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A Hybrid LCA Approach to Quantify the Environmental Impacts during Construction

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ABSTRACT:The developmental path taken globally over the past few decades has been ultimately detrimental to the health of our surroundings leading to problems of excessive natural resource depletion, waste generation and environmental stress through harmful emissions. The construction industry being a major contributor to these problems, now faces increasingly restrictive environmental conservation and protective, laws, and regulations. Yet 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. To address this problem, this study identifies materials and energy flows during construction and develops a method to quantify and measure environmental impacts during raw materials extraction, production, fabrication and installation. By using a Hybrid Life Cycle Assessment approach, this paper provides a detailed assessment of both direct and supply chain impacts. The results quantify and compare the two floor systems in terms oftheir environmental impacts.

KEYWORDS:Hybrid, Life Cycle Costs, Life Cycle Assessment, Emission, Sustainability, Prefabrication

I. INTRODUCTION AND BACKGROUND

Life Cycle Assessment (LCA) is one of the methods being applied to examine the level of environmental performance contributed by building construction, thus promoting environmentally friendly construction practices. LCA is a scientific methodology for compilation and evaluation of inputs, outputs and the potential environmental impacts of a product, process or activity, throughout its entire life cycle and cross all media (Air, Water and Land). According to ISO 14040, LCA is generally carried out in four phases: the first phase is the Goal definition and scoping phase, which is the planning part of an LCA study; phase two is life cycle inventory analysis (LCI), where the material and energy balance of the system is calculated; the third phase is life cycle impact assessment (LCIA), where the potential environmental impacts of the system are evaluated; and phase four is interpretation, where results are evaluated and the impact of each option assessed.

The goal of this study is to determine environmental impacts due to raw materials procurement, fabrication, and installation processes associated with the construction of different floor types. The knowledge developed as a result of this study can not only help owners save money by making informed decisions from an environmental perspective, but can also help delivery of better, environmentally sustainable projects. This should ultimately increase competitiveness in the industry as firms move to include opportunity costs of reduction in environmental degradation during construction in their bidding strategies. Stakeholders may, therefore, create competitive advantage through using resources productively in a way that is different from their competitors.
The objectives of this research are to:

- Identify and quantify material and energy flows for Hollow Core and Composite Metal floor construction.
- Develop method to measure environmental impacts during raw materials extraction and production, fabrication, and installation.
- Identify and quantify environmental impacts (e.g., air, liquids, and solids) for off-site and on-site construction approaches. These include several categories for comparative assessment—energy use, carbon dioxide, carbon monoxide, nitrogen dioxide, sulphur dioxide, PM10 and VOC(volatile organic coumpound) emissions. Other categories include solid waste and liquid emissions.
- Compare environmental effects for off-site and on-site construction.

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The scope covers comparison of environmental effects due to construction of hypothetical Hollow Core and Composite Steel Deck floor Systems by conducting a “cradle to gate” Life Cycle Assessment. A hybrid approach is used to perform the LCA in which Economic Input/output (EIO) and Process-based LCA models are applied to identify impacts associated with installation of the two floor systems. EIO model is used in the mineral extraction and manufacture phase, while Process-based model is utilized in the fabrication and installation phase. Building use, maintenance and end of life phases are assumed to be common to both floors and will be excluded from this study. According to Curran (Curran 1996), “in a comparative LCA study, it may be logical to exclude operations that are common to the products being studied.”

There are few studies conducted to compare how different construction processes contribute to the overall environmental effects during construction. Technological advances in construction 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 stakeholders to incorporate off-site manufacturing/prefabrication into the construction process. According to Hui and 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, notes that “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. This paper introduces a model to compare the environmental impacts of offsite construction (i.e., prefabrication) to onsite construction.

