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The Environmental Impacts of Fabrication Process; Methods, Equipment and Materials

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ABSTRACT:The concept of sustainability in construction has been widely accepted among all stakeholders of the industry. However, at present, there has been a lack of sufficient, credible and reliable quantitative indictors, metrics and/or data on the actual benefits of sustainable construction. In particular, reduction of environmental effects during construction activities has been one of the main issues facing stakeholders. This study represents a single process emission analysis for the hollow-core floor systems of our case studies using theconstruction environmental decision support tool (CEDST). A comprehensive set of results is obtained from the study. These results are presented in several categories for comparative assessment - energy use, Carbon Dioxide (CO2), Carbon Monoxide (CO), Nitrogen Dioxide (NO2), Sulphur Dioxide (SO2), PM10 and VOC emissions. Other categories include solid waste and liquid emissions.

KEYWORDS: Emission, Process, Sustainable, Floor Systems, Equipment, Materials**,** Hollow-Core

I. INTRODUCTION

This case study is part of a larger project. Therefore, we should give the readers more background information to understand this component. It is important to incorporate the goals of sustainability within the decision-making process at different stages of the life cycle of a capital project, from initial planning, design, construction, and operation/maintenance, to ultimate rehabilitation, decommissioning and/or disposal. However, most stakeholders within the capital project delivery process such as owners, designers, suppliers and contractors face a myriad of challenges when attempting to implement the sustainable construction approach. According to Venegas and Pierce (2001) “First, they already face the challenges imposed by increasingly limited resources on the effective and efficient delivery of capital projects. Second, they do not have clear incentives, the proper resources, nor the mechanisms or tools to do so. Finally, there is a lack of awareness and understanding of the actual or potential impact and/or implications of environmental regulations and standards on the capital projects; a lack of awareness and understanding of the opportunities and potential benefits to an organization created by a suitable approach to its capital projects; and finally, a lack of credible and reliable quantitative indictors, metrics and/or data on the actual benefits and associated costs.” In view of the above, Sustainable construction demands a different way of thinking as compared to conventional construction. Full adoption of the sustainable approach in construction therefore will require a concerted and integrated effort by all stakeholders in the industry.

Technological advances inconstruction have enabled stake holders to better understand the construction process, leading to adoption of various construction methods and techniques. For example, the introduction of Lean Construction paradigm (Koskela,1992) has led to sustained efforts by stake holders to incorporate off-site manufacturing/prefabrication into the construction process. According to Huiand Or(2005), prefabrication not only minimizes site activities and environmental impacts, but also can provide efficient, safe, high quality and fast construction. Gibb (1999), however, note sthat “methods for evaluating these benefits are lacking.”Therefore it has been difficult for project participants to make “full evaluative comparisons of traditional versus prefabricated design options.”

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II. METHODS AND MATERIALS

To address the issue of methods for quantification, various approaches have been presented in proceedingsection for assessing environmental performance of construction processes in the building construction phase. Examples include the construction environmental decision support tool (CEDST) by Guggemos and Horvath (2006), sustainability decision support system (SDSS) by Pierce et al (2001), and the augmented process-based Life Cycle Analysis (LCA) method by Billecetal (2006). Therearefewstudiesconductedtocomparehowdifferentconstructionprocesses contributetotheoverallenvironmentaleffectsduringconstruction. In the case study we applied CEDST model to quantify the environmental impacts of hollow-core floor system.

III. RELATED WORKS

Sustainable construction has emerged as a guiding paradigm to create a new kind of built environment: one that meets the needs of humans in the present without limiting the ability of future generations to meet their own needs (Ofori, 2000). Traditionally, the competitive factors in construction have been cost, quality and time. With the new sustainable construction paradigm, these have now evolved to include environmental quality aspects such as minimizing resource depletion and harmful emissions and maintaining biodiversity. Economic constraints together with social equity and cultural heritage issues are the other dimensions that add up to complete the sustainable construction paradigm triad. Sustainable construction is therefore looked at as a process rather than a state and sustainability of the building sector and the built environment is seen to increase sustainable development in our society (Huovila, 1999). The merits and otherwise of sustainable construction have been discussed by many authors.

