycle: raw material acquisition, material processing, manufacture and assembly, use, and disposal. The second objective is to inform the future design process of the composite material construction. As we determine the areas of greatest impact, we can give greater input into how to further reduce those impacts.

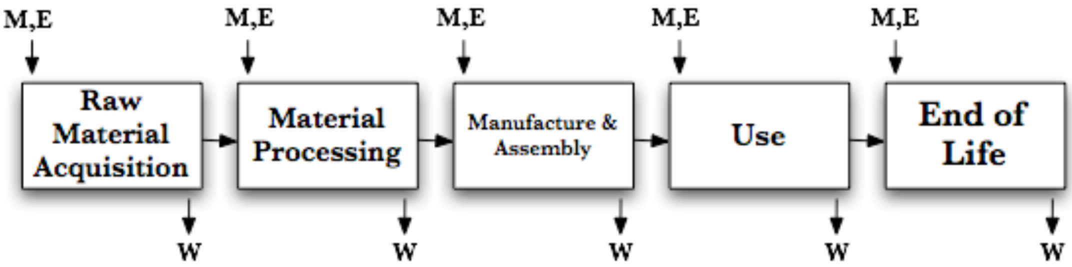

Figure 1: Diagram of the scope of our project starting with Raw Material Aquisition and ending with the End-of-Life/Disposal phase. Note that in this version of the LCA, only Raw Material Acquisition, Material Processing, and Manufacture and Assembly are covered by the analysis. In future versions of this LCA, the Use and End of Life disposal/recycling stream will be more extensively examined.

Functional Unit:

The functional unit we will use in this LCA is a single house of the following dimensions:

—20' X 8' Floor and Ceiling

—8' tall walls

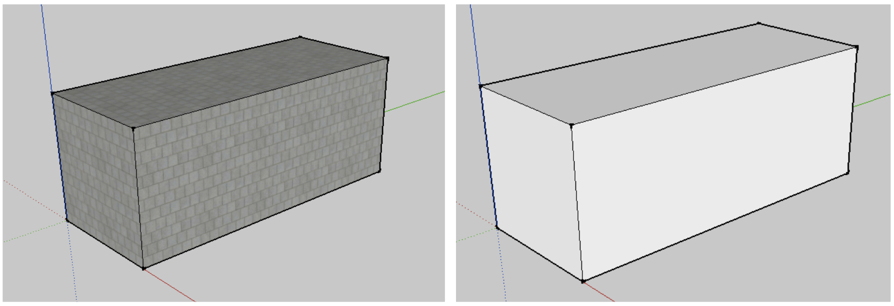

Figure 2: Two images, showing a simple model of the functional unit (concrete masonry on the left, composite materials on the right).

This study assumes that the panels making up the walls are 4" thick and the panels representing the ceiling and floor are 6" thick. Each panel is 4' X 8' and is joined using tongue-and-groove joints with extruded edges at the end of each panel. The concrete-masonry construction is made up of block on the walls and the floor and ceiling are made up of reinforced concrete. The edges of the concrete-masonry construction are reinforced concrete columns/pillars.

Because this study does not currently examine the use and end-of-life phases of the lifecycle, these are not currently modelled. The eventual goal of this project will be to take inputs from MIT's models and instantly generate an LCA for several different designs based on the various parameters which may be adjusted in the design phase. This will enable rapid feedback in terms of environmental impacts during the design and prototyping phases.

Methods—

We used SimaPro 7.2 Multiuser software to conduct a process-based life cycle assessment according to the ISO 14040 LCA standards (modified for the moment to exclude use and end-of-life). The first stage of this assessment included compiling an inventory of relevant energy, transportation, and material inputs, as well as throughputs and waste types. This information was used to construct process flow diagrams for each product. The process flow diagrams indicate the scope of the assessment, which in this project was the full life cycle of the systems. As mentioned above, the analysis includes all phases from raw material acquisition to final disposal. The outputs to the environment could then be calculated using SimaPro and this raw data was analyzed to provide quantitative differences in the impacts of each product.