The built environment consumes space and natural resources. Natural resources such as sand and aggregate are extracted from quarries. These materials are then hauled long distances exerting pressure on transportation systems not to mentions harmful emissions from transport equipment. During construction, workers are exposed to a wide range of pollutants and noise. Residents in surrounding areas are subjected to excessive noise and air pollution. In this phase, the main sustainability concern would be to minimize these impacts to the local community and also to reduce waste from the site. One effective way of achieving this is by introducing offsite fabrication in the construction process. Prefabrication not only helps to reduce site activities but also introduces an efficient, safe high quality and fast method of construction. It also allows optimization of the design through computer aided design and manufacture and enables waste to be minimized during the construction process.

II. MATERIALS AND METHODS

Prefabrication VS. Onsite Construction: Prefabrication literally means to “assemble before” and usually covers the offsite manufacture and assembly of buildings or parts thereof, and subsequent assembly into their final position. The historical development and theory of prefabrication has been discussed by various authors (Russell 1981; Gibb 1999; Song et al 2005).Compared to traditional construction, Prefabrication offers the potential to achieve the goals of Sustainable construction - It can reduce waste in terms of materials; it can reduce environmental emissions from construction site; it can improve recyclability of waste from the construction. Further, prefabrication/offsite construction has become an important and cost-effective concept in today’s fast track culture in the construction world. This approach of construction addresses the problems associated with conventional methods such as shortening the on-site construction period and therefore maximizing return on investment (Hui and Or, 2005).

A study carried out by Gibb and Isack (2003) about client’s expectations and drivers in re-engineering construction towards prefabrication concluded that more and more clients now want to see an increase in the use of prefabrication on their projects. The interest is largely due to the fact that prefabrication offers key benefits that would help them achieve their business objectives. These benefits include less environmental impacts by reduction and better control of site activities, improved product quality, improved health and safety, and reduction of on-site duration. Furthermore, moving construction into the factory has social benefits for those involved because it provides better and safer working conditions, allows for greater investment in technology and allied to this is more training of staff and greater job security (Burgan and Sansom 2006).

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III. CONSTRUCTION PHASE ENVIRONMENTAL EFFECTS

Because environmental effects of the construction phase have been assumed to be negligible in comparison with other building phases (Junnila and Horvath, 2003), the effects in this phase have not been consistently quantified. Studies in this phase have therefore tended to be at a relatively broad level. Better, more detailed studies of this phase should be carried out. Klunder (2001) recommends that assessments in construction phase should really get down to the level of components, first focusing primarily on building components that involve large quantities of materials such as (e.gwalls, floors and foundations). Other areas in the construction phase, such as contractors/subcontractors and construction methods can also be studied.

IV. LIFE CYCLE ASSESSMENT (LCA)

Life Cycle Assessment (LCA) is an environmental management tool that enables quantification of environmental burdens and their potential impacts over the whole life cycle of a product, process or activity. In order for LCA to be an effective and well accepted approach, standard LCA guidelines had been first developed by the Society for Environmental Toxicology and Chemistry (SETAC, 1994). Soon afterwards, the International Organization for Standardization (ISO) started similar work on developing principles and guidelines on the LCA methodology. Among the points emphasized by these guidelines is the need to clearly list all the assumptions and data sources used in the LCA in an objective and transparent manner.

V. ISO 14040

According to the ISO 14040 standards, LCA is a compilation and evaluation of the input, outputs and the potential environmental impacts of a product system throughout its life cycle. Inputs are defined as the material or energy that enters a unit process. Outputs are material or energy that leaves a unit process, (ISO 14040 1997). LCA studies cannot measure the "real" impacts, but only "potential" impacts, because the actual impacts depend on many variables such as exposure, and sensitivity of the receiving environment (ecosystems, humans etc.). LCA is a "systematic, holistic, objective process" used to evaluate the environmental burdens associated with a product or process. The process identifies and quantifies energy and material releases of the studied system, and evaluates the corresponding impacts on the environment.

VI. LCA FRAMEWORK

The ISO 14040 describes the four steps that have to be taken in a LCA study:

- International Standard ISO 14040 (2004) - on principles and framework.
- International Standard ISO 14041 (2004) - on goal and scope definition and inventory assessment.
- International Standard ISO 14042 (2004) - on life cycle impact analysis.
- International Standard SO 14043 (2004) - on life cycle interpretation.

