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A COMPREHENSIVE GUIDELINE FOR SELECTING BUILDING MATERIALS FOR A SUSTAINABLE BUILT ENVIRONMENT: AN APPROACH THROUGH LIFE CYCLE ANALYSIS

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Abstract: A Life Cycle Costing (LCC) of building materials reduces the shortcomings of purchase decisions based on initial investment cost. However, this method too would not capture all adverse environmental impacts, which are difficult to be expressed in monetary terms, especially any harmful emissions during the life and the disposal stage of the material. A Life Cycle Analysis (LCA) instead could capture almost all adverse consequences throughout a Life Cycle (LC) of a material. But, the vagueness of the process of LCA with different approaches and complicated procedures applied to the concept has made the costing process through this approach unrealistic. This study was designed to investigate different approaches to LCA and present a common, user friendly framework that captures the environmental consequences in the selection of building. Secondary data of five building material LC's and literature on the approaches to LCA were reviewed to investigate the components of life cycles. Field investigations were carried out simultaneously for contextual verifications of LC components and for the reliability of the data gathered through literature. The secondary data was coded and categorised to build a common framework. The study presents a compiled, user friendly guideline, that capture all possible costs on the end user as well as the environment that could guide in selecting any type of building material. The findings of the research will assist the building industry to maintain their social responsibility by selecting environmentally friendly building materials to avoid adverse environmental consequences, in order to ensure a sustainable built environment.

Keywords: LCA Guideline; Building Material; Sustainable Built Environment

1. Introduction

With the vast growth of the building construction industry, selection of building materials becomes a crucial factor since the cost of material plays a major role in the entire cost of a building. The tendency is to go for the lowest cost in material selection, specifically focused at, and limited to, the initial investment cost as the only criteria for the purchasing decision as stated in literature (Korpi and Ala-Risku, 2008) as well as observed in field investigations for almost all construction industry applications. This may have long term serious issues on operational and maintenance costs. In addition, some material may be harmful to the environment in the long run, due to their carbon content and emission factors, albeit their low initial investment cost. Therefore, a decision based on initial investment cost, which is widely made, could be harmful for the end user as well as global environmental protection efforts. Moussathche and Languell (2001) state that selecting low initial cost material results in higher life cycle costing; the impact of continuing costs such as operational and maintenance costs often outweigh the benefits of purchasing the less expensive material.

This research study is designed to capture the costs involved throughout a LC of a building material while addressing the negative effects to the environment during its LC introducing compensation as a Monterey item to its LC.

2. LCC

A Life Cycle Costing (LCC), as stated by Woodward (1997), the sum of all funds expended in support of the item from its conception and fabrication through its operation to the end of its useful life, is a method to capture the drawbacks and rectify issues embedded in a decision based on the initial investment cost. It identifies the initial investment as well as the maintenance and operational costs including any disposal costs. Although the LCC has many benefits to the end user as well as to the environment, the adoption of this method has been relatively slow worldwide (Seif and Rabbani, 2014; Woodward, 1997) and almost nil in most of the countries where development activities are taking place. This could be due to many reasons such as the lack of standards or the difficulty in understanding the complicated procedures of the standards available, lack of reliable data of specific material emissions (Ardit and Messiha, 1999) and basically the lack of knowledge in the area. Despite that fact that there could be possible negative impacts, decision based on initial investment cost will tend to confine the buyer to propose low cost material. As observed during the field investigations, due to inflexible procedures and regulations; the selection of lowest tender, the decision maker has very limited options to interfere with the buyer's selection of low cost materials available in the market. However, this decision may be unhealthy for both user as well as the environment in the long run and may affect sustainability. Although a decision based on LCC could reduce this harm and promote the buyer to purchase better alternatives and decision maker to interfere into long-term damages, the difficulty in the application of such a process makes the adoption of this approach very slow. These factors lead to the necessity for an appropriate user friendly LCC approach to outfit both designer as well as end user to enable an acceptable purchase decision to be long-term cost effective and to protect the environment from further pollution. In order to introduce a better approach the knowledge of a LC of a material becomes crucial and this tends to review the approaches available for LCA of building materials.

