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Subject	Miami science Museum Material Embodied Energy Status Report		

1 Introduction

The materials selected for the Miami Science Museum are being considered for their performance value, cost effectiveness, aesthetic characteristics and environmental impact. The metrics most commonly used to asses the sustainability of building materials are embodied energy and embodied carbon comparison.

Given the limited amount of information about specific building system options, this study will begin with a general analysis of the two systems that are most typically used in commercial buildings. Embodied carbon will be the common unit of comparison to take advantage of the largest amount of pre-existing research. As the design develops, more defined parameters for materials analysis will provide a localized and more accurate focus such as air and water pollution impacts.

Arup is examining the largest material systems and identifying, by comparison, which system has a smaller carbon footprint. The parameters applied for this initial comparison are based on data from typical commercial buildings. Because the museum design is at an early conceptual stage, this initial comparison will be working with data inputs that we have already developed from national averages. The structural systems account for a large percentage of a building's overall construction embodied carbon footprint. The first structural system comparison will be to determine if, based on available inputs, a cast-in-place concrete system or a structural steel system has a smaller embodied carbon footprint. When information about the Miami Science Museum's potential structural systems becomes available this input set will be refined.

This report is a comparison of the carbon footprints of a typical square foot of steel construction and of cast-in-place reinforced concrete construction in the US. The purpose of this report is to determine which type of construction is more sustainable.

This analysis is based on two conceptual large commercial buildings. It takes into account carbon emission contributions from all processes from the mining and harvesting of raw materials to the end of the construction process, including transportation of materials. It does not include operational carbon emissions.

The introduction of supplementary cementitious materials (SCM) is included in this analysis to further investigate the possibilities for reducing the carbon footprint of concrete. The two types of SCM used were Ground Granulated Blast Slag (GGBS) and Fly Ash (FA). The analysis compares the carbon footprints of several different concrete mixes, including the following:

- 100% Portland Cement
- 40% GGBS, 25% FA

- 50% GGBS, 30% FA
- 40% GGBS, 40% FA

The mixes above were chosen based on the maximum allowances detailed in Arup's Master Specification for cast-in-place concrete. Arup's master spec was used as a baseline for best practice specifications. The specification states that Fly Ash may be substituted for cement at a rate of between 25 and 40 %, and that GGBS may be substituted at a rate of between 40 and 60 %. It also states that when both substances are present, the total substitution should be between 50 and 80 %, and neither component shall exceed 50 %.

This analysis takes into account only embodied carbon emissions, not operational. Although the operational carbon footprint of a building far surpasses the embodied carbon footprint in size, embodied carbon is a legitimate concern. Because of the enormous volume of construction in cities, reducing the carbon emissions associated with it could make a significant difference in an urban area's carbon footprint.

2 Material Quantities

2.1 Concrete

Concrete is comprised of a mixture of water, coarse and fine aggregate, and cement. Coarse aggregates are made up of materials such as gravel, and fine aggregate of sand-like materials. For this investigation, coarse aggregate accounts for about 40% of concrete, fine aggregate for about 35%, cement for about 18%, and water for about 7%. Although cement is a small component by weight, it is the largest contributor to concrete's carbon footprint. In order to reduce carbon emissions, supplementary cementitious materials (SCM) are used. Two common types of SCM are Ground Granulated Blast Slag (GGBS) and Fly Ash. For every kilogram of Portland cement manufactured, 0.809 kg of CO_2 is emitted. One kilogram of each of these materials produces 0.08 kg and 0.02 kg of CO_2, respectively, which is one tenth or less of the figure for Portland cement. Both of these materials are by-products of other processes, and are therefore reduces waste directed to landfills.

Slag is typically used to replace as much as 50% of Portland cement in general concrete applications, up to 65% in high strength/durability applications, and up to 80%+ for mass pour applications. When slag cement is used to replace 50%, the greenhouse gas emissions per cubic yard of concrete are reduced by 45%. Slag is a by-product of iron manufacturing. Fly ash is a commonly used SCM in US construction projects. It is a by-product of the combustion of coal in electric power generation plants. Fly ash does not possess cementitious properties on its own, and is therefore usually limited to up to 40% cement replacement. Based on information we have collected thus far, both fly ash and slag are available in Florida and should not create any permitting challenges unique to the area.

The carbon footprint of concrete can be further reduced through the use of recycled aggregates. The most common recycled aggregates are glass cullet and crushed recycled concrete. According to the Portland Cement Association, recycled aggregates can be used for up to 100% of coarse aggregates and for 10-20% of fines.