The findings from Zimmermann et al (2005) research on benchmarks for sustainable construction show that most pollutant emissions are a result of construction activities. However, Siddiqi et al (2004) points out that there is hardly motivation by the construction industry, being a service industry, to comply with environmental laws and the larger sustainable development agenda. In view of this dilemma, they suggest two factors for motivation of stakeholders; (1) strict enforcement of environmental laws; and (2) economic incentives. While they recommend deterrent penalties and fines for the former, the latter should be the guiding factor, and here, they recommend that compliant projects should fetch a higher market value, and appreciate more quickly compared to the non compliant projects. Such differential treatment and incentives would encourage stakeholders to go for sustainability. Ngowi's (2001) study on creating competitive advantage by using environmentally friendly building processes argues that inclusion of environmental issues in the firm's strategies might create competitive advantage for the firm. In fact, according to Burgan and Sansom (2006) - "there is research emerging from around the world that links sustainably managed companies with good business performance and this is increasingly being taken into account by institutional investors". Further, Beheiry et al (2006) carried out a survey to examine the business impact of owner commitment to sustainability and concluded that commitment to sustainability atthe executive level translated to better planning and execution of sustainable project practices. The adoption of social and environmental factors by the investment community, therefore, will help drive the change towards more sustainable construction.

Other research efforts have been studying the environmental impacts for different phases in the life-cycle of buildings; from the construction phase (Shen et al 2005, Guggemos and Horvath 2006, Bilec et al 2007), to maintenance and user phase (Junnila and Saari 1998, Junnila and Horvath 2003). Others have quantified environmental effects for entire life-cycle of buildings (Kohler and Lutzkendorf 2002).

Several initiatives have been adopted based on research efforts in sustainable building. One example is the U.S. Government-sponsored National Institute of Standards and Technology (NIST) Building for Environmental and Economic Sustainability system(Lippiatt 1999). This initiative promotes the use of more sustainable materials in buildings by offering community based information and software tools that help in the sustainability of construction materials Judgment call. Another effort towards sustainability of buildings is from the U.S. Green Building Council (US-GBC). They came up with a program known as LEED (Leadership in Energy and Environmental Design) which evaluates the environmental performance of buildings in areas like sustainable site, water efficiency, energy and atmosphere, materials and resources, and indoor environmental quality (US-GBC 2008).

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IV. CASE STUDIES

In this study we have considered the cases of construction of two floor systems; hollow-core slab and metal deck floors (Molavi and Ndungu 2014). We begin with the description of circumstances in which we conducted our studies. The hypothetical Hollowcore floor is assumed to be the first floor of asingle story building located in Cincinnati, Ohio. Total floor area is 10,000 square feet and the design is based on recommendations for typical Hollow Core floor designs by precast concrete institute (PCI2000).

Hollow-Core Floor Specifications

Shown below the Table 1 is design and associated specifications data for Hollow-Core Floor design.

Table1HollowCoreFloorData

Parameters	Quantity	Unit	Datasource
Floorarea.	10,000	ft^2	Assumed
Slabdepth.	6	in	PCI,2004
Slabwidth.	4	ft	PCI,2004
Span.	10	ft	PCI,2004
SlabUnitweight.	49	psi	PCI,2004
Slabcross-sectionalarea.	187	in^2	PCI,2004
Serviceload	450	Psf	PCI,2004
No.ofreinforcingstrands	6		PCI,2004
Dia.ofstrands	0.375	in	PCI,2004
Concretetoppingthickness.	2	in	PCI,2004
Concretetoppingunitweight	25	psf	PCI,2004
Concretestrength	5,000	psi	PCI2004
Concretedensity	150	psf	PCI2004
Weldedwirefabric	6x6–1.4x1.4		Means,2007
LocationofhollowcoreSlab Supplier.	100	miles	Assumed
Locationtoppingconcrete Supplier.	50	miles	Assumed

In order to quantify the environmental impacts for Hollow core floor slab system, the construction method has been broken down into various processes. Some of the processes made relatively insignificant contribution to the system's overall environmental impact and were left out.

