Abstract: Sustainability of a construction project is often considered as a very important parameter in evaluating the success of the project. Though the management of material waste that generated as a result of on-site construction activities were initially regarded as less important to the overall sustainability of the project, current trends proves it otherwise. Leadership in Energy and Environmental Design (LEED) is one of those driving-forces that make the construction waste management an important sustainability indicator of a construction project. As a result of LEED as well as other assessment tools, construction waste management is very common in practice. However the effectiveness of the current management practices is questionable because prediction of waste material quantities is often neglected during the process. Therefore, to accomplish effective construction waste management (minimization, recycling, reuse, etc.) it is essential to predict quantities of construction waste which essentially depends on identifying the sources of waste generation and their relationships to quantity of waste.

This paper presents the findings of a current research work on prediction of construction waste based on activity based construction waste generation method. The proposed activity-based construction waste generation modeling facilitates material waste predictions using several parameters including activity specific factors, environmental factors, worker related factors, etc. Statistical model that Predicts the drywall waste generation was presented in this paper. The study was based on the work carried out at several building construction sites in Calgary, Alberta. The findings can be incorporated into a planning tool which can essentially be used for the construction waste management process at sites.

Keywords: Construction waste management, Planning, Prediction

1. Introduction

Sustainable development practices, which ensure societal and environmental advancements in addition to economic benefits, are well recognized and enforced by almost all municipalities/local governments in Canada if not across the globe. Being one of the largest business sectors, construction industry plays a significant role in providing social and economical development to the society. For instance, the Canadian construction sector contributes 5.95% of the GDP through employing over one million individuals [1]. Beside that, construction industry consumes large amounts of natural resources and generates large amounts of material wastes (the amount of material waste produced over the year 2000 being 11 million tonnes from the construction sector [2].
It is the reality that construction industry’s profit margin is tight and that construction companies have to streamline their processes and activities in such a way to survive in the industry [3]. Because economic benefits are not usually revealed through implementation of waste management programs on-site, it seemed to be common that contractors give little consideration to waste management aspects of construction compared to meeting other targets and schedules [4]. Therefore, the most common solution for construction waste materials generated during construction was to deposit at landfills. At times construction waste materials were considered harmless for the environment, and therefore social and environmental acceptance for such practices were also evident [5]. However with the evolution of research in the area of solid waste management, and with global acceptance on sustainable construction principles, landfill disposal of construction waste materials is now considered the last available option in the waste management hierarchy (Figure 1).

![Waste Management Hierarchy](image)

Figure 1: Waste Management Hierarchy

Although landfill disposal of construction waste materials is still the most preferred option for many construction companies, more than 75% of construction waste materials have the potential for reuse or recycling [6]. In fact sustainable rating systems such as Leadership in Energy and Environmental Design (LEED) encourage such practices in new building construction projects.

**LEED** rating system that launched in 2004 by LEED Canada provides relatively more comprehensive tool to evaluate the sustainability of a building, especially in the Canadian context. It recognises leading edge buildings that incorporate design, construction and operational practices that also ensure healthy, high-quality and high-performance in the process with reduced environmental impacts. Presently, LEED is one of the widely accepted sustainable building rating systems [7] that has been adopted by almost all construction companies in Canada. LEED measures sustainability of a building using five key areas under which credits are awarded for each sustainable practice recognized within the area. Major categories in the rating system are: Sustainable sites, Water efficiency, Energy and atmosphere, Materials and resources, and Indoor environmental quality. LEED has four performance ratings available as illustrated in Table 1.
Table 1: LEED Canada Performance Rating

<table>
<thead>
<tr>
<th>Level</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Certified</td>
<td>26 – 32</td>
</tr>
<tr>
<td>Silver</td>
<td>33 – 38</td>
</tr>
<tr>
<td>Gold</td>
<td>39 – 51</td>
</tr>
<tr>
<td>Platinum</td>
<td>52 - 70</td>
</tr>
</tbody>
</table>

LEED recognizes the importance of on-site construction waste management within its rating system allocating maximum of 6 points dedicated for waste management from the materials and resources category. Further, it is noteworthy that construction waste management credits are the most common to obtain by the Canadian construction companies to attain their desired LEED certification [8].

Because Leadership in Energy and Environmental Design (LEED), one of the mostly accepted and widely recognized sustainable building rating systems [7], gives an impeccable place to on-site construction waste management within the rating system; there now exists a growing trend towards the implementation of sustainable waste management techniques. However, the economic viability of waste management programs has rarely been studied while a previous study confirms all such programs may not be delivering the sustainability goals [9].

2. Background: Construction waste, generation and management

This study defines construction waste as “waste materials produced in the process of construction of structures; the structures include both residential and non-residential buildings as well as roads and bridges”. Building construction waste is the main focus of the study. Typically building construction waste stream consists of materials such as concrete, brick, wood, rubble, metals, drywall, cardboard, floor tiles and roofing materials.