Composite House Assumptions:

The panels are made of GLASS POLYPRO and expanded polystyrene (EPS). Fiber Glass Industries uses patented Twintex technology to create woven glass polypro. Sand, clay, and limestone are first melted together to make glass, then extruded to generate fine glass fibers. The polypropylene is also extruded into fibers, and is then commingled into larger strands of glass polypro. The glass polypro is then woven into the final product, GLASS POLYPRO, and is delivered by truck to AS Composites. All percentages in the process flow diagram are by mass.

The panels are put together at AS Composites. Two sheets of GLASS POLYPRO (either 1.0 or 1.5 mm thick) sandwich an EPS core (either 4” or 6” thick) to form a panel. The panels can be 4 or 8 ft wide. In order to make a panel, the glass polypro is first unwound. Heat is applied to two sheets of glass polypro to the sides that will eventually form the outside surfaces of the panel. Next, the skin is fed continuously through a set of rollers that apply pressure. The inside surfaces of the two sheets are then heated, and pressure is again applied to laminate to the core. The panels are then trimmed with a loss of 5-7% per panel. The scraps can be recycled by shredding and extruding to form reinforced polypropylene foam. This recycling process, however, is under development and it is not yet determined if the recycling will occur in Haiti or elsewhere. One machine performs all of the functions necessary to produce a panel, and the operation is continuous. Once the machine is up and running, power consumption decreases slightly. Overall, in one 120-minute shift, the machine consumes 365 kW and produces 420 running feet of panel.

Material inputs of glass polypro and expanded polystyrene were calculated based on the functional unit. The panel manufacturer, Hossein Borazghi, provided the density of the materials to calculate the mass of the input. The chart below shows the material input for the different panel sizes. Once the skin and core are bound, the panels are trimmed. We assumed a 5% waste rate where unspecified. Packaging, transport, diesel generator, and other necessary equipment were included in the calculations. Table 1 (below) shows the assumed amounts of material inputs to make the various panel sizes.

Panel Size	GLASS POLYPRO (1480 kg/m^3)	EPS Core (54 kg/m^3)
4’ x 8’ x 4”	9.26 kg	15.99 kg
4’ x 8’ x 6”	13.89 kg	25.25 kg

Table 1: Amounts of material inut for each panel size.

Haiti-Specific Assumptions:

This lifecycle assessment was conducted on the basis that the panels would be assembled into a final house in Haiti. This requires further transportation assumptions and the transportation of a significant portion of the equipment required to produce the panels. For the panels, we assumed that the raw materials required to make the panels would all be shipped to AS Composites in Québec, where the panels are currently manufactured. Then, the materials and the machinery would be shipped to Haiti by ship. The materials would be made into panels and the panels built into houses on site in Haiti. The house would be secured by large foundation screws instead of a concrete slab.

For the concrete-masonry house, we assumed that the materials would come from a variety of locations both inside Haiti and the Dominican Republic. The average assumed transportation distance was 100 km by truck.

Results—

Environmental impact is difficult to quantify directly with one number, since each impact has a different effect, and are often prioritized differently. Therefore, we categorized the environmental impacts of the eleven products using SimaPro, which measured each impact using the following categories: greenhouse effect, ozone depletion, acidification, eutrophication, heavy metals, carcinogens, summer smog potential, and winter smog potential. Overall, the composite house (without foundation) demonstrated greater sustainability in all categories, with the exception of two models compared to the concrete masonry house (without foundation). Below is an overview of the significance of each category, as well as a quantitative comparison of the results from each product.

Greenhouse Gasses

Greenhouse gas emissions are measured in carbon dioxide (CO_2) equivalent emissions. Greenhouse gasses such as carbon dioxide absorb energy and radiates it back into the atmosphere in the thermal infrared range. Since the IPCC published its Fourth Assessment Report: Climate Change 2007, the anthropogenic nature of climate change has become a well-established fact in both the sciences and general population. This has led to an increasing awareness of greenhouse gasses among the business community, where greenhouse gas emissions have become the first and primary identification of the level of sustainability of a product.