3. LCA

According to ISO14040, "LCA considers the entire life cycle of a product, from raw material extraction and acquisition, through energy and material production and manufacturing, to use and end of life treatment and final disposal." Two main approaches of performing an LCA were identified through literature: an LCA through LCC method (Hsu, 2010; Steen, 2005; Woodward, 1997) and an LCA based on environmental decision-making and energy utilization (Babaizadeh et al., 2015; Ng and Chau, 2015; Mangana and Oral, 2015; Means, P. and Guggemos, A). The LCC approach is mostly carried for the mere purpose of comparing costs of the material in their LC. However, the LC components such as raw material extraction, manufacturing, transportation, installation, operation, maintenance, recycle, reuse, and disposal have been considered for the evaluations, and a relevant monetary term is assigned to the specific component of the LC to get the total cost of the material.

The LCA approach based on environmental decision-making and energy utilization tries to identify energy equations and emissions factors such as carbon, nitrogen, and any other harmful effluent related to the LC of the material. For example, the term embodied energy originated from the LC process includes energy factors during raw material acquisition, manufacturing, and any other process till the production of a material to be used for building construction. Any other emission factors on top of the direct costing of materials or processors are overlapped as taxations in order to obtain the total LCC of a material which gives an additional cost compared to the former approach as a compensation for any environmental damage done by the production of the material. LCA based on environmental decision making captures all possible items throughout the LC of a material without limiting to its items that could be introduced with a monetary values as in the approach thorough LCC.

4. The Research Gap

Although both approaches discussed above could give an LCA to capture the LC of a material from birth to death, they do not highlight the transportation that takes place after the manufacturing of the material if the material is used in a context different to the origin of the material. Although it is up to the user to add this factor at the level of purchasing decision, since the decision is limited to lowest investment cost, in most of the instances as observed in the field, transportation factor after purchasing is not captured in this decision too. Some materials used in the construction industry have been subjected to studies on LC in global context. But these LC's may vary in most of the applications as materials are being transported across borders for utilization. Therefore, the LC of most of the imported material, which is not manufactured in the vicinity of the context where the building is to be stipulated, could vary by its transportation component that involve a high energy factor. Thus, even for a material for which the LC or LCC is identified by the producer, a rechecking for the context of application is necessary though a better LCA. Although many methods have been identified for LCA through research, a context specific method for building material is yet to be investigated.

This research study is focused on identifying the LC of commonly used building material and their origin, to build up a comprehensive LC to be used at the costing level. The user could identify the direct and indirect costs that a material may involve, not only at initial investment level, but during the transportation from a different context, operation and maintenance period of the life cycle of its usage till the disposal stage. It is expected to identify a common framework for building material LCA through this research which could be utilized for any building material used in the construction industry.

5. Methodology

A comprehensive, qualitative literature review to identify the concept of LCA and LC of building material was conducted simultaniously with primary data collection to verify the concepts and componenetns of the LC of these materials. The secondary data gatehered were used to identify the LC of most of the building materials through coding and catogorising of data. Gathering primary data was done by carrying out indepth interviews to verify the LC's identified and to investigate any context specific factors in the LC. The LC's were established by coding and catogorizing the primary data related to five selected materials, during raw material acquisition, manufacturing, purchasing, opreation, maintenance, and discarding processors from the field. Then the categories Identified through the two approaches were compared to develop a common framework to represent the LC of any building material including contextual categories.

6. Categorization

The analysis of the secondary data collected through the literature allowed the researches to develop categories of an LC as raw material acquisition, manufacturing, transportation, installation, operation, maintenance, recycle, reuse, and disposal. Each category identified is built up of components that could be estimated by the decision maker of material selection such as equipment and labour cost for raw material acquisition or material, equipment and labour cost for manufacturing. A category such as transportation will have a significant difference in the cost component assigned to it depending on the mode of transportation used such as: road freight, rail, deep sea, coastal vessel, and air transportation. This could also get affected by the type of energy/fuel used for transportation. The type of fuel could also affect the emission taxes introduced at each level of the categorization. If the manufacturing equipment use electricity generated through a non-renewable energy instead of a renewable energy, the emission factors will be higher and this too could affect the purchasing decision indirectly, leading to the selection of sustainable material.

Categories such as raw material extraction and manufacturing of a material are identified under the category of initial investment, which is related to the embodied energy of the material when the emission factor is considered under the application of the simple categorization of the components in the results.

