DEVELOPING A FRAMEWORK FOR ASSESSING ECO-COSTS OF CONSTRUCTION SITE ACTIVITIES

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Sustainable development is a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are made consistent with the future as well as present needs. This requires a simultaneous consideration of many environmental factors in the process of determining optimum decisions in construction site activities. One of most important elements in sustainable development is eco-costs. Eco-costs are one important contributor to sustainable construction processes. Hence, a comprehensive framework for assessing the sustainability of construction site activities is presented. The relationship between process, policy, technology, impact and cost as well as the relationship between the environmental cost and the construction activities over the construction period is also discussed. A mathematical model for eco-costs for construction activities is presented.

Keywords: eco-cost, environmental, construction, sustainable,

INTRODUCTION

Sustainable waste management encourages the generation of less waste, and the reuse, recycling and recovery of the waste that is produced. The blueprint for effective social, economic and environmental development throughout the 21st century can be envisaged through the Agenda 21 framework. Agenda 21 is a comprehensive plan of action to be taken globally, nationally and locally by United Nations organisations, and amongst other issues, focuses upon the efficient management of waste.

The categorisation of waste has taken various guises to include material, time, money, labour, resource, energy etc. Some researchers (Koskela 1992, Alarcon 1993, Serpell et al. 1995 and Ishiwata 1997) defined construction waste as that that includes delay of time, quality, cost, lack of safety, rework, unnecessary logistics, improper choice of management, methods or equipment and poor constructability. Several definitions of waste have also been proposed in the literature including "any losses produced by activities that generate direct or indirect costs but do not add any value to the product from the point of view of the client" Farmoso et al. (1999). Symond (1999) defines wastes as any substance or object, which the holder intends, or requires to discard. However, construction material waste refers to any expended material from the construction processes that are unusable for the purpose of construction and require

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discarding due to the measurement, size and quality. It could be in the form of one or mixed of the following; solid, liquid, gas.

Though it seems that construction site waste makes a smaller contribution to the generation of C&D waste than demolition waste, this research focuses on construction waste. Construction waste is an important topic to quantify and analyse despite the lower volumes in comparison with demolition waste, since

- construction site waste consists of materials that contain high levels of contamination and a large degree of deterge neatly and very hard to recycle (Brooks et al. 1994}
- prevention of construction waste is preferable to recycling of demolition waste "at the end of the pipeline".
- construction waste contains a relatively large amount of chemical waste

cost reductions caused by preventing the generation of construction waste is of direct benefit to most of the a construction project stakeholders

Kincaid (1995) argues that waste is considered hazardous if it exhibits one of the following characteristics of hazardous waste such as ignitability (i.e., the ability to burn or cause a fire), corrosivity (i.e., the ability to eat away materials and destroy living tissue when contact occurs), toxicity (i.e., the ability to poison, either immediately or over a long period of time) and reactivity i.e., the ability to cause an explosion or release poisonous fumes when exposed to air, water, or other chemicals.

Several studies have been conducted in Brazil to determine the waste rates for construction materials on site. According to Pinto and Agopayan (1994), experimental studies pointed out that the waste rate in the Brazilian construction industry is as high as 20-30% of the weight of total materials on site. Hamassaki and Neto (1994) conclude on the basis of research in the south region of Brazil that 25% of construction materials are wasted during the construction process. Finally, Formoso et al. (1993) estimated the amount of construction waste generated in Brazil to be as much as 20% of all materials delivered to site. Fishbein (1998) reported that the construction site waste is estimated to be as much as 30 % of the weight of total materials on site. In a city, where the land is scarce in supply, the amount of space occupied by landfills will creates a severe problem for the state and local government in terms of social and economic management. Gavilan and Bernold (1994) and Craven et al. (1994) described lack of good management generally as one of the main causes of excessive waste generation.

Since the construction industry has historically consumed large quantities of raw materials, this sector has an important role in achieving progress towards sustainable development programme objectives. This requires a simultaneous consideration of many environmental factors in the process of determining optimum decisions in construction site activities. One of most important elements of sustainable development is the consideration of eco-costs. Eco-costs are one important contributor to sustainable construction processes. Therefore, the scope of this study will focus principally upon the eco-costs of construction site activities and processes.

MATERIAL WASTE AT CONSTRUCTION SITE

Material waste can occur not only through construction activities but also external factors such as theft and vandalism. These external factors are likely to influence the statistics on construction waste (Skoyles and Skoyles 1987). A second critical note is that the waste rates may not be directly comparable between countries due to differences in used in the construction techniques, work procedures, and common practices. Soibelman et al. (1994) stated, for example, that the real average loss of material has a significant variance, and is located between 0.85 and 8 times the usual recorded waste levels. Although some residual level of construction waste seems unavoidable, the potential cost reduction by preventing generation of construction waste on site is substantial and can be an incentive for construction project stakeholders to focus efforts on minimizing construction waste (Boussink and Browers, 1996).

