Carbon Footprint Analysis

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We have recently documented the carbon footprint of two buildings. Both buildings are new 300,000 square foot concrete frame office buildings in Houston, Texas commissioned by the same developer, built by the same contractor, yet designed by different architects. We tracked the carbon emitted from materials, workers transportation, energy use on site, and waste.

It is becoming increasingly important for designers to understand the implications of their material choices and this study helps clarify some of the results of design decisions.

INTRODUCTION

Current architectural practice is engaged in research to help develop innovative building systems, exterior envelopes, and uses of materials in response the quickly changing technology. Schools of architecture must prepare students for this new way of integrating practice and research.

The Materials Research Collaborative (MRC) at the Gerald D. Hines College of Architecture and Design serves as a materials resource for material discovery, innovation, instruction, and research. The MRC has developed a web-based database that catalogs the physical materials in its collection. On going work of the MRC includes uncovering new and innovative materials, cataloging the physical samples and researching and inputting data regarding the specific extrinsic and intrinsic properties of these materials.

The MRC is also engaged in specific material research projects funded by grants, gifts or other sources. We have completed two carbon footprint studies, consulted on LEED v4 precertification, and developed databases of local materials, local fabricators, and building recycling nationwide.

Architects are accepting their role in mitigating climate change and overall levels of Greenhouse Gas Emissions (GHG) as they search for ways to make buildings use limited resources more efficiently. There has been a great emphasis on improving the overall efficiency of a building in its operations, through developing more efficient thermal envelope systems and more efficient human comfort systems. As we reduce the energy required, and therefore the emissions of, building operation systems the relationship between energy and emissions used during operation and the embodied energy and emissions required for the construction of the building change. The amount of energy consumed and gases emitted during the construction process are becoming more important as we look at the total impact of our building activity.

One way to understand (and then hopefully reduce) the amount of emissions created during the construction of a building is to do a carbon footprint analysis. This analysis tracks the amount of carbon emitted during the construction related activities as separate from the carbon emitted during the lifespan and operations of the building once it is built and occupied. It includes documenting all activities that contribute to the emissions of carbon, the main GHG emissions, from the use of both fossil fuel and not fossil fuel related activities. Carbon footprint analysis is different from Life Cycle Analysis (LCA). LCA holistically documents all of the environmental impacts (including carbon emissions), as well as, the social and economic impacts of a specific product or service.

CARBON FOOTPRINT ANALYSIS METHODS

The carbon emissions that are generally associated with buildings construction include emissions during the manufacturing of building materials, the transportation of building materials and labor force to the construction site, the transportation of waste material, the treatment of waste material, and any energy or water used on site for construction purposes.

There are several carbon emissions calculators available. The *Athena Eco Calculator* requires the input of information regarding: foundations and footings, columns and beams, intermediate floors systems, exterior walls, windows, interior walls, and roof assemblies. The calculator however does not factor in any on-site waste, on-site electricity or the transportation of craft worker and building materials. The calculator also uses a generic emissions amount for building materials.

The *GHG Protocol* provides an electric emissions spreadsheet. The spreadsheet allows for the option to choose regional mixes to find the CO2 / Kwh. When we compared their data to our data, they showed carbon emissions of 536 kgCO2/Kwh compared to our source of 568 kgCO2/Kwh. The *GHG Protocol* also has industry specific spreadsheets for items such as ammonia, cement, steel mills, etc. The cement manufacturing spreadsheet requires exact quantities such as clinker to cement ratios.

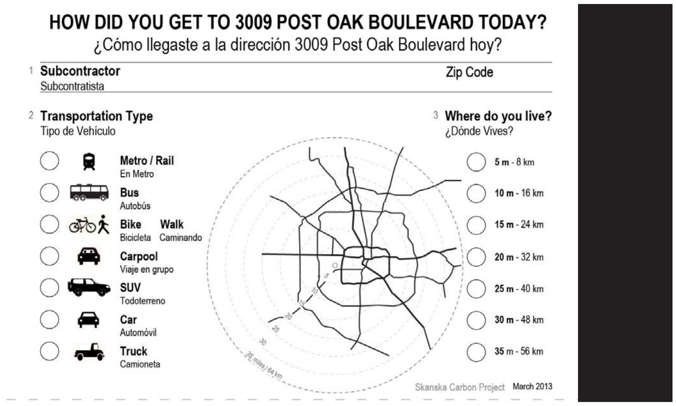

Figure 1: Transportation Survey Form

Transportation spreadsheets are also available showing vehicle types, weights of materials and distances traveled. However waste and material embodied carbon are not included on this web site. The University of Minnesota also has a Carbon Calculator for Buildings and Sites called *Techne* .