The goals and scope--in this phase, the LCA-practitioner formulates and clearly specifies the goal and scope of study in relation to the intended application (ISO 14000, 1997). The goal should clearly state the reasons and intent of the study, and the target audience. This is so because system limitation and therefore theresults depend on the goal of the LCA study. On the other hand, scoping is an iterative process that results in three things:
Definition of the functional unit: The functional unit is the important basis that enables alternative goods, or services, to be compared and analyzed.

The establishment of system boundary:The definition of system boundary in LCA is important since it identifies what will be considered in the analysis. The system by definition, describe how the processes in the study are materially and energetically connected.

The data quality requirement.

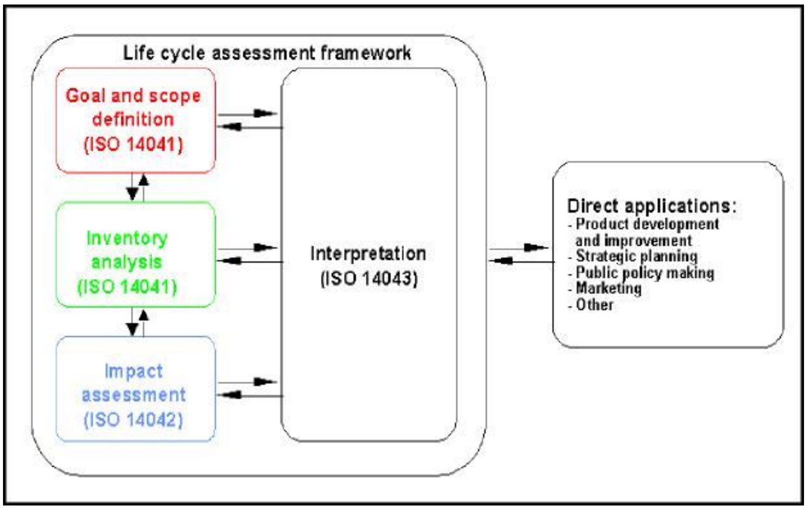

Figure 1--ISO 14000 LCA FRAMEWORKS

VII. INVENTORY

The Inventory phase involves the actual collection, description and verification of data. The data must be related to the functional unit defined in the goal and scope definition. Data can be presented in tables and some interpretations can be made already at this stage. The goal of this phase, therefore, is to evaluate the quantities of different resources required and emissions and waste generated per functional unit (Figure 2).

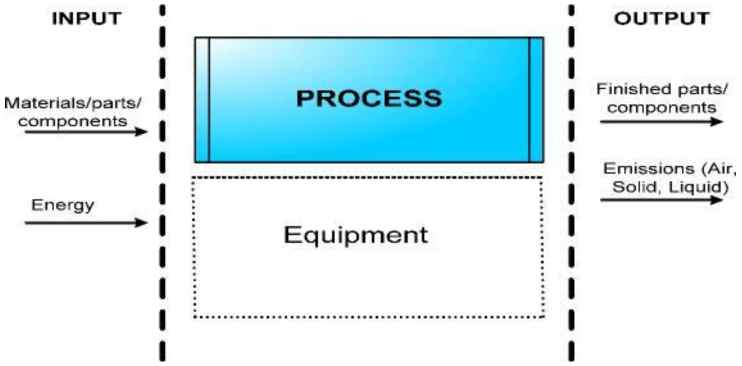

Figure 2--Inventory data category

There are two basic methods used in practice for conducting an inventory analysis:

- Process-based analysis: For the Process-based analysis, process flow diagrams are employed to empirically gather environmental releases of products or processes
- Economic Input-Output (EIO): The EIO model uses economic input-output matrices to estimate

environmental products. In the real world, each technique is most useful for particular type of problem.The aggregation nature of EIO makes nationwide problems well suited to this model while the Process-based model is more suited to specific products and processes for which physical flows are easy to trace.