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Hollow-Core Fabrication Process

This section gives an analysis of each process, detailing the method, equipment and materials used. As noted earlier, hollow core production methods are patented and are not readily available to the general public. The fabrication process detailed in this study is the Elematic method (Elematic Co, 2008), one of the main Hollow Core Floor manufacturers in the U.S.A.

Bed Clearing and Strand Pulling

Pre-stressed hollow-core slabs are molded on casting beds. Before casting, the beds are cleaned and oiled using specialized bed cleaning equipment. The Bed Cleaner brushes the debris off the casting beds and then sprays a light even coat of Mould Oil. The Bed Cleaner is also designed for simultaneousmulti-strand pulling. The hydraulic strand carrier can pull and deposit up to 10 pre- stressing strands at a time. It also lifts and places them over and beyond the stressing abutments.

Strand Tensioning

All the strands of one bed are tensioned simultaneously. The tensioning unit moves transversely at one end of the hall so that each casting bed can be handled by the same machine. Casting bed specific stressing cylinders can also be used as alternative stressing methods.

Concrete Transportation

An overhead transportation system is used to transport concrete from the batching and mixing plant. The system consists of an automatically controlled shuttle that delivers the batch to the correct place over an overhead bucket gantry, which then discharges the batch into the extruding machine. Other transportation methods such as the folk lift or overhead crane can be used.

Extruding

Extrusion is the key process in hollow core production. First a fairly dry concrete mix is supplied to the extruder's hopper. The mix then falls into the mould chamber by gravity. The rotating augers inside the extruder pick up the concrete and force it towards the back of the extruder. This action forces the mix into the moulding chamber were it is gradually pressed into the final slab shape before being extruded from the back of the machine. The stationary steel pans upon which the extruder runs remain in place holding the finished product.

Slab Cutting

After curing, tension on the strands is released and the slab is cut according to the measured markings. The saw requires an Operator to control the machine. The Operator has a clear unobstructed view of the hollow core slabs and directs all movements through a hydraulic control system. The saw travels on the same rails as the extruder.

Transportation of Slab to Storage

Once the slabs are cut, they are lifted by an overhead crane which sets them onto transfer wagons. The slabs are then inspected and any voids fixed before transporting them to the storage area.

Transportation of Slab to building Site

The most common method of transporting hollow core slabs is by trucking using standard flat-bed trailers. Hauling capacity is limited to 50-60 kips for loads without special permits. The slabs are stacked on each other separated by cushion boards or any other method that would protect them from damage.

Staging and Installation

On erection day, Hollow Core slabs are delivered by trailer or lorry and unloaded by crane. Clear access is necessary for hollow core slab delivery trucks and mobile crane to the place of erection. The procedure is executed in accordance with design layout. Installation of hollow core slabs is an uninterrupted continuous operation. Each hollow core slab is laid on the designed location with the sufficient seating length. Hollow Core slabs are lifted with specially designed clamps hanging on a steel spreader. 8 hrs.shift day is assumed for the erection process.

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Grouting Hollow-Core Slab Connections

For good distribution of load between two adjacent panels, mortar grout at slab keyway should be applied. The recommended proportion of mortar is 1 part of cement: 4 part of sand by volume. The amount of water used depends on the method used to place the grout but will generally result in a wet mix. Clean all the debris from the slab keyway then damp the concrete slab at the keyway with clean water. Fill mortar into the keyway and consolidate the mortar with steel bar or trowel. Smooth the top surface of mortar by trowel.