When pouring concrete, formwork must be used to shape it appropriately while it cures. It is common practice to use timber formwork, as opposed to steel formwork. Steel formwork is much more sustainable because it is highly durable and can be reused for long periods of time. Timber formwork is also reused, but not nearly as often or for as long as steel is. Although the process of manufacturing timber formwork has a small carbon footprint, it does not take into account the emissions associated with disposing of the material. Timber is either burned, which produces CO_2, or put into a landfill and produces methane, which, in terms of greenhouse gases, is far worse than CO_2. In order to get a more accurate estimate of the carbon footprint of timber formwork, the figure associated with the disposal of the formwork will also be taken into account.

2.2 Steel

Steel construction consists of a steel beam framework, reinforced concrete used as floor slab, and metal decking. Steel is created by first making pig iron from iron ore, then converting the pig iron into steel. It is also commonly recycled, which is done by reprocessing scrap metal in an Electric Arc Furnace into new steel. The carbon footprint of steel construction can be reduced by using recycled, salvaged and/or locally produced products. Though carbon is emitted through the process of melting and reforming steel, the emissions due to recycling are less than those due to mining and processing new steel. The higher the recycled content of steel, the lower the carbon footprint of that steel will be. According to the Recycled Steel institute, the average recycled content of steel in the United States is 96 %. This study uses 84 % recycled content, which is a conservative estimate.

The concrete used in steel construction is lightweight concrete, usually with a density of around 1,800 kg/m². For the purposes of this analysis, the lightweight concrete makeup is as follows: cement accounts for approximately 25%, fine aggregates are approximately 45%, coarse aggregates 20% and water for about 10%. The large reduction in amount of coarse aggregate is very effective in reducing the weight of concrete. Since concrete is also used in steel construction, the contents of the concrete used contribute to the carbon footprint of the building. It is important to use sustainable concrete mixes in steel construction as well, as it can still help decrease the carbon footprint of construction.

3 Methodology

This preliminary investigation took into account all carbon emissions associated with the mining, manufacturing, production and transportation of all materials, as well as the construction required to put those materials in place. The assumptions upon which this analysis is based are stated above (see Material Quantities). The first step was to determine the total quantities of each material in each type of construction using the assumptions laid out in the previous section.

The next step was to determine all components of material production that contributed to the carbon footprint for a building. For concrete construction, this included the fabrication of the concrete, the steel formwork, the timber formwork, and the rebar, as well as the transportation of each material. For steel construction, this included pig iron production, steel beam and steel connection production, fireproofing manufacture and transportation of each of these contributors, as well as all emissions associated with the concrete included in steel construction. The transportation distances for each material are based on approximate figures applicable to North America. After determining the carbon emissions associated with material production, the footprint associated with the construction of each type of building was calculated. The figures for the carbon footprint of each process were obtained through researching existing databases including ATHENA, BEES, NREL, Arup’s proprietary information and other databases.

The emissions associated with each step were first calculated on a per tonne basis in the case of steel and a per cubic meter basis in the case of concrete. The emissions associated with the construction of each building were calculated on a square meter basis. These figures were then adjusted for the entire building, and then finally divided by the total square footage to obtain comparable figures.

4 Results

The bar chart below presents the preliminary results of structural material analysis for concrete and steel.