Particularly in our analysis, greenhouse gas emissions largely correspond to energy consumption. The composite house (without foundation) has less than half the of the greenhouse gas emissions of the masonry house (without foundation)—with emissions of 2,715 kg CO_2-e, where the masonry house was at 7,989 kg CO_2-e. Composite and masonry house with steel-base foundation screws show greenhouse gas emissions at 4,933 kg CO_2-e and 10,182 kg CO_2-e respectively. With the foundation, greenhouse gas emissions from the composite house nearly doubled mostly due to the energy intensity of steel manufacturing. Another advantage of the composite house is its significantly lighter weight compared to the masonry house, which decreases emissions from transportation.

Ozone Depletion

Ozone depletion is measured in trichlorofluoromethane (CFC-11) equivalent emissions. The ozone layer in the stratosphere blocks much of the harmful rays from the sun. What is called the ozone hole is actually a thinning of the ozone layer over Antarctica, caused by anthropogenic chlorine and bromine compounds that react with UV rays and ozone to break apart the molecules. The Montreal Protocol on Substances that Deplete the Ozone Layer became effective in 1989, and since then has been successfully implemented as compounds that are destructive to ozone have been internationally phased out from direct production and use. However, these compounds are also byproducts of high-energy reactions and can be created by electricity generation and internal combustion engines in low quantities. Thus, ozone production is highly correlated with electricity use and transportation.

The composite house has an advantage over the masonry house—showing emissions at 0.0014 kg CFC-11-e, while the masonry house was at 0.0023 kg CFC-11-e. Composite and masonry house with steel-base foundation screws show higher emissions at 0.0023 kg CFC-11-e and 0.0031 kg CFC-11-e respectively.

Acidification

Acidification is measured in sulfur dioxide (SO_2) equivalent emissions. SO_2 and other acidification chemicals react with other common compounds such as water to release more protons into the atmosphere. These acids can enter soils, surface waters, and oceans through acid rain or other transport mechanisms, and the resulting lower pH can be detrimental to both flora and fauna.

In acidification, the composite house has an advantage over the masonry house—showing emissions at 17 kg SO_2-e, while the masonry house was at 31 kg SO_2-e—nearly double of the composite house. Composite and masonry house with steel-base foundation screws show higher emissions at 27 kg SO_2-e and 39 kg SO_2-e respectively.

Eutrophication

Eutrophication is measured in phosphate (PO_4) equivalent emissions. Nutrients such as phosphate and nitrogen are necessary in plant growth, but the increasing availability of these can cause blooms of algae, which are simple organisms that can take up these nutrients most quickly. However, algae growth and death can monopolize the dissolved oxygen in water systems and choke fish and wildlife. Some algae also produce toxins that can accumulate and harm people as well as animals.

The composite house has lower eutrophication emissions than the concrete masonry house with emissions of 1.5 kg PO_4-e, while the masonry house was at 2.51 kg PO_4-e. Composite and masonry house with steel-base foundation screws show higher emissions at 2.16 kg PO_4-e and 3.13 kg PO_4- respectively.

Heavy Metals

Heavy metals are measured in lead (Pb) equivalent emissions. Heavy metals can accumulate in the body and can cause health problems such as developmental issues in the case of lead, and kidney stones in the case of cadmium. Some common sources are mining and purification of metals.

The composite house has lower eutrophication emissions than the concrete masonry house with emissions of 0.01 kg Pb-e, while the masonry house was at 0.42 kg Pb-e. Composite and masonry house with steel-base foundation screws show higher emissions at 0.17 kg Pb-e and 0.58 kg Pb-e respectively. Concrete masonry houses have much higher heavy metals mainly due to steel manufacturing and mineral acquisition.