7. Results

As the output of the research, considering a material "M," the related LC components of initial investment (raw material extraction and manufacturing), transportation, installation, operation and maintenance, recycle and reuse, and disposal, were identified as categories to be taken into consideration in the process of costing for the selection of building materials. In addition, an environmental tax was added related to the emissions at each stage of the LC of the material which was based on the energy used at each level. Any such taxes are indicated as costs at each level and this cost will be an additional monetary item introduced as compensation for energy usage during a specific component of the LC. Hence, the final cost related to the usage of a material throughout its LC could be expressed as:

$$\mathbf{LCC_M = (C_{II} + C_{EEE} + C_T + C_{TEE} + C_I + C_{IEE}) + (C_{OM} + C_{OMEE})\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] + (C_D + C_{DEE})\left[(1+i)^n\right]}$$

Where,

LCC_M - Life Cycle Cost related to Material M
C_{II}- Initial investment cost
C_T- Transport costs
C_I - Installation costs
C_{OM} - Operation and Maintenance cost
C_D - Disposal Cost (Reuse, Recycle, Disposal)
C_{EEE} - Embodied Energy Emissions cost
C_{TEE} - Transportation Energy Emissions cost
C_{IEE} - Installation Energy Emissions cost
C_{OMEE} - Operations and Maintenance Energy Emissions cost
C_{DEE} - Disposal Energy Emissions cost
n - Useful life time of the material for the designed purpose
i - Discounting factor

Energy emissions costs are derived by considering any taxes related to all emissions during each process as presented in Table 1. It should be noted that, the transportation cost may vary significantly with the context and in addition, related emission taxes could affect the purchasing decision. As observed in the field investigation this factor is not taken into account seriously although consideration is given to initial investment and installation costs.

Table 1: Guide for Energy Emission Tax

<table>
<tr><td colspan="3">Emissions Components</td><td>Energy Emissions Tax (related to CO, CO_2, SO_2, NO_x, etc.)</td></tr>
<tr><td colspan="3">Raw material acquisition</td><td rowspan="7">C_{EEE}</td></tr>
<tr><td rowspan="6">Manufacturing</td><td colspan="2">Material</td></tr>
<tr><td rowspan="5">Energy</td><td>Diesel</td></tr>
<tr><td>Petrol</td></tr>
<tr><td>Coal</td></tr>
<tr><td>Electricity</td></tr>
<tr><td>lite fuel oil</td></tr>
<tr><td rowspan="10">Transportation</td><td rowspan="5">Emission factor for building materials during transportation</td><td>Road freight</td><td rowspan="10">C_{TEE}</td></tr>
<tr><td>Rail road</td></tr>
<tr><td>Deep sea</td></tr>
<tr><td>Coastal vessel</td></tr>
<tr><td>Air transport</td></tr>
<tr><td rowspan="5">Emission factor for transportation of building materials</td><td>Road freight</td></tr>
<tr><td>Rail road</td></tr>
<tr><td>Deep sea</td></tr>
<tr><td>Coastal vessel</td></tr>
<tr><td>Air transport</td></tr>
<tr><td colspan="3">Installation with any accessories</td><td>C_{IEE}</td></tr>
<tr><td colspan="3">Operation</td><td rowspan="2">C_{OMEE}</td></tr>
<tr><td colspan="3">Maintenance</td></tr>
<tr><td colspan="3">Disposal (Recycle & Reuse)</td><td>C_{DEE}</td></tr>
</table>

8. Conclusion

The guideline developed through the research could be used as the primary costing framework for the selection of material. This captures not only manufacturing cost which is reflected in initial investment but also operation and maintenance cost, compensation costs for any environmental damages. The compact equation will make it more convenient for the decision maker to verify the effects of the usage of the martial thorough out of its LC and come to a final conclusion on the decision allowing a better flexibility in the decision in comparison to decision based on initial investment cost. The decision maker could suggest the factors for compensation for any environmental damagers if the host country does not have any taxation procedures for emissions related environmental damages. Any other such factors are more transparent in this approach and it gives the decision maker the flexibility to incorporate of all the factors that are crucial for sustainability.

As observed from the results, most crucial factor for the decision becomes the transportation component which may vary on the context of usage of the material. A particular material that may give a lower cost and less damage to the environment in one context may not be suitable for another context since emissions related to transportation may vary significantly with the transportation of the material across geographical borders.

The guideline developed through the research enables the buyer too to identify all components for costing related to building materials at the purchasing level and could be used as an alternative to the initial investment cost. This output captures all effects related to operation and maintenance which burden the end user. Effects on the environment too could be reduced at the level of the purchasing decision by the introduction of related taxes as compensation, which may change the purchasing decision. This change of decision will lead to selecting less harmful building materials and as a result will lead to a sustainable built environment.

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