Steel Wire Fabrication Installation

After the grouting of slab, the surface of hollow core slab should be cleaned and free from oil. Temperature steel or steel wire mesh as designed is then laid on the hollow core slab surface before placing of topping concrete.

Pumping of Concrete Topping

The Hollow Core slab surface should be saturated with water before placement of concrete topping. The concrete pump works by forcing concrete through a pipeline much the same manner that a piston pumps water. The rate of pumping will depend on the consistency of the concrete. The concrete is delivered to thejob by a mixer truck and deposited directly into the remixing hopper on the pumping equipment and pumped the required floor.

Surface Finishing

A power screed is used to strike off concrete after it is placed. The screeding machine makes 21/2'' transverse strokes on the header boards, leveling and compaction of the mix. Finishing the surface is achieved by use of a troweling machine. The concrete should be allowed sufficient time to set hard enough to walk on before the troweling operation can begin. Troweling is a two-step operation: Floating and "finishing" the main difference being steel plates used on each operation. In the Floating phase, heavy steel blades are used while in the "finish" phase, lighter gauge plates are utilized. The floor is floated first and then the heavy gauge steel floating trowels are removed and replaced with the steel trowels to "finish" the floor. The operator guides the rotating, adjustable pitch trowels over the slab until a smooth, level surface is obtained.

Floor Curing

After finishing the floor, water is sprinkled on the floor surface and the whole area is covered with a tarpaulin and left to cure.

V. DATA INPUT

In the material extraction phase economic data is required as input for the EIO-lCA model. This economic data should be the cost of purchasing materials used in fabricating the floor systems in our study. For hollow core floor system, the primary materials considered are concrete, steel wire strands and welded wire fabric.Construction phase is analyzed using the Process based CEDST analysis tool. Data input for CEDST is obtained from various sources. The data is divided into three categories: Temporary materials, transportation equipment and fabrication and construction equipment use. Temporary materials used in fabrication and installation for Hollow Core slab floor are mainly welding rods, oil and water. This study assumes environmental impacts due to these materials is not significant and therefore have been ignored. For the trucks used to transport materials and equipment, their model year is assumed to be 2006 with cumulative mileage of 50,000 miles. Only three types of trucks have been considered in the analysis: concrete mixer trucks, small capacity trucks and large capacity trucks Table .3.

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Table 3 Material costs and weight of primary materials in Hollow Core floor system.

Material	EIO-LCA Item	Cost in 1997$	Mass (kg)
Steel strands	Steel Wire drawing	8,657.00	20,100
Concrete	Ready Mix concrete manufacturing	13,680.00	338,318
Welded wire fabric	Steel Wire drawing	860.00	1,050

Table 4 Weight and transportation distance of materials for Hollow Core Floor

Weight (ton)		Destination	One way distance (Miles)
Concrete	219.1	Precast shop	5
Reinforcing Strands	20.0	Precast shop	50
Concrete	109.8	Site	20
Wire mesh reinforcement	1.1	Site	50
Grout	11.1	Site	20
Hollow core slabs	236.4	Site	100

Table 5 Weight and transportation distance of equipment for Hollow Core floor

Weight		Destination	One way distance (miles)
Crawler Crane	40.0	Site	20
Mobile Crane	20.0	Site	20
Grout pump	1.1	Site	20

During fabrication and construction of Hollow Core slabs, each equipment is utilized for a specific duration. The duration is determined using estimation guidelines (RS Means 2014, Walker Estimator), data from equipment suppliers (refer bibliography for detailed list of equipment suppliers) and relies on standard construction processes and methods. Table 6 shows equipment use duration and power source. Model year for Diesel powered equipment is assumed to be 2006.