In addition there are several more general carbon emissions calculators. *Target Finder* allows architects and construction industry to plan an energy-efficient target for building projects. Conservation International , which factors your living conditions, automobile information, and air travel along with how much money it takes to offset your carbon footprint. The Nature Conservancy website calculates carbon emissions for individuals or households by state and offers tips on how to lower CO2 emissions. The Carbon Neutral Company website calculates household or personal transportation footprint. The *EPA Household Emissions Calculator* includes home energy use, household vehicle use, and recycling. EarthLab calculates vehicle transportation and *Carbon Domestic Household Calculator* calculates vehicle transportation including motorbike and train transport.

We elected not to use any of the existing calculators listed above as they are not very specific about the materials used and many did not include craft worker transportation to the site. We did look carefully at the existing calculators in order to develop our own methods.

CALCULATING CRAFT WORKER TRANSPORTATION EMISSIONS

We first developed a questionnaire, which asked each craft worker to tell us the miles driven to the site and the type of vehicle they drove. We had both English and Spanish on the questionnaire as well as icons. We determined two dates during the construction period where we would have a variety of subcontractors on site and a large pool of craft workers. Our team joined the daily "stretch and flex" morning safety meeting (at 6:30 am!), and I briefly outlined, along with a Spanish speaking student translator, the purpose of the study. We asked each subcontractor foreman to return the forms by the mid-morning break. Each completed form was exchanged for a small treat for each craft worker. Our return rate of response was about 95%

We then developed a spreadsheet to calculate miles, emissions per vehicle mile, and calculate average per person. We could then review the daily report from the contractor's tracking software to determine the number of craft workers on site per construction day. We added up total the craft worker days multiplied by the average emissions per craft worker over each month for the course of construction. We conducted a second transportation survey four months later to verify our craft worker transportation average. We also wanted to educate the craft workers and entire project team about total carbon used for transportation to the site. We then designed a graphic poster and installed it at the construction site to help communicate the impact of transportation.

Our spreadsheet allows us to evaluate the carbon emitted per person by subcontractor, as well as, providing valuable feedback for any ride sharing programs or other transportation reduction initiatives. Highly specialized subcontractors often travel greater distances. The elevator subcontractor averaged 72 pounds of carbon per person per day while the lowest emitting subcontractor work force emitted just 22 pound of carbon per day for transportation to and from the job site. The project average for craft worker transportation was 41 pounds of carbon per day per worker. We utilized the Environmental Protection Agency (EPA) Greenhouse Gas Emissions from Vehicles database to calculate vehicle emissions per vehicle type.

CALCULATING BUILDING MATERIALS EMISSIONS

We tracked the four largest components from the schedule of values representing 44% of the building cost. These items included: concrete, curtain wall, precast concrete, and miscellaneous steel. We meet individually with each of the four major subcontractors regarding their materials and all the sub-components of the materials they provided. We tracked both the embodied carbon from the material manufacture as well as carbon emitted to get the materials to the site, with many of the materials having multiple travel segments and a variety of transportation methods to get to the construction site.

Embodied carbon is the sum of fuel related carbon emissions (i.e. embodied energy which is combusted – but not the feedstock energy which is retained within the material) and process related carbon emissions (i.e. non-fuel related emissions which may arise, for example, from chemical reactions). This can be measured from cradle-to-gate, cradle-to- grave, or from cradle-to grave. We utilized the database from the Inventory of Carbon and Energy (ICE) from the University of Bath. The ICE data is cradle-to-gate.