Carcinogens

Carcinogens are measured in Benzo(a)Pyrene (B(a)P) equivalent emissions. Carcinogens can cause cancer through either corrupting DNA, or interfering with cellular metabolic processes. In either case, the cells that are affected do not die, but undergo uncontrolled growth and altered metabolisms.

The composite house shows a higher carcinogen emissions compared to the masonry house with emissions of 0.0014 kg B(a)P-e, while the masonry house was at 0.001 B(a)P-e. Composite and masonry house with steel-base foundation screws show higher emissions at 0.0018 kg B(a)P-e and 0.0014 B(a)P-e respectively. The higher emissions from the composite house correspond with the manufacturing of resin and its petroleum-based origin.

Summer Smog

Summer smog potential is measured in Ethylene (C_2H_4) equivalent emissions. Although ozone in the stratosphere protects us from harmful rays from the sun, summer smog chemicals can increase ozone production in the troposphere during the summer heat. Summer smog can interfere with breathing, especially for vulnerable populations such as children, the elderly, and those with respiratory difficulties such as asthma.

The composite house shows a higher summer smog emissions compared to the masonry house with emissions of 4.11 kg C_2H_4-e, while the masonry house was at 2.63 C_2H_4-e. Composite and masonry house with steel-base foundation screws show higher emissions at 4.9 kg C_2H_4-e and 3.4 kg C_2H_4-e respectively. The higher emissions from the composite house correspond with the manufacturing of resin and its petroleum-based origin.

Winter Smog

Winter smog potential is measured in solid particulate matter (SPM). Usually, warm air rises because of its lower density than the surrounding air and carries pollutants higher into the atmosphere where they are dispersed. However, in the winter cold air close to the ground facilitates temperature inversions and creates local air stability. Thus, products of incomplete combustion such as particulate matter, carbon monoxide, and nitrogen oxides can accumulate locally rather than being dispersed as usual. As with summer smog, winter smog interferes with the respiration vulnerable populations.

In winter smog, the composite house has an advantage over the masonry house—showing emissions at 11 kg SPM, while the masonry house was at 18 kg SPM. Composite and masonry house with steel-base foundation screws show higher emissions at 18 kg SPM and 28 kg SPM respectively.

Energy Consumption

Energy consumption accounts for the electricity, heat, and transportation inputs of the products. The composite house consumes less energy than a concrete masonry house with a usage of 69 x 10^2 MJ LHV, while concrete house consumed 118 x10^2 MJ LHV of energy. Composite and masonry house with steel-base foundation screws show higher energy consumptions at 109 x 10^2 MJ LHV and 158 x 10^2 MJ LHV respectively. This does not include the use phase energy consumption of either house, which will significantly alter the results depending on the assumptions used in later analyses.

Solid Waste

Solid waste included all estimated excess waste during product assembly but does not include end of life disposal of the products. For the composite house the total amount of solid waste was calculated to be 388 kg. The composite with steel-foundation screw shows higher solid waste at 449 kg. This analysis does not include the potential reuse and recyclability of the composite panels. The concrete masonry house has not been sufficiently defined to include solid waste in the calculation yet.