VIII. PROCESS ANALYSIS

The Process-based assessment model approach is rooted on the framework recommended by the Society of Environmental Toxicology and Chemistry (SETAC), In the Process analysis model, we begin by identifying and compiling all the flows between the environment and the system that has been specified at the scoping stage. The result of process analysis is a quantitative description of all flows across the system boundary, either into or out of the system itself. Process-based LCA is "bottom up" in the sense that the subjects of analysis are individual processing units and the flow rate and composition of streams entering and exiting such units.

One of the disadvantages for process-based LCA is the problem of subjective boundary definition. Since process analysis seeks to specify each relationship in the process in an attempt to estimate their material use and environmental discharges, some relationships are difficult to capture. This forces the analyst to draw a boundary around a smaller part of the processes that can be included in the analysis resulting in higher truncation errors. For example, a steel mill requires inputs such as iron ore, coal and electricity and this will usually be included in process analysis. However, indirect supplies such as office equipment, food, vehicles, etc., are generally excluded in order to keep the analysis manageable. Another disadvantage with process analysis is that it is time consuming because inputs and environmental burdens are gathered empirically.

IX. ECONOMIC INPUT-OUTPUT (EIO) ANALYSIS

The EIO model employs economic input-output analysis was based on the idea of the general interdependence that exists among different sectors of a national economy. This interdependence results in direct or indirect interrelationships between the economic sectors. The model divides the entire economy into sectors that interact to produce a supply chain that satisfies a final demand. For example, one input-output coefficient my represent the national average amount of cement used to make concrete. Likewise, another coefficient may give the national average amount of gas required in the firing of bricks. A matrix of coefficients is then constructed, which allows upstream tracing of input to a sector through multiple transactions. The I/O framework is then completed by applying matrix inversion so that all possible transactions between sectors of the economy are included.

In order to evaluate the environmental impacts, a column is added to the EIO matrix, thus creating a hybrid of the original EIO model. This column represents the environmental impacts associated with each unit of output for all of the sectors associated with the material or service. Input-output analysis allows the user to track indirect flows that would be more difficult to determine using a process model. EIO-LCI treats the whole economy as the boundary of analysis and therefore one does not need to draw any boundary. This is one of the main advantages of this model because it makes an LCA analysis of complex systems faster and cheaper (Hendrickson et al 2006). Environmental impacts that can be calculated include energy use, air pollutants, hazardous wastes, toxics emissions and dollar estimates of external air pollution costs.

X. HYBRID MODEL

The main limitation of EIO-LCI analysis is the broad aggregation of data for the product being analyzed rather than applying detailed data for each process (Joshi 2000). This approximation introduces errors in the results. A good example is the generation of electricity using a 50 year old coal plant and using a new gas turbine. The U.S input-out table usually does not distinguish between the two. Clearly the former produces much higher pollution than the latter. Another limitation is that EIO-LCA analysis captures the upstream environmental outputs related to acquisition of raw materials but not those associated with product use and end-of-life phases.

Hybrid LCA models both the process LCA and EIO-LCA to produce a more versatile model. This is achieved by incorporating the advantages of the two models. It is important to note here that a "hybrid" in this case implies that the tools that constitute the model are connected with one another only by data flows and are not fully compatible with each other. The main elements of incompatibility include level of resolution, the inclusion of capital goods, treatment of imports and the applied location principle. Despite these incompatibilities, a hybrid model gives better results with reduced uncertainties as compared to the two models applied individually. The hybrid model therefore has broader applicability in LCA assessment due to the following benefits:

- The inclusion of detailed, process-level data, as well as the economy-wide effects in the assessment.
- Provision of environmental and economic information about every major product and process in the economy.
- Quantification of the widest range of environmental data.

As a guide for hybrid models, EIO-LCA should be applied in background processes, products and supply chain elements where sector aggregation is not a major issue, while process LCA model focuses on foreground processes were specific process data is readily available. In practice therefore, with a careful choice of number of stages in a process, the application of Hybrid analysis can reduce the errors in both techniques and produce the most accurate result possible.