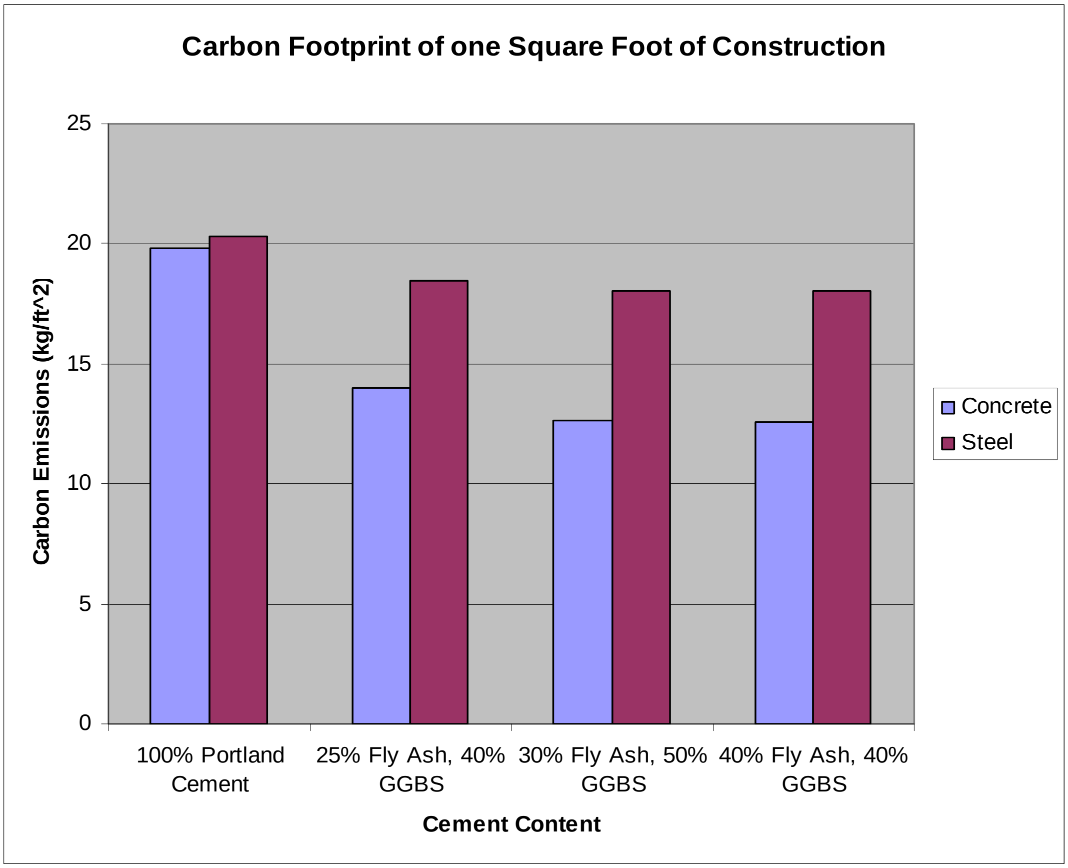

Figure 1. Carbon Footprint of one square foot of concrete and steel construction using multiple concrete mixes

Table 1. Carbon Footprint of one square foot of concrete and steel construction using multiple concrete mixes and the difference between the two figures

Carbon Emissions (kg/ft^2)			
	Concrete	Steel	Difference
100% Portland Cement	19.815304	20.321617	0.5063137
25% Fly Ash, 40% GGBS	13.997561	18.469405	4.4718435
30% Fly Ash, 50% GGBS	12.660498	18.043536	5.3830377
40% Fly Ash, 40% GGBS	12.589093	18.021685	5.4325922

5 Conclusion

The initial material comparisons show that when GGBS/FA concrete is used, concrete construction has a smaller carbon footprint than steel construction. As concrete content varied from 100% Portland Cement to a 40% Ground Granulated Blast Slag, 40% Fly Ash mix, the carbon footprints of concrete and steel construction varied between 19.8 and 12.6 $kgCO_2/ft^2$, and 20.3 and 18.0 $kgCO_2/ft^2$, respectively. The difference between steel and concrete construction ranged from 2.5 to 30 % in carbon emissions.

It is also possible to further reduce the environmental impact of the project’s structure, for example, using recycled aggregates in concrete would reduce its carbon footprint. Using re-usable steel formwork exclusively could also lessen carbon emissions. As can be seen in the breakdowns of the carbon footprint of steel, the production of steel beams is by far the largest contributor. Pig iron production is the second largest contributor to carbon emissions. Using salvaged steel could greatly reduce both of these figures, and therefore have a large impact on the carbon footprint of steel construction. As salvaged steel is generally not an option for most projects, it can be assumed that the steel that is modelled here is the most sustainable steel profile that would be reasonably available to most projects.

There are several variables that could be altered and methods that could be employed to further reduce the carbon emissions of both types of construction. It is important to note that where the variance in cement content had a very significant impact on concrete construction, it had little impact on steel construction. If the project focused on minimizing the use of foreign virgin steel and used standard Portland cement based concrete mixes; the steel structure would most likely be the more sustainable choice.

6 Next Steps

A comparative analysis must be performed based on the material quantities for the project and local production characteristics i.e. concept designs and Florida specific data. Understanding the typical carbon profile for specific materials being considered for the project will allow for a more accurate comparison. Arup will continue gathering local data and developing material quantity lists with the project design team. Based on the information gathered thus far, there is very little data available for the Florida area. If ultimately it is determined that local data is not available, the calculations will be performed using national averages and inputting local fuel and transport information wherever possible.

Once these numbers are available, variations on the project’s structural systems can be evaluated. The building’s embodied carbon footprint can then be reduced by: first, reducing the quantities of high-carbon emitting products through optimized structural engineering and secondly, selecting and specifying the most sustainable products available and financially feasibility. The sustainability rating of each material system will be further developed using industry developed life cycle analysis tools as well as internally developed tools and expertise. After this data has been analyzed, a report will be provided summarizing the research findings and material recommendations.