The building material Gate to Site carbon emissions were calculated based on the specific materials used for this project. We developed a flow chart of major materials that included the source of raw materials, path of travel, as well as the type of travel to site . We asked each subcontractor for documentation of weight or volume of each material in the project. We then calculated the total carbon emissions, which included the cradle-to-gate as well as the transportation emissions for each segment of the travel from gate-to-site.

We then adjusted value the carbon value so that the final report includes the remaining 56% of building components that were not tracked. For this project we specifically decided not to calculate the embodied carbon for items such as the elevators and hvac systems due to their complexity.

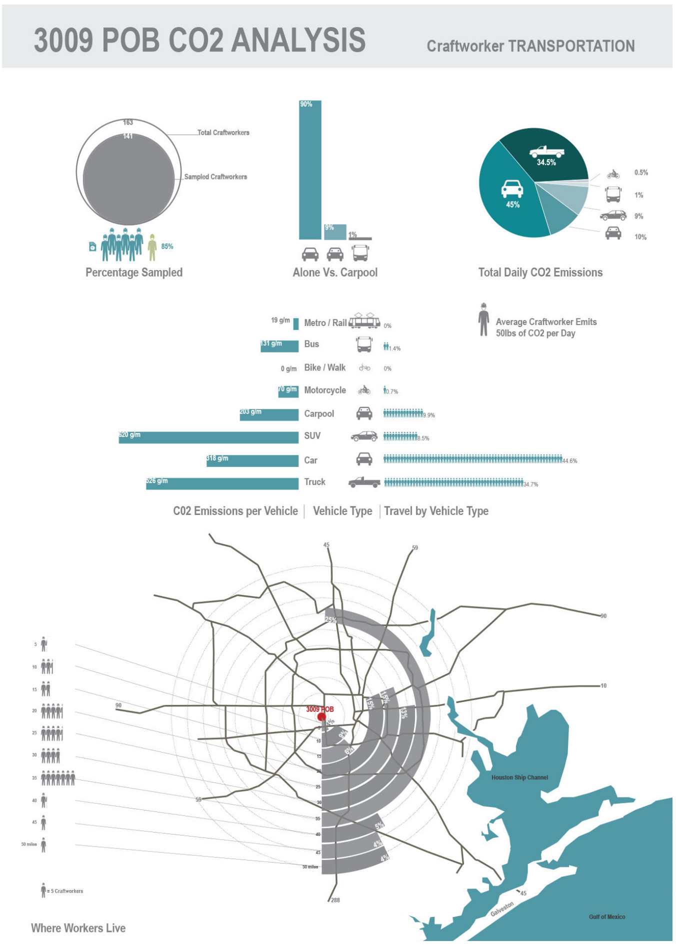

Figure 2: Transportation Emissions Poster

We are able to compare the first project, at 3009 Post Oak Boulevard, with a similar office building (same size and structural system) constructed two years later. We looked at the curtain wall system for each project. The curtain wall for 3009 Post Oak is aluminum frame that came from China by boat through Chile and then to the Port of Houston. The curtain wall for West Memorial, the second office building, is a domestic aluminum frame coming largely from Tennessee by truck. The domestic curtain wall frame has larger carbon emissions due to its transportation method than the aluminum frame coming all the way from China. The curtain wall for West Memorial also uses stone in addition to glass which also helps to increase the total curtain wall emissions, due to the weight of the materials, to 1,200 tons compared to the 775 tons of carbon emitted for the curtain wall for 3009 Post Oak Boulevard project. This also speaks to the specificity required to have any accurate carbon footprint analysis.

CALCULATING WASTE AND RECYCLED MATERIALS EMISSIONS

In addition to calculating the carbon for building materials utilized in the building we also needed to account for the building material waste and recycling. We met with the waste subcontractor to review dumpster, dump, and recycling records. The waste subcontractor removed all building waste to an off-site facility for sorting. We reviewed waste reports and tracked the transportation of all waste from the site and included the embodied carbon from any building materials that were not recycled. We developed a spreadsheet to track materials by type, that calculated carbon emissions for dumpster hauling (tonnage x mileage) for recycled materials and for materials sent to landfill only.

