ON-SITE CONSTRUCTION WASTE MANAGEMENT: ACTIVITY-BASED WASTE GENERATION

B. A. D. S. Wimalasena[1], J. Y. Ruwanpura [2], J. P. A. Hettiaratchi[3]

[1]PhD Candidate, Project Management Specialization, Department of Civil Engineering, University of Calgary, 2500 University Drive NW, Calgary AB, T2N 1N4, Canada.
[1]E-mail: swimalas@ucalgary.ca; sujeewaw@gmail.com
[1]Telephone: 1 403 220 4812; Fax: 1 403 282 7026

[2]Director and Associate Professor, Project Management Specialization, Department of Civil Engineering, Schulich School of Engineering, University of Calgary, 2500 University Drive NW, Calgary AB, T2N 1N4, Canada.
[2]E-mail: janaka@ucalgary.ca
[2]Telephone: 1 403 220 6892; Fax: 1 403 282 7026

[3]Professor, Centre for Environmental Engineering Research and Education (CEERE), Schulich School of Engineering, University of Calgary, 2500 University Drive NW, Calgary AB, T2N 1N4, Canada.
[3]E-mail: jhettiar@ucalgary.ca
[3]Telephone: 1 403 220 5503; Fax: 1 403 282 7026

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).

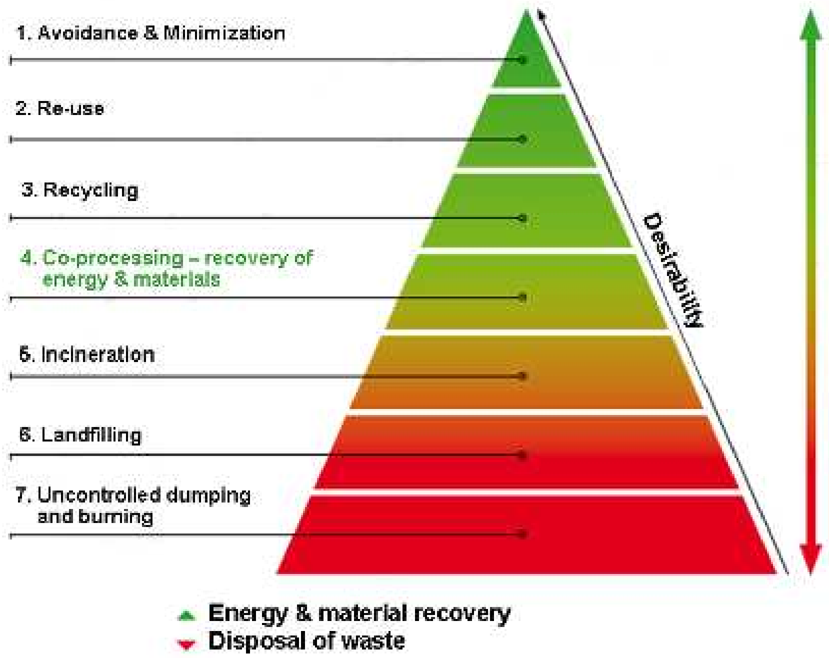

Figure 1: Waste Management Hierarchy

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

Level	**Points**
Certified	26 – 32
Silver	33 – 38
Gold	39 – 51
Platinum	52 - 70

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 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

Non-Human Factors	Comfort Index (CI)	Working Temperature (C)
		Relative Humidity (%)
		Wind Speed(km/h)
		Precipitation(mm)
		Light Level(lux)
		Work Space(m^2)
		Distance to Material Store (m)
		Labour Hours (h)
		Work Quantity (m^2)
		Material Size Required/Material Size Ordered
Human Factors	Competency	Labour skill

		Adaptability to the Organization
		Adaptability to the Job site
		Knowledge about waste generation methods
	Satisfaction	Satisfaction over the method of communication (to receive instructions, etc.)
		Satisfaction over the Working hours

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 dependant variable is given below:

$$QW = \beta_0 + \beta_1 WQ + \beta_2 LH + \beta_3 LL + \beta_4 CI + \beta_5 CI^2 + \beta_6 DM + \beta_7 SL + \beta_8 SLLH + \varepsilon_1$$

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

Table 3: Model Coefficients

Variable	**Variable Description**	**Coefficient Label**	**Coefficient Value**	**Significance (p value)**
Constant	-	β_0	330.035	0.086
WQ	Work Quantity	β_1	1.193	0.000
LH	Labour Hours	β_2	-50.508	0.007
LL	Light Level	β_3	0.033	0.000
CI	Comfort Index	β_4	-22.937	0.026
CI^2	Comfort $Index^2$	β_5	0.974	0.014
DM	Distance to Material store	β_6	-2.431	0.075
SL	Skill Level	β_7	-271.119	0.177
SLLH	Skill Level*Labour Hours	β_8	70.539	0.006

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.