Generation of solid waste occurs at the fabrication shop as well as at the site. Concrete waste is generated at fabrication shop and on site. Grout waste is generated on site. To compute overall quantities of waste for concrete, apply 2% while for grout use 5% (Guggemos 2003). Liquid wastes have not been considered due to unavailability of credible data and they have therefore not been considered in this study.

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Table 6 Equipment type and duration of use for Hollow Core Construction.

Equipment	Use	Location	Power Diesel HP Electric-KW	–Power source
Mixer Truck	1.2	Site	350	Diesel
Concrete Pump	1.2	Site	476	Diesel
40 Ton Crane	16.1	Site	300	Diesel
Mobile Crane	0.5	Site	130	Diesel
Forklift	5.3	Fabrication shop		
Electric saw	3.3	Fabrication shop	55	Electric
Power Trowel	4.0	Site	6	Diesel
Concrete Extruder	5.3	Fabrication shop	30	Electric
Precast bed Cleaner	0.6	Fabrication shop	50	Diesel
Grout pump	0.6	Site	37	Diesel
Pre-stressing M/C	0.6	Fabrication shop		Electric

VI. RESULTS

These results were generated from data input into the CEDST tool as was described in the methodology section. Out of the five categories considered, the largest contributor to energy and environmental impacts was equipment use, followed by transportation of materials. Total impacts for the construction of hollow core floor system are summarized in table 7.The Largest contributor to energy and environmental impacts was equipment use, averaging about 70 percent. Other significant impacts were caused by transportation of materials. The average for this was about 30 percent. Material transportation impacts for CO and HC were actually higher; both having values about 50 percent. This could be largely due to the fact that this floor system is prefabricated and most materials are transported in bulk to the site for final assembly. Table 8 represents the proportions contributed by each category.

Table 7 Construction phase impacts for Hollow Core floor.

	Energy GJ	CO kg	NOx kg	PM10 kg	SO2 kg	CO2 100*kg	HC kg	Cr(VI) kg	Ni kg	Cr kg	Mn kg	Solid waste*10 (kg)	Liquid Waste (gl)
Temporary Materials	0	0	0	0	0	0	0	0	0	0	0	0	0
Transport Materials	27.12	18.97	7.23	0.14	0.34	18.82	5.35	0	0	0	0	0.00	0
Transport Equipment	2.86	1.19	0.78	0.10	0.04	2.03	0.25	0	0	0	0	0	0
Equipment use	52.56	15.52	32.64	0.39	7.77	38.53	3.92	0	0	0	0	27.85	0

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Other Impacts	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL IMPACTS	**82.54**	**35.68**	**40.65**	**0.63**	**8.15**	**59.38**	**9.51**	**0.00**	**0.00**	**0.00**	**0.00**	**27.85**	**0.00**

Table 8 Proportion of total construction impacts for hollow core floor

	Energy %	CO %	NOX %	PM10 %	SO2 %	CO2 %	C %	Cr(VI) %	Ni %	Cr %	Mn %	Solid waste (%)	Liquid Waste (%)
Temporary Materials	0	0	0	0	0	0	0	0	0	0	0	0	0
Transport Materials	33	53	18	22	4	32	56	0	0	0	0	0	0
Transport Equipment	3	3	2	16	0	3	3	0	0	0	0	0	0
Equipment use	64	43	80	63	95	65	41	0	0	0	0	100	0
Other Impacts	0	0	0	0	0	0	0	0	0	0	0	0	0

VII. CONCLUSION

In this paper the environmental impacts during construction of hollow-core floor system were performed and demonstrated using the CEDST tool for quantification and later for comparison with the metal deck for the total environmental burdens of each floor systems.Further research should explore the application of a similar comparative analysis at a broader perspective of all building elements; especially in the context of the building envelop elements and systems such as Walls (internal and external), Roofs and Mechanical, Electrical and Plumbing systems (MEP). Results obtained from such studies can be used by AEC stakeholders to make valuable environmentally based decisions during the building conception and design phases.

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