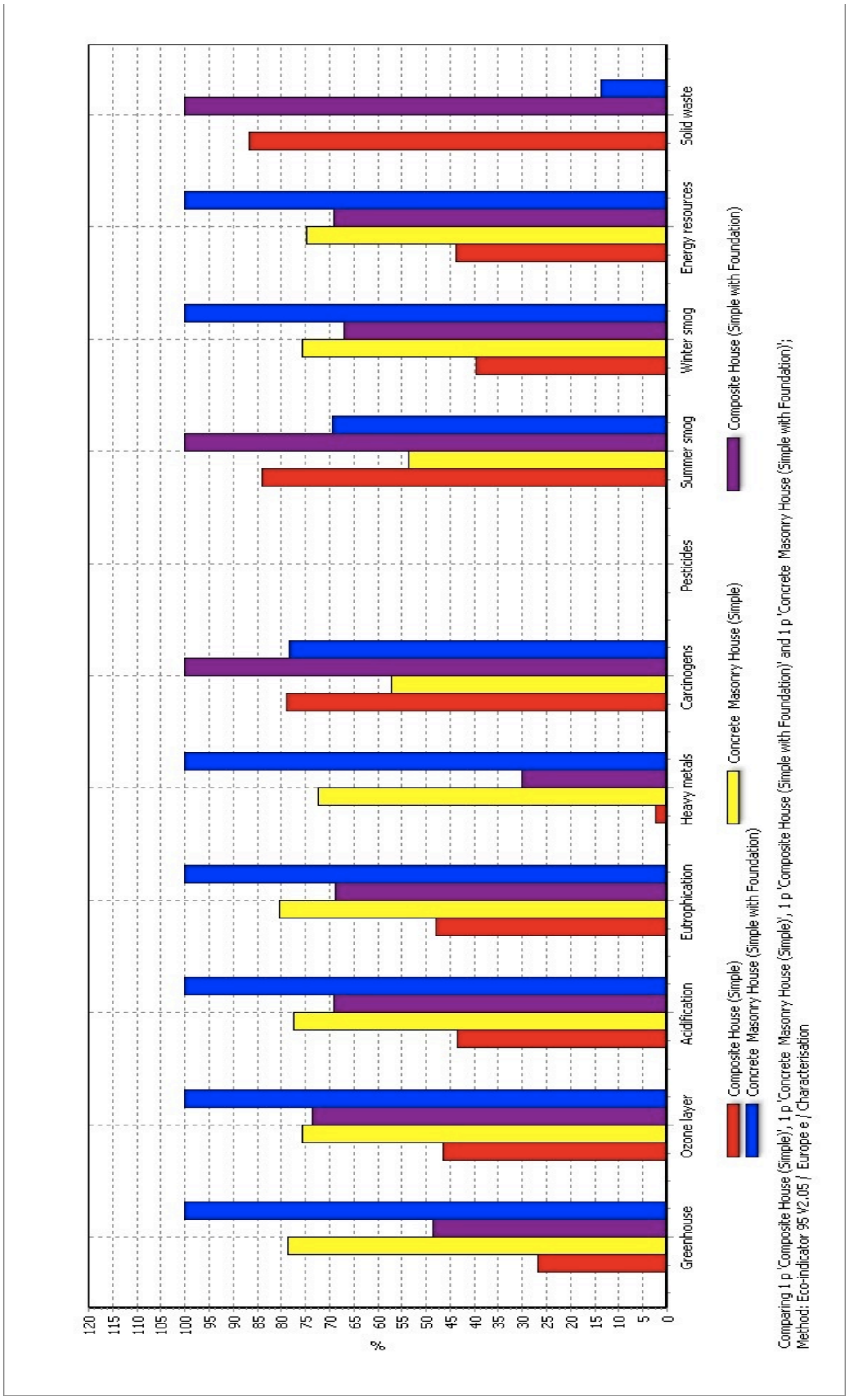

Figure 1: The impact assessment comparison between concrete masonry house and composite house—with and without foundation screws in all of the analyzed impact categories.

Impact category	Unit	Composite House	Concrete Masonry House	Composite House (with Foundation)	Concrete Masonry House (with Foundation)
Greenhouse	kg CO2	2715	7989	4933	10182
Ozone layer	kg CFC11	0.0014	0.0023	0.0023	0.0031
Acidification	kg SO2	17	31	27	39
Eutrophication	kg PO4	1.50	2.51	2.16	3.13
Heavy metals	kg Pb	0.01	0.42	0.17	0.58
Carcinogens	kg B(a)P	0.0014	0.0010	0.0018	0.0014
Pesticides	kg act.subst	0	0	0	0
Summer smog	kg C2H4	4.11	2.63	4.90	3.40
Winter smog	kg SPM	11	21	18	28
Energy resources	MJ LHV	68988	118105	109214	157956
Solid waste	kg	388	1	449	61

Table 2: The quantitative impacts of the concrete masonry house, composite house with foundation, and composite house without foundations in impact categories above.