Boussink and Browers (1996) reported the percentages of generated waste during construction operations for specific materials. The results showed that there is an enormous variation in waste percentages between different construction materials in the study. It was found that a waste percentage of 1% for concrete and 50% for mortar existed. The differences between waste percentages for specific construction materials between the three studies, is in most cases small. For instance, Pinto (1989) [cited in Boussink and Browers (1996)] and Pinto and Agopayan (1994) found a waste percentage for sand equal to 28%; Soibelman et al. (1994), a percentage of 31%. The percentages thus agree more or less with each other.

Gavilan and Bernold (1994) and Craven et.al (1994) describethe main causes of waste generation, which among others include, error in contract documentation, changes to design, ordering error, accident, lack of site control and lack of waste management, damage during transportation and off cuts from cutting materials to length. However, Chen (2002) emphasised that construction waste is still beyond control because of these three factors, construction firms reluctant to adopt low-waste technique as it is expensive to use; design coordination has a major impact of waste generation; on-site construction waste.

Smith et al (2003) identified the total material resource requirements by this sector in the UK in terms of the use of construction products and materials in 1998 by quantifying the total UK production and net imports and the waste generated in the production of construction products. The total estimation for the total mass of primary material resource used in the built environment by this sector is 295 Mt. Figure 1.0 shows the percentage of the primary materials used in the construction industry.

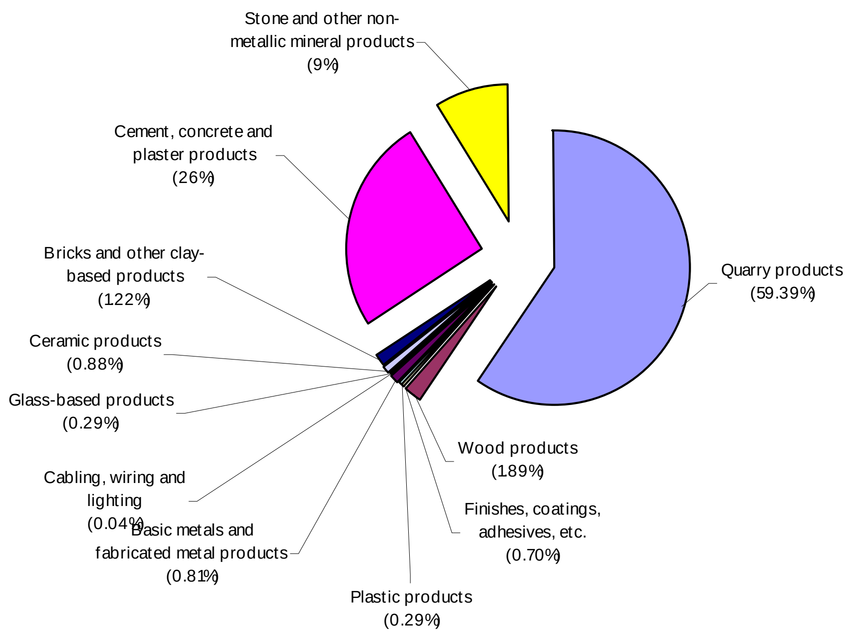

Figure 1.0: Percentage of the primary materials resources used in UK's construction industry [Adopted from Smith et al (2003)]

A case study conducted by researchers from Cardiff University on construction waste minimisation in UK housing recently revealed that waste streams vary greatly between different construction phases. However, in many cases overlapping of construction phases were observed that affect the type of waste arising on specific phases of the project. The study also found that the most of waste arises during the structure and fitting phases of construction. The fraction and volume of waste is shows in Figure 2.0 and Figure 3.0.

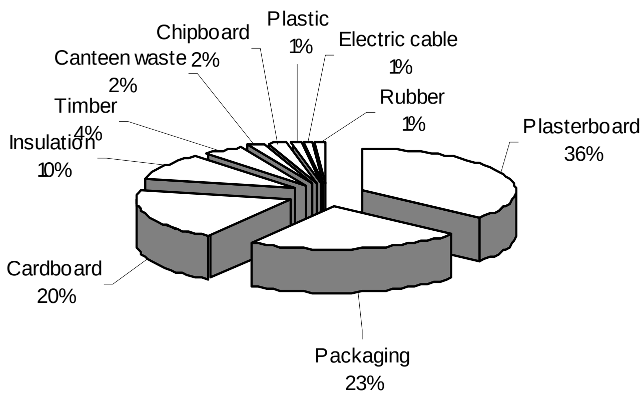

Figure 2.0: Waste fraction at various phase of construction (Source: Cardiff University)