XI. IMPACT ASSESSMENT

The first step of impact assessment is termed characterization and “translates” the inventory data into environmental impact potentials such as global warming and acidification. If necessary, a valuation is carried out that could include normalization and weighting. Normalization provides a basis for comparing different types of environmental impacts and the weighting step reflects the seriousness of each impact category. The result of the LCIA is an “evaluation of a product life cycle, on a functional unit basis, in terms of several impacts categories (such as climate change, toxicological stress, noise, land use, etc.) and, in some cases, in an aggregated way (such as years of human life lost due to climate change, carcinogenic effects, noise, etc.).” (Rebitzer et al, 2004).

XII. LCA FOR BUILDINGS

Carrying out a LCA of buildings is essential to identifying and evaluating how key design parameters will influence a building’s environmental performance. However, compared to consumer goods buildings are more difficult to evaluate. According to Blom, there are four major bottlenecks in the use of LCA for buildings:

- The first bottleneck consists of the gaps in current knowledge on the environment and its mechanisms leading to different levels of uncertainties whose distinction is not always clearly stated or considered in the results.
- Another bottleneck is the omission of temporal and geographical characteristics of environmental impacts which results in simplification of the assessment by assuming the object is ‘frozen’ in space and time. This means that all impacts during the life cycle of the product are assumed to take place at once at a single geographic location leading to overestimation of environmental impacts.
- The third bottleneck is the long service life of buildings which introduces an element of uncertainty when modeling life cycle of the building. For example, the much shorter lifespan of building components means that an assumption must be made on the maintenance and replacement of building components without factoring in the technological changes and stage of knowledge development over the entire service life.
- The fourth bottleneck is the complexity of buildings which makes it virtually impossible to get a closed mass and energy balance in the LCA, which is the basis of this assessment method. This is due to the fact that buildings are connected to many other production processes which cannot completely be incorporated in the LCA of the building.

In general, LCA for the buildings can be broken down to the following phases (Junnila, 2003):

- Building material extraction and manufacturing phase.
- Construction processes.
- Building use/Maintenance phase.
- Demolition phase.

XIII. BUILDING MATERIAL PHASE

This phase considers all the materials used in the constructing the building. Extraction and production of raw materials in considered in this phase. This phase also includes transportation of produced materials to the wholesaler’s

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warehouse.

XIV. CONSTRUCTION PHASE

The construction phase of the building includes all the materials and energy used in the fabrication and on-site activities. Issues to consider include transportation of materials and equipment to site, on-site equipment use, waste management and water use.

XV. BUILDING USE PHASE

In the building use phase, the biggest impact on sustainability is energy use. According to Burgan and Sansom (2006), the ratio of embodied to operational energy for an air conditioned building with a 60 year lifespan is around 1:10. Designers can therefore help reduce operational energy consumption of buildings by adopting designs that reduce heat losses through the building envelop, reduce cooling and heating loads and by introduction of energy saving measures.

At the end of life phase sustainability issues that need to be considered are the reduction of waste when the buildings are demolished. During the demolition, rubble and debris are hauled away and disposed into the sea and sometimes at abandoned quarries. All avenues to recover materials by recycling and reuse should be explored. This helps sustainability in three aspects (Burgan and Sansom 2006):

- Minimization of using natural resources.
- Reduction of energy usage.
- Reduction in waste generation.

Sustainable construction has emerged as a guiding paradigm to create a new kind of built environment. 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.

The building use phase is usually divided into three services: heating services; electrical services; and other services which includes but not limited to water use, waste water generation, landscaping and office waste generation.

XVI. BUILDING MAINTENANCE PHASE

The maintenance phase usually will include all the life cycle elements needed during the entire life of the building. Depending on the scope of the study, building modernization or any other improvement measures can be included or omitted from the study.

XVII. DEMOLITION PHASE

The building end of life or demolition phase includes all on-site demolition activities, transportation of discarded building materials to a landfill and the shipping of recovered building materials to a recycling site.