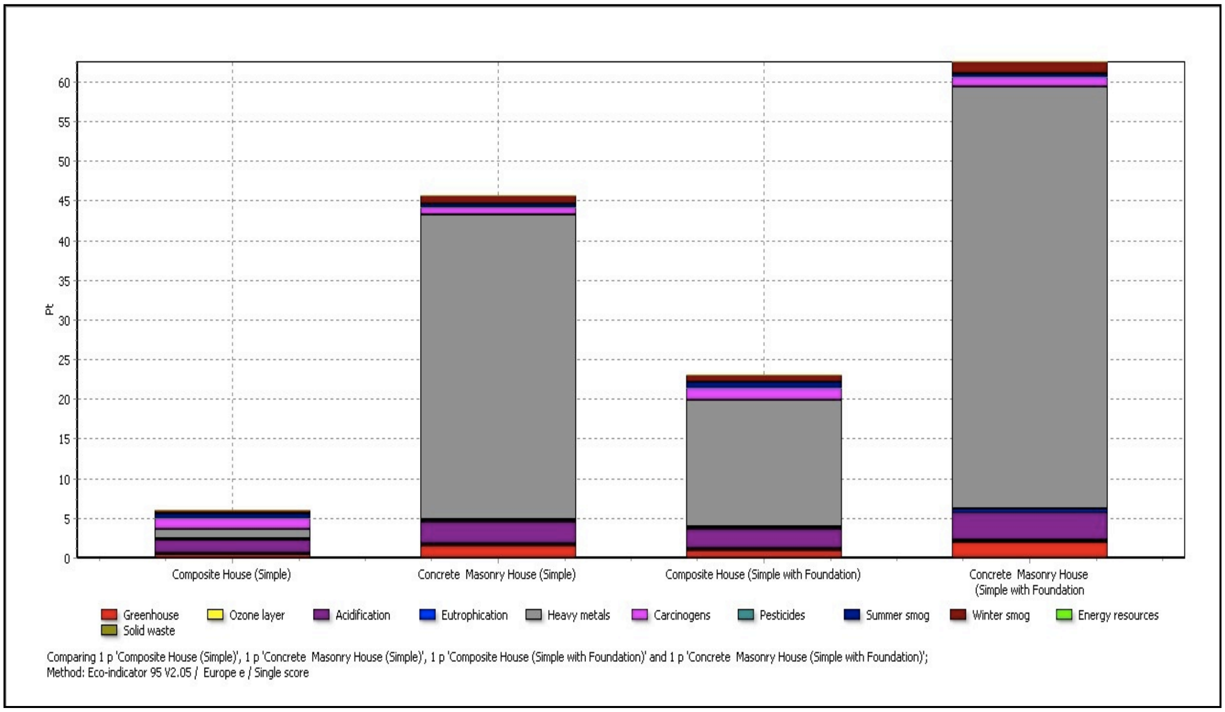

Figure 2: The embodied energy of various house types—single score.