Construction waste generation

The severity of the construction waste problem can be identified from the studies performed in different parts of the world on building waste material quantities [10, 11, and 12]. Skoyles (1976) identified thirty seven building materials of having material wastages from 2 to 15% of the designed amount of material [10]. 1-10% wastes from the purchased material quantities based on a study in Netherlands [11]. Another study based on the construction projects in Australia, indicates the material wastage to be 2.5-22% of the total material purchased [12]. Though the percentages of waste from construction materials are different from region to region, the important finding is that the quantity of construction waste generation is significant irrespective of the location. Evidently the type of construction, construction technology, and the rules and regulations imposed by the local authorities can have an impact on the material wastages indifferently. It is evident that the generation of construction waste is increasing over the years creating a series of problems in various regions in Canada. For instance in Alberta, one of the rapidly growing provinces in Canada has reported a 68.6% increase of construction and demolition waste generation over the period 2000-2006 [13] where, approximately one third of C&D waste is coming from new constructions in Alberta.

Significance of annual construction waste generation and its impact on the environment and the society as a whole has created a situation that encourages every builder to consider construction waste management seriously. It is the current trend to seek socially accountable building/construction practices from the industry. However for effective management should be preceded by planning and scheduling and to facilitate front end planning of the waste management process for a given construction project, it is essential and necessary to predict the waste quantities. To the astonishment, the studies that focus on construction waste management and cost effectiveness of the waste
management programs do not include predictions.

3. Planning construction waste management

Prediction gives us an opportunity to see the future and plan events beforehand. Predictions can be based on experience or knowledge, but not always. Scientifically, prediction can be identified as a rigorous, often quantitative statement forecasting the future events under specific conditions. Prediction has become a challenging task because of the unavailability of construction waste quantity and quality related data in the industry [14]. Unavailability of data may be considered as a result of many reasons identified by previous researchers [14, 15, and 16] and could be listed as follows:

- not keeping construction waste records due to reasons such as not having or not adapting regulatory requirements
- not motivated to keep records or manage in any form because it has been considered as a non-value added task
- Considered as a potential trouble for other activities’ progress

This paper focuses on prediction of construction waste using activity-based waste generation principle. Principle of activity-based waste generation assumes that total quantity of construction waste generated at a particular time in a construction site is the accumulation of waste quantities from each construction activity that is being executed at that moment. Therefore, prediction of total quantity of construction waste is possible only if each and every activity’s waste generation can be predicted.

Factors of Waste Generation:
Prediction of construction waste quantities starts with identifying relationships with other measurable factors in the environment where waste is generated. More importantly, identification of causal relationships is the key to prediction. Construction being a highly labour intensive industry research on construction waste management should also consider on people’s attitudes and behaviour as well. More importantly the labourers, foremen, leadhands and tradesmen who directly involve with the construction activities need to be part of the study. Construction waste generation cannot narrow to the construction phase because recent findings confirm that causes of construction waste generation spans over almost all the stages of the project [3, 11, 17, and 18].

After extensive literature reviews and the pilot study which was carried out in a Calgary building construction site, the authors identified the factors identified in Table 2 as of important to waste generation and considered for further study aiming for the purpose of prediction of waste quantities. Further, it must be noted that these causes were of great interest specifically for the main focus which is drywall construction waste generation predictions. Some of the human and non-human factors that considered for the study were grouped to facilitate statistical inferences and the detailed procedure of factor grouping is available in Wimalasena et al. (2010) [19].

Table 2: Factors of waste generation

<table>
<thead>
<tr>
<th>Non-Human Factors</th>
<th>Comfort Index (CI)</th>
<th>Working Temperature (°C)</th>
<th>Relative Humidity (%)</th>
<th>Wind Speed (km/h)</th>
<th>Precipitation (mm)</th>
<th>Light Level (lux)</th>
<th>Work Space (m²)</th>
<th>Distance to Material Store (m)</th>
<th>Labour Hours (h)</th>
<th>Work Quantity (m³)</th>
<th>Material Size Required/Material Size Ordered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Factors</td>
<td>Competency</td>
<td>Labour skill</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4. The proposed model

Developing waste generation prediction model was conducted using multiple regression analysis and the computation procedure includes the following main steps:

1. Calculate the correlations between different factors (Bivariate correlation analysis). The Statistical Package for Social Sciences (SPSS) was used to perform this analysis.
2. Select appropriate independent variables employing the backward elimination regression procedure and then the possible variable interactions were also considered.