XVIII. LIFE CYCLE ASSESSMENT OF BUILDING FLOOR SYSTEMS

This section describes in detail the two floor systems under study. A summary of raw materials used for production of each system is then analyzed and finally the construction processes are briefly mentioned.

XIX. COMMERCIAL BUILDING FLOOR LCA

A full LCA of a commercial building floor system would include the life cycle stages. As has been noted in the study objectives, this analysis considers the material extraction and Construction phases. Floor use, maintenance and end of life phases are beyond the scope of this study. Through the use of EIO-LCA and Process analysis model, the full set of activities associated with construction of each floor system included in the boundary is encompassed in our analysis.

XX. RESULTS

These results were generated from data input into the CEDST tool. Out of the five categories considered, the largest contributor to energy and environmental impacts was equipment use, followed by transportation of materials. For example, for CO emissions out of 24.2 kg per functional unit, 14.6 kg was from equipment use, 9.2 kg was from transportation of material while equipment transportation was a mere 0.5 kg. Total impacts for the construction of Hollow Core floor system are summarized in Table 1below.

	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)
Temporary Materials	0.00	0	0	0	0	0	0	0	0	0	0	0
Transport Materials	13.2	9.2	3.5	0.1	0.3	9.1	2.6	0.0	0.0	0.0	0.0	0
Transport Equipment	1.2	0.5	0.3	0.0	0.0	0.9	0.1	0.0	0.0	0.0	0.0	0
Equipment use	51.4	14.6	34.0	0.9	8.1	40.2	3.4	0.0	0.0	0.0	0.1	8.4
Other Impacts	0.00	0	0	0	0	0	0	0	0	0	0	0
Total Impacts	65.9	24.2	37.9	1.0	8.4	50.2	6.1	0.0	0.0	0.0	0.1	8.4

Table 1--Proportions of total Construction phase impacts for Hollow Core Deck Floor.

Table 2shows the proportions of environmental impacts during the construction phase. For energy use, equipment use contributes a total of 78% while 20% contribution is for transportation of materials. Total Contributions of impacts fromequipment used during construction range from 56% (HC) to 97% (SO2).

	Energy %	CO %	NOX %	PM10 %	SO2 %	CO2 %	HC %	Cr(VI) %	Ni %	Cr %	Mn %	Solid waste (%)
Temporary Materials	0	0	0	0	0	0	0	0	0	0	0	0
Transport Materials	20	38	9	11	3	18	42	0	0	0	0	0
Transport Equipment	2	2	1	4	0	2	2	0	0	0	0	0
Equipment use	78	60	90	85	97	80	56	1 00	100	100	100	100
Other Impacts	0	0	0	0	0	0	0	0	0	0	0	0

Table 2--Proportions of total Construction phase impacts for Composite Deck Floor.
Summary of total impacts of transportation of materials, equipment, and other impacts

XXI. COMPOSITE METAL DECK FLOOR LCA

Unlike the previous section which was only concerned with environmental impacts during construction, this section looks at the entire life cycle imp acts of the floor system. Since this is a comparative study, our LCA is confined to material extraction and manufacture and construction phases only. Environmental impacts for Maintenance/use and end of life phases have been assumed to be similar to both floor systems and have

XXII. DATA INPUT

Most of the data input are based on estimation guides (RS Means and Walker Estimator), and general construction knowledge. Some of the floor design data is also used as input. The estimation guides provide data such as material quantities and also help in computation of duration of construction processes. Other data include estimated travel distances based on the location of the project, in this case Cincinnati, Ohio.

For the material extraction and production phase, cost data is obtained from RS Means and then converted to 2013 dollars (Table 3). This is a requirement for using the EIOLCA tool, since it utilizes 1997 economic data. This is one of the major drawbacks of using this tool, and our assumption is that errors introduced by this limitation are not significant.