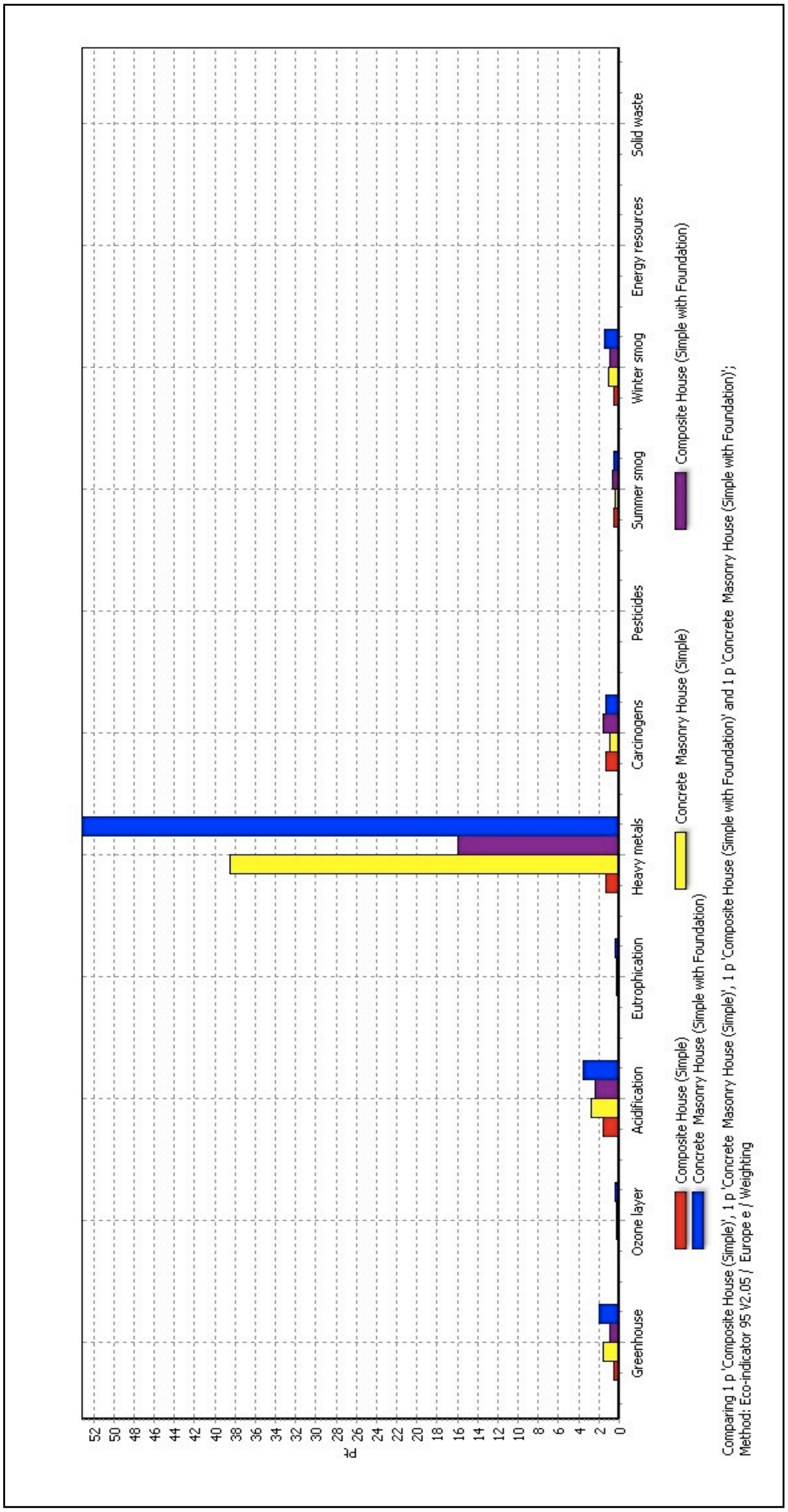

Figure 3: The embodied energy of the composite house—weighted.

Conclusion—

The initial analysis confirms what the MIT and Stanford teams had hoped—the use of composite materials in buildings results in less energy and material inputs and lower emissions than the closest alternative of concrete masonry. As the project develops and more information becomes available, it will be necessary to consider the full life cycle yet it will be simple to build upon this existing, preliminary analysis. This project might also benefit from other forms of analysis, such as an Environmental Impact Assessment to examine the impacts of the material on the ground at a specific site. Examining this project through the "green building" or LEED lens would also be beneficial. Finally, social aspects (e.g. is the house desirable to Haitians?) should also be considered. Although more analysis is necessary, composite housing has the potential to meet disaster housing needs in an innovative, eco-conscious way that could potentially revolutionize the building industry.

Glass Polypro Page