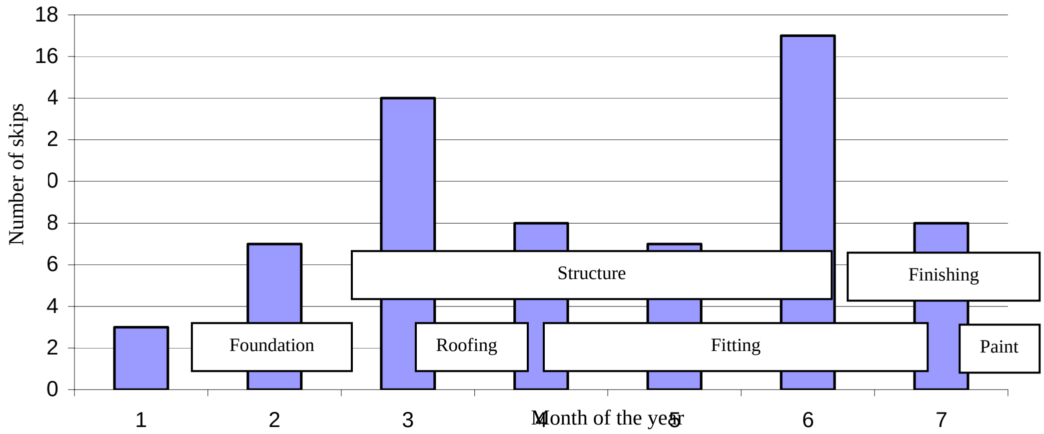

Figure 3.0: Number of skips used per month throughout the construction (Source: Cardiff University)

A FRAMEWORK FOR ASSESSING ECO-COSTS OF CONSTRUCTION SITE ACTIVITIES

The study will adopt a framework proposed by Yahya and Boussabaine (2004) that suggests using five key elements as shown in Figure 4.0. All these elements fall within the whole life cycle risk management category, where risk management is a key part of the techniques used to assist decision makers in evaluating whole life alternatives, in order to maximise the investment success in a building asset.

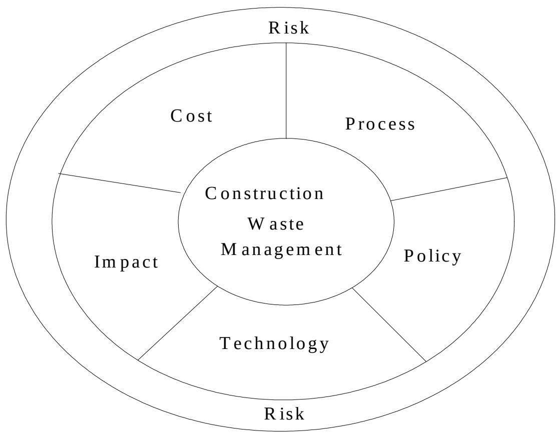

Figure 4.0: A framework for Assessing eco-costs of construction site activities [Adopted from Yahya and Boussabaine, (2004)]

IDENTIFICATION OF CONSTRUCTION SITE ACTIVITIES

Construction site activities will vary from one site to another depending upon the nature of the design. Generally, construction activities involve several phases that can be broadly grouped as land preparation, work in connection with utility supplies, substructure work (excavation and foundation work), superstructure (framing), 1st and 2nd fix and services installation (wiring, plumbing, insulation, drywall), finishing works (paint, exterior finishing and roofing), snagging and preparation for handover; landscaping and completion of external works. These may involve many parties like main contractors, sub-contractors and statutory undertakers. Each of these activities have the potential to produce waste like soil, contaminated soil, wood, metal, concrete, plastics, waste solvents, gypsum, wallboard, cardboard, boxes, paint solvents, brick, masonry, vinyl, stucco, asphalt shingles and tiles.

Investigation of waste management policies

Environment protection is an important aspect of the 21st century construction industry nowadays. For this research, the investigation will focus upon the identification of the current policy on handling of waste with respect to construction activities. An in-depth review of policy and best practices from several countries on construction waste is established. Investigation on the strategy taken by stakeholders is made in order to compare and broaden the ideas on how to tackle waste. Impact of the European landfill directive on waste management especially on construction industries is also reviewed. These include the Waste Strategy 2000 for England & Wales that describes the policies concerning the recovery and disposal of waste.