Metal Deck CCosProdufo for

Material	Cost $
Composite deck panels	12,967.00
Concrete	15,607.00
Fire proofing	3,684.00
Shear studs	4,516.00
Welded wire fabric	1,032.00

Table 3--Production Cost for Composite Metal Deck floor materials. Costs are based on estimation guides of RS Means and Walker's estimation handbook

Material	EIO-LCA Item	Cost $1,997	Energy GJ	CO Kg	Nox Kg	PM10 Kg	SO2 Kg	CO2 100*kg	HC 10*Kg
Composite deck panels	Sheet Metal Working	10,806.00	422.4	272.7	61.9	32.6	73.7	333.7	297.7
Concrete	Ready Mix concrete manufacturing	13,006.00	281	220	103	13	82	251	99.7
Fire proofing	Other concrete product manufacturing	3,070.00	36	27	10	2	0.9	29.2	19.7
Shear studs	Iron and Steel Mills	3,764.00	113	95	16	9	18	91.5	81.7
Welded wire fabric	Steel Wire drawing	860.00	12	12	2	0	2	9.42	8.9
TOTAL MATERIAL IMPACTS		**31,506**	**864**	**627**	**193**	**57**	**177**	**715**	**508**

Table 4--Material extraction and production phase impacts for Metal Deck Floor

For Composite Metal Deck floor impacts, the highest environmental impact material extraction and production phase are contributed by Metal Deck panels for almost all emission categories considered. The exception is NOX and SO2 where Concrete production tops all the other materials. Table 5 represents the total environmental impacts per material in the material extraction and production phase for Composite Metal Deck floor system.

A comparison of the total environmental impacts between material extraction phase and construction phase shows the material extraction is the dominant contributor with overall contribution for all the flows considered ranging between 84% for NOx to 98% for PM10. Detailed results on this are represented by Table 5.

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	Energy	CO	Nox	PM10	SO2	CO2	HC	Cr(VI)	Ni	Cr	Mn	Solid waste
	%	%	%	%	%	%	%	%	%	%	%	(%)
Material Impacts	93	96	84	98	95	93	100	-	-	-	-	-
Construction impacts	7	4	16	2	5	7	0	100	100	100	10 0	100

Table 5--Proportion of impacts during material extraction phase for CompositeMetal Deck floor

XXIII. COMPOSITE METAL DECK FLOOR SECTION

Table 6 shows the total construction phase impacts for Hollow Core and Composite Metal Deck while Figure 5.13 is a graphical representation of this data. Overall, Composite Metal Deck floor has lower impacts in the construction phase than Hollow Core System. Hollow Core floor energy impacts are higher by 58%, CO impacts are higher by 78% and CO2 impacts are higher by 49%.

	Energy	CO	NOx	PM10	SO2	CO2	HC	Cr(VI)	Ni	Cr	Mn	Solid waste
	GJ	kg	kg	kg	kg	100*kg	10*kg	kg	kg	kg	kg	(10*kg)
Composite Deck Floor	65.9	24.2	37.9	1.0	8.4	50.2	0.6	0 .0	0.0	0. 0	0.1	8.4
Hollow Core Floor	82.5	35.7	40.6	0.6	8.2	59.4	1.0	0 .0	0.0	0. 0	0.0	2 7.9

Table 6–Summary of Floor Construction Phase comparing the floor systems impacts

In the material extraction phase, Composite Metal Deck floor impacts are far much higher than Hollow Core. The percentage differences range from 45% for NOX to 147 %for HC impacts.

When all the phases are combined and impacts compared, Hollow Core floor system ends up with lower overall impacts on all impact categories considered. The only exception is solid wastes where Composite Metal Deck floor has lower by about 23 1%. Possible reasons for this are discussed further in the discussion section.