CALCULATING SITE ENERGY AND WATER USE EMISSIONS

We also calculated the carbon emitted from the production of the electricity and water used on site during the construction period. We first determined the major site used resources such as water, diesel, and electricity. We did not track diesel as all equipment was fueled from off site resources. We reviewed the monthly bills and records of use for both water and electricity. We determined the carbon emissions standards for each type of fuel or resource. For electricity this required understanding the specific electricity contract for the project . We then developed a spreadsheet to calculate the carbon emissions.

Using the adjusted figures we estimate that the building construction used 33,385 tons of carbon or about 100 kg of carbon per square foot. We found the largest part of the carbon is from the embodied carbon from the manufacturing of building materials and an estimated 20% of the overall building carbon emissions are from the concrete manufacturing alone. This points to areas of potential savings in carbon emissions for future projects.

We also developed a list of items for future carbon analysis studies. We recommended the following:

Discussing carbon tracking as early as possible with all subcontractors, capturing data from the start of the construction process, have carbon analysis requirement in the subcontracts, train the construction project manager, and have a kick-off training with construction and subcontractors. Many of these items were implemented in the second carbon study.

The data we have collected from both projects can also be useful to develop potential carbon saving strategies. We can develop van, carpooling, and public transportation programs and be able to estimate carbon savings for future projects. We can analyze various trades for average carbon emissions for craft worker transportation per each trade and develop target transportation emissions limits. We can compare site cast vs. pre-cast, steel vs. concrete frame structural systems and estimate carbon emissions difference between structural systems.

The information we have gathered can be used to compare to industry standard waste records. We can also compare carbon emissions vs. potential cost savings. This is especially easy to do when comparing the price and emissions of different electricity generation methods.

This study helps connect research to the design and decision making process. It is becoming increasingly important for designers to understand the implications of their material choices and this study helps clarify some of the results of design decisions.

GENERAL REFERENCES

http://www.cleanmetrics.com/html/building_carbon_footprints.htm
(No longer available)

http://www.ghgprotocol.org

http://www.ghgprotocol.org/calculation-tools/all-tools

Listing of calculation tools

http://www.carbontrust.com/home

http://co2now.org

Carbon Footprint Analysis: Concepts, Methods, Implementation, and Case Studies. Matthew John Franchetti and Defne Apul, New York: CRC Press, 2014

ENDNOTES

1 According to co2now.org the current level of atmospheric CO2 for October 2014 is 395.93 parts per million.

2 http://www.athenasmi.org/our-software-data/ecocalculator/

3. http://www.ghgprotocol.org/Third-Party-Databases/GHG-Protocol

4. http://www.ghgprotocol.org/calculation-tools/all-tools

5. http://www.csbr.umn.edu/research/carboncalc.html

6. http://www.energystar.gov/buildings/service-providers/design/step-step-process/evaluatetarget/epa%E2%80%99s-target-finder-calculator

7. http://www.conservation.org/act/live_green/carboncalc/Pages/default.aspx

8. http://www.nature.org/greenliving/carboncalculator/

9. http://www.carbonneutralcalculator.com/flightcalculator.aspx

10. http://www.epa.gov/climatechange/ghgemissions/ind-calculator.html

11. https://www.earthlab.com/createprofile/reg.aspx

12. http://www.carbonfootprint.com/calculator1.html

13. A member of our team on another project calculated the variability of embodied CO2 for 5,000-PSI concrete to be between 300 and 475 Kg CO2e, depending on which of the 50 or so specific concrete mixes were used.

14. http://www.epa.gov/climatechange/ghgemissions/sources/transportation.html

15. http://www.circularecology.com/nuqdjaidjajdkladklasa.html

16. We used the EPA website to document carbon emissions for various transportation types. http://www.epa.gov/climateleadership/documents/emission-factors.pdf

17. http://www.epa.gov/climateleadership/documents/resources/commute_travel_product.pdf

18. The contractor had an electricity contract using the standard Electricity Reliability Council of Texas (ERCOT) mix of 39/5% coal, 38.2% natural gas, 13.1% nuclear, 7/8% wind, 0.3% hydro, and 1.1% other.