Selection of suitable technologies on site

Chen et al. (2002) stressed that construction waste is still beyond control because of three factors, firstly construction firms are reluctant to adopt low-waste disposal techniques as it is expensive to use; secondly, design coordination has a major impact on waste generation; thirdly, on-site construction waste. The identification of all options available for handling the waste stream from the construction site is essential before any of the waste from the construction site can be transferred to the landfill or incinerator. An investigation of the waste material should be made to determine any recyclable and reusable material. Waste separation techniques, storage and transport systems are amongst the common technologies use on site. Some examples of approach use on site are: bins or piles for separated wastes; mixed bins sorted off-site; removal of waste by sub-contractors; clean-up and removal of waste by a specialized waste hauler as shown in Table 2.0

Table 2.0: Several approaches use to manage wastes in construction site

Process	**Management Techniques**
Bins or piles for separated wastes	Separated loads must be transported by a waste hauler or company truck to recycling depots.
Mixed bins sorted off-site	Materials are recycled, but there is generally minimal or no cost saving on disposal fee because of the sorting required off-site. Some waste hauling companies may want to do the sorting themselves or some facilities specialize in sorting mixed loads. Some of these facilities only accept mixed loads with a high-percentage of recyclable materials.
Removal of waste by sub-contractors	Subcontractors usually generate a specific type of waste, and therefore, if waste is cleaned-up and separated as it is generated, recycling should be easy. If the sub is to be responsible for the clean-up and removal of the waste materials which he generates, then a definite clause should be written into the contract before work begins.
Clean-up and removal of waste by a specialized waste hauler	Some specialized waste haulers will clean-up and sort wastes from around a site. This saves the time of on-site workers from sorting the wastes. Contamination is also minimized, because the waste hauler has direct control over what is loaded on the truck. This waste hauler could either be a sub-contractor or a company employee.

(Source: City of Burnaby, Canada)

Determination of impact of construction site waste

The volume of waste generated depends on the waste management policy of the respective project stakeholders. Major potential sources of pollution from construction process are; waste materials, emissions from vehicles, noise and release of contaminants to atmosphere, ground and water. Though construction site waste makes a smaller contribution to the generation of C&D waste than demolition waste, it is important to prevent or reduce construction waste in order to enable of recycling of demolition waste "at the end of the pipeline". Hence, by preventing the generation of construction waste is of direct benefit for most of the participants who work at the construction project (Brooks et al. 1994). Otherwise, it may have cause an impact in achieving construction project objectives, such as environmental, financial, duration of work, quality of work, reputation, depletion of natural resources etc.

CONSTRUCTION SITE ECOLOGICAL COSTING QUANTIFICATION

Ecological Costing of Construction Site Waste

The ecological cost includes the direct and indirect environmental cost of the construction process. Different types of construction involve different types of activities. Each activity requires many types of resources; from materials, labour, time, cost capital etc. At the construction phase, whether in the form of indirect or direct, negative impact on the environment will occur. One important element that should be considered as sustainable is the environmental cost or the eco-costs of construction wastes. Eco-costs of the construction site activities will include waste control, recycling and reuse, waste disposal, repair, impact, eco policy (i.e. taxes and levy), labour, equipment, emission and energy. Each of these elements has it own cost breakdown that contributes toward the main heading of cost structure of the eco-costs. The identification of these elements of each category will help to clarify the specific cost related to the environment during the construction stage.

The cost structure of the eco-costs of construction waste at the construction stage includes [Adopted from Senthil Kumaran, D et al. (2000); Yahya and Boussabaine (2004)]:

$$\Sigma \text{ Cost of waste control, } C_{wc} = C_{wc1} + C_{wc2} + C_{wc3} \quad (1)$$

Where, C_{wc1} = cost of waste control system implementation

C_{wc2} = cost of waste control system operation

C_{wc3} = cost of waste control system maintenance

$$\Sigma \text{ Cost saving of recycling and reuse, } C_{rr} = C_{rr1} - (C_{rr2} + C_{rr3}) \quad (2)$$

Where, C_{rr1} = cost of implementation/operation

C_{rr2} = cost of saving from recycling strategies

C_{rr3} = cost of saving from reuse strategies

$$\Sigma \text{ Cost of waste disposal, } C_{wd} = C_{wd1} + C_{wd2} + C_{wd3} \quad (3)$$

Where, C_{wt1} = cost of waste collection

C_{wt2} = cost of waste transportation

C_{wt3} = cost of waste landfill or incineration

Σ Cost of impact, C_i = any cost of all damage, accidents, health disorder, production losses etc. (4)

Σ Cost of eco policy, $C_{ep,}$ = any cost involving taxes, levy, penalties etc. (5)