Table 4. ANOVA

Model	Sum of Squares	df	Mean Square	F	Significance
Regression	202166.507	8	25270.813	19.475	.000
Residual	80452.703	62	1297.624		
Total	282619.210	70			

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

29. Statistics Canada. (2008). *Waste management industry survey-Business and government sectors 2006.* Statistics Canada, Environment Accounts and Statistics Division, Ottawa, Canada.
30. Statistics Canada. (2000). *Waste management industry survey 2000-business and government sectors survey guide* (No. STC/NAD-291-04165). Environment Accounts and Statistics Division, Canada.
31. McGrath, C. (2001). Waste minimisation in practice. *Resources, Conservation and Recycling, 32*(3-4), pp. 227-238.
32. Poon, C. S., Yu, A. T. W., and Ng, L. H. (2001). On-site sorting of construction and demolition waste in hong kong. *Resources, Conservation and Recycling, 32*(2), pp. 157-172.
33. Kartam, N., Al-Mutairi, N., Al-Ghusain, I., and Al-Humoud, J. (2004). Environmental management of construction and demolition waste in kuwait. *Waste Management, 24*(10), pp. 1049-1059.
34. Nobe, M. C. (2007). *Values and construction waste recycling: An application of the cognitive hierarchy to construction management education.* Ph.D., Colorado State University.
35. Syal, M. G., Mago, S., and Moody, D. (2007). Impact of LEED-NC credits on contractors. *Journal of Architectural Engineering, 13*(4), pp. 174-179.
36. Da Silva, L., and Ruwanpura, J. Y. (2009). Review of the LEED points obtained by canadian building projects. *Journal of Architectural Engineering, 15*(2), pp. 38-54.
37. Wimalasena, B. A. D. S., Madanayake, H. L. S. P., Weerasinghe, I. P. T. R., Ruwanpura, J. Y., and Hettiaratchi, J. P. A. (2010). Recycling as a construction waste management technique. *Proceedings of Institution of Civil Engineers: Waste and Resource Management, 163*(2), pp. 49-58.
38. Skoyles, E. F. (1976). Material wastage: A misuse of resources. *Building Research and Practice,* July/April, pp. 232-243.
39. Bossink, B. A. G., and Brouwers, H. J. H. (1996). Construction waste: Quantification and source evaluation. *Journal of Construction Engineering and Management - ASCE, 122*(1), pp. 55-60.
40. Forsythe, P., and Marsden, P. K. (1999). Modeling construction waste performance-an arising procurement issue. Paper presented at the *Profitable Partnering in Construction Procurement, CIB W92 (Procurement Systems) and CIB TG23 (Culture in Construction) Joint Symposium,* London, UK, pp. 679-688.
41. Alberta Environment. (2010). *Construction and demolition.* Retrieved Aug. 17, 2010, from http://environment.alberta.ca/02794.html
42. Kofoworola, O. F., and Gheewala, S. H. (2009). Estimation of construction waste generation and management in thailand. *Waste Management, 29*(2), pp. 731-738.
43. Boileau, H., Achard, G., Lachambre, V., Charvin, F., Hibon, F., and Duc-Jacquet, E. (1996). Building sites construction waste management and reduction: The experience of a french school of engineering. *Proceedings of the 1st International Conference on Environmental Engineering Education and Training, EEET'96,* , pp. 229-238.
44. Yost, P. A., and Halstead, J. M. (1996). A methodology for quantifying the volume of construction waste. *Waste Management and Research, 14*(5), pp. 453-461
45. Poon, C. S., Yu, A. T. W., Wong, S. W., and Cheung, E. (2004). Management of construction waste in public housing projects in HongKong. *Construction Management and Economics, 22*(7), pp. 675-689.
46. Urio, A. F., and Brent, A. C. (2006). Solid waste management strategy in botswana: The reduction of construction waste. *Journal of the South African Institution of Civil Engineering, 48*(2), pp. 18-22.
47. Wimalasena, B. A. D. S., Ruwanpura, J. Y., and Hettiaratchi, J. P. A. (2010b). Modeling construction waste generation towards sustainability. Paper presented at the *Proceedings of the 2010 Construction Research Congress (CRC),* Banff, Alberta, Canada., pp. 1498-1507.

Acknowledgements

The researchers wish to acknowledge the support and funding for this research project by Natural Sciences and Engineering Research Council (NSERC) for its discovery grant titled "Project Management (PM) Models and Practices to Improve and Manage Sustainability of Building Construction Projects"**.**

About the Authors

B. A. D. S. WIMALASENA, B.Sc. Hons. Moratuwa., is a PhD Candidate at the Department of Civil Engineering, University of Calgary, Canada. His research interests are in the areas of sustainable construction, environmental consideration in built environments, and project planning and controls.

J. Y. RUWANPURA, PhD. Alberta., PQS (Canada), is an Associate Professor and Director of Project Management Specialization at the Department of Civil Engineering, University of Calgary, Canada. He also holds the Canada Research Chair in Project Management Systems. His research interests include: Integrated Risk Management and Simulation, Modeling tools, sustainability, technological advancements and productivity improvement.

J. P. A. HETTIARATCHI, M.Eng., PhD. Alberta., is a Professor at the Department of Civil Engineering, University of Calgary, Canada. His research interests are sustainable landfill technology, complex hydrocarbon contaminated sites remediation, green house gas emission technology development, optimization of landfill construction and operation, and recycling of construction waste.