The resultant model, waste generation function for drywall construction activity, which explains 71.5% of the variability (R square = 0.715) of the dependent variable is given below:

\[ QW = \beta_0 + \beta_1 WQ + \beta_2 LH + \beta_3 LL + \beta_4 CI + \beta_5 CI^2 + \beta_6 DM + \beta_7 SL + \beta_8 SLLH + \epsilon_1 \]

where, coefficients of the reduced model is shown in Table 3.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Variable Description</th>
<th>Coefficient Label</th>
<th>Coefficient Value</th>
<th>Significance (p value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-</td>
<td>( \beta_0 )</td>
<td>330.035</td>
<td>0.086</td>
</tr>
<tr>
<td>WQ</td>
<td>Work Quantity</td>
<td>( \beta_1 )</td>
<td>1.193</td>
<td>0.000</td>
</tr>
<tr>
<td>LH</td>
<td>Labour Hours</td>
<td>( \beta_2 )</td>
<td>-50.508</td>
<td>0.007</td>
</tr>
<tr>
<td>LL</td>
<td>Light Level</td>
<td>( \beta_3 )</td>
<td>0.033</td>
<td>0.000</td>
</tr>
<tr>
<td>CI</td>
<td>Comfort Index</td>
<td>( \beta_4 )</td>
<td>-22.937</td>
<td>0.026</td>
</tr>
<tr>
<td>CI^2</td>
<td>Comfort Index^2</td>
<td>( \beta_5 )</td>
<td>0.974</td>
<td>0.014</td>
</tr>
<tr>
<td>DM</td>
<td>Distance to Material store</td>
<td>( \beta_6 )</td>
<td>-2.431</td>
<td>0.075</td>
</tr>
<tr>
<td>SL</td>
<td>Skill Level</td>
<td>( \beta_7 )</td>
<td>-271.119</td>
<td>0.177</td>
</tr>
<tr>
<td>SLLH</td>
<td>Skill Level*Labour Hours</td>
<td>( \beta_8 )</td>
<td>70.539</td>
<td>0.006</td>
</tr>
</tbody>
</table>

The fitted model implies that there is a positive impact of light level (p value < 0.0001), work quantity (p value < 0.0001) on the drywall waste quantity, and a negative impact of Distance to Material Store (p value = 0.075) on waste quantity after controlling for Labour skill Level and labour hours. However, there is a quadratic effect of CI (p value = 0.014) on waste quantity and interaction effect (p value = 0.006) of Labour Hours and Labour skill Level on the waste quantity.

ANOVA table (Table 4) tests the acceptability of the model from statistical perspective. It confirms that more than 71% of the variation of dependent variable is explained by the model. Because the significance of the F test is less than 0.05, the variation explained by the model is not due to chance. Therefore the ANOVA test confirms the model’s strength in explaining the variation of the dependent variable.
5. Practical Applications of the model

There are two main practical implementations of the waste generation prediction model in building construction projects:

1. The model helps identifying the significantly correlated factors to quantity of waste generation from a construction activity. This is useful for developing material waste reduction strategies, as it enables focusing on important environmental factors.

2. Prediction model is an essential part of the on-site waste management planning process. A planning tool which can easily be integrated to a simulation model is useful for on-site waste management operations planning and even at the pre-planning stage.

The following are applications of the prediction model for a planning tool:

1. Simulate the quantity of waste generation from construction activities accounting for the randomness of activities and dynamic nature in the representation.

2. Simulate the cost and benefits of the entire waste management process to identify the costs or benefits of practicing alternative waste management options, reuse, recycle and landfill disposal for all waste types. This will be helpful to determine the cost-effective waste management alternative for each material type.

3. Simulate waste material storing process to determine site space requirement for the waste management process. This will be an important finding to make specially when the construction site is located in a highly populated, congested area.

4. Simulate cost benefits of the process to determine the cost-effective hauling schedule.

In order for a model to be successful in the construction industry, model requires to be easily learnt and used by a person without much simulation knowledge. Also the model must be able to change with the change of project as industry is dynamic by nature. It is necessary to accommodate already existing project information without further processing into such a planning tool to ensure it saves time and energy avoiding duplicate work.
6. Conclusions

On-site construction waste management is an important component of a construction project; thus plays a significant role in project’s sustainability. However, success of the waste management program mostly relies on planning and scheduling as other construction activities do. The paper introduces a drywall waste prediction model based on a novel concept “activity-based construction waste generation principle” and based on the data collected from several building construction projects in Calgary, Alberta. The model which can easily be integrated into a planning tool will be useful for decision making at different stages of the project, construction operations as well as pre-planning stages. Other main applications of the model in building construction industry are also discussed in the paper. The proposed planning tool incorporating the prediction model, other project information and a simulation model which would be a ready-to-use tool for the construction industry is also included. This would be a useful tool to evaluate economic viability of the on-site waste management programs such as recycling, and reuse.

References

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