Σ Cost of energy, C_e = Σ $C_{ei,}$, i = 1 to *n* (energy consumption) (6)

Σ Cost of emission of equipments, C_{em} = any cost of related to emission from the equipment use on site (7)

Σ Cost of depreciation of equipments, C_{de} = depreciation cost of equipment on site (8)

Σ Cost related to labour, C_{lab} = any cost related to labour on site (9)

The cost breakdowns of eco-costs for construction waste during construction stage are based on the following simple mathematical eco-costs algorithm:

$$\text{Total of Eco-costs} = C_{wc} + C_{wd} + C_{ep} + C_e + C_{rr} + C_i + C_{em} + C_{de} + C_{lab} \quad (10)$$

An attempt will be further developed and refined to include all the elements related to eco- impacts that are linked to construction waste by developing a format for quantifying all the construction eco-costs attributes. Afterwards, comment from construction stakeholders will be used to develop a questionnaire for data gathering.

Eco-cost construction site activities quantification

Eco-costs of construction site activities are a part of the total eco-cost on construction site. For the complete calculation of eco-costs, attributes in the previous section (section 3.5.1) should take into account as well. However, to clearly understand the calculation and the illustration on this section, the attribute in section 3.5.1 is deliberately ignored. Based on the construction site activities in Figure 3.0, eco-costs are calculated by using data in Table 3.0. Assumption value has been made for the average built-up area of housing and number of housing as 90m^2 and 50 respectively. The eco-cost is calculated for the lifetime of the building.

Table 3.0: Eco-costs of construction materials and activities on site

CONSTRUCTION SITE ACTIVITIES	**Eco-costs** (Euro/m^2)	**Life time** (year)	**Eco-costs** (Euro/m^2/annum)
Main material in construction:			
- concrete, 300 kg/m2 (eco-costs 0.2 Euro/kg)	60	40	1.5
- steel, 50 kg/m2 (eco-costs 1.8 Euro/kg)	90	40	2.25
- miscellaneous materials, 50 kg/m2 (glass, wood, PVC, etc.)	30	40	0.75
- building activity (energy, etc.)	40	40	1.00
Subtotal construction building structure	220	40	5.50
Building systems (heating, electrical, water, etc.)	60	20	3.00
Interior (painting, decorating, furniture, etc)	120	15	8.00
Total			**16.5**

(Adopted from: Vogländer and Hendriks, 2002)

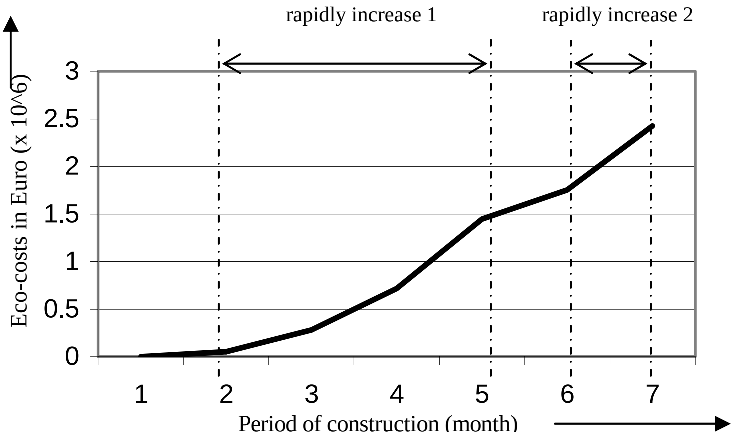

Figure 6.0: Trendline of eco-cost by period of construction

The trendline of the cumulative eco-costs of the construction site activities is shown in Figure 6.0. It is shows that the eco-costs is rapidly increase at two period of time that are from the beginning of construction of building structure until the completion of the phase and during interior works is done. It is also shows that the fitting installation phase contributes to this phenomenon. It is also noted that, trendline may vary from one construction site to another but it believed that the eco-costs and volume of waste is significantly higher at structure and fitting stages compared to other phases of construction.

CONCLUSION

Waste generation by construction activities has a significant impact on environment. The need of establishing indicators to measure the sustainability of construction site activities is crucial. Eco-cost is one of the indicators that can help to monitor sustainable construction. It is the authors' intention to develop a sustainable waste quantification eco-costs model based on an empirical study approach during the construction site stage as a contribution to construction industry. As part of the research, the development of eco-costs algorithm will be made in each of the activities during the construction processes. Past research shows that construction waste management is broad and most of the current research on this area has focused upon a fairly limited number of materials in a few construction sites. It is also the authors' hope to complete this research with the cooperation of construction stakeholders and the result will beneficial to the construction industry.

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