For each of the impacts measured, Composite Metal Deck floor dominates the material floor has higher impact values in the extraction and production phase, while Hollow Core construction phase. When total impacts are combined over the entire life cycle, Hollow Core floor ends up with lower impacts than Composite Metal Deck floor

XXIV. DISCUSSIONS

In this study, a hybrid assessment method for quantifying environmental impacts has been applied on two different kinds of Building floor systems. Hollow Core floor system represented offsite constructed floors and Composite Metal Deck represented on-site construction. The analysis consisted of Material extraction and construction phases. Only processes that had significant impacts in the overall environmental burdens were considered in the overall assessment. Some of the less important processes in terms of environmental burdens were omitted in the process analysis due to lack of credible data. One example is the overhead crane equipment used to transfer Hollow Core slabs from their casting beds to the storage area. This process was assumed to have low environmental impacts when compared to other processes in the fabrication phase and would not have significantly affected our results.

The environmental flaws selected in this paper include CO, SO2, CO2, HC, NOX, PM10, Solid waste and total energy. It is clear that the total environmental burdens from the Composite Metal Deck floor are higher than those from the Hollow Core floor for almost all emissions considered. The environmental burdens from the Metal Deck range from nearly 8% higher for SO2 to 32% higher for HC. A notable exception is solid waste impacts which are higher for the Hollow Core floor slabs by nearly 232%. Excessive handling of concrete during construction phase accounted for most of this difference. For example, during the fabrication of Hollow Core slabs, concrete is delivered to fabrication shop

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and offloaded onto the shuttle system that delivers concrete to the casting beds. Again, during erection of the slabs on site, there is delivery and pumping of topping concrete and grout to their final placing locations. Losses occur at each one of these handling points, and the losses at each point all add up to significant values. A reduction of these handling points would definitely result in some saving.

Breaking the impacts into the two phases considered in the study (Material extraction phase and construction phase), Hollow Core Floor impacts where observed to be higher compared to Composite Metal Deck floor in the construction phase for most of the emissions considered. The reverse seemed to be true in the material extraction phase. For example, energy use in the construction phase by Hollow Core floor system was 58% higher than Composite Metal Deck floor. Likewise, in the material extraction phase, Composite Metal Deck floor system energy consumption was higher by 23%.

With the exception of some process emissions such as welding, most air emissions originated from the consumption of fuel by construction equipment. The study broke down these emissions among the various stages of the construction processes. The equipment use was the most dominant on environmental impacts during construction. This was closely followed by material transportation and then equipment transportation.

Although the study aimed at comprehensiveness, there are several limitations. First, choices such as boundary system selection were made subjectively introducing truncation errors in the final results. Truncation errors are inherent in the methodology of conventional LCAs and are caused by the setting of system boundaries and, as a consequence, omission of processes outside these boundaries. Some of the omitted processes could have significant effects on final results. For example, the fabricator facility overheads such as heating and lighting. Based on the volume of work handled by the facility, these overheads can significantly affect the environmental burdens of the facility.

Secondly, accuracy of the study may be limited by accessibility or availability of relevant data. For example, some environmental burdens that could have significant impacts on the final results were not included in this study due to lack of data. This includes dust emissions, water emissions, noise and vibration, solid waste generation and disposal and transportation of workers to and from the jobsite were not considered in the analysis were not assessed. If these effects had been included, our assessment could probably have yielded different conclusions.

XXV. CONCLUSIONS AND FUTURE WORK

LCA was performed on Hollow Core floor and Composite Metal Deck to quantify and compare the environmental burdens of each floor system. The analysis was based on a hybrid approach which combined the EIO LCA and Process LCA methods. Test results show that the overall environmental burdens for Hollow Core floor system are lower compared to Composite Metal Deck floor system for the impacts considered. It is clear that total environmental burdens from Composite Metal Deck floor system are larger than Hollow Core floor system for almost all emissions considered. The environmental burdens from the Metal Deck range from nearly 8% higher for SO2 to 32% higher for HC. This LCA analysis therefore suggests that if all other performance parameters are equal, Hollow Core floor systems may appear to be the environmentally preferable based on the data and assumptions made. It is important to note here, however, that results of this analysis should be interpreted in conjunction with other considerations such as social, economic and political as a whole to enable more balanced decision making.

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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