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Quantification of brick waste generated in housing construction sites via site sampling: development of a linear regression mode

Siti Hafizan Hassan[1, 2, *], Hamidi Abdul Aziz [1], Izwan Johari [1], Mohd Nordin Adlan [1]

[1]*School of Civil Engineering, Engineering Campus, University Sains Malaysia, Nibong Tebal, Penang, Malaysia*
[2]*Engineering, Faculty of Civil Engineering, UiTM Pulau Pinang, Permatang Pauh, Pulau Pinang*

Abstract: Construction waste generated on construction sites, such as new housing developments, are typically buried and hidden. However, this practice may result in unstable land settlement and ground water pollution. Aside from causing environmental pollution, such wastes can incur construction costs as well, of which construction materials account for the largest proportion. An example of the waste generated on construction sites is brick waste; therefore, in this study, we determine the brick waste generated in various construction stages and conduct a multiple linear regression analysis of the amount of waste produced. The methodology employed involves site observations, interviews with site personnel, and the sampling of brisk waste of housing construction sites via the weighing method. The regression model established based on the sample data reported an R^2 value of 0.781; therefore, the model can predict approximately 78.1% of the factors involved in brick waste generation. Moreover, the multiple linear regressions can be applied as tools to predict the brick waste generated at construction sites.

Key words: Brick waste; Site sampling; Quantification; Multiple linear regressions

1. Introduction

Reducing, reusing, and recycling waste can help reduce the costs of construction projects. By implementing good practices starting from the early stages of the design and planning process, clients and contractors can secure these savings and demonstrate corporate responsibility. Such actions reflect the commitment of corporations to supporting the target sector in halving the amount of landfill waste generated (WRAP, 2015).

Fatta et al. (2003) found that few materials are reused such as wires, glass, frames of doors and windows. Some of the construction waste likes broken brick and concrete can be reused as a sub-grade of access road to the construction (Nagapan et al., 2012). Osmani (2011) promotes the awareness in the building construction industry about the benefit of waste minimization including cost savings and environmental issues and use of recycled and reclaimed materials.

Waste is generated on construction sites usually due

to defective materials, leftover materials, wastage, etc. Poon et al. (2004) and Shen, Tam, Tam and Drew, (2004) identified the construction waste as the waste which arises from construction, renovation and demolition activities including land excavation or formation, civil and building construction, site clearance, demolition activities, roadwork, and building renovation. The expected waste generated from conventional construction is shown in Table 1 below. The generation of waste was divided by the construction stages.

Table 1: Expected waste generated from conventional construction (Hassan et al., 2009)

Construction Stage	Expected major construction waste
Site clearance	Soil, rock
Sub-structure works	Reinforced concrete, steel bar, concrete, wood
The super - structure works	Wood, steel bar, cement, sand, aggregate, brick
Finishing works	Cement, sand, aggregate, tiles, paints, lime
Infrastructure works	Bituminous materials, timber, concrete

1.1. Brick waste causes

According to Hassan et al. (2015) brick wastes are the highest amount generated at the site. Brickwork starts after the structural work completed. The sources of waste for bricks start when the workers work with the bricks. The workers put the bricks in a wheelbarrow to the working area. Rough jobs lead bricks to crack and splinter. Brick management strategies need to be applied in reducing the brick waste at the sites. From the site observation, the use of skilled workers for bricklaying will reduce the amount of brick waste.

Some of the bricks got damaged because of improper handling by the workers. The use of used bricks as a part of construction materials is very important in order to reduce brick waste at the sites.

* Corresponding Author.

The role of supervisor in managing waste is important because the supervisor is the waste solver at the sites. Another reason that causes the brick waste are the supervisor's mistakes. Muhwezi et al. (2012) point out that improper handling such as changing orders or instructions by supervisor is part of waste contribution. Poon et al. (2004) highlighted that improper stacking and handling is one of the reasons of waste generated. Table 2 is presenting the common causes of waste by Lau et al. (2008).

Table 2: Common causes of construction waste generation (Lau et al., 2008)

Waste Type	Descriptions	Causes
Brick	Clay brick Cement brick Wall, fencing works, Partition walling Cinder block	Wall, fencing works, Gutters Wall, fencing works, Partition walling Wall, fencing works

1.2. Previous study on the weighing method and regression analysis

Franklin Associates (1998) presented an approach similar to the waste-weight-per-construction area. Previous studies have been carried out such as by Lu et al. (2011) which focus on four ongoing high rise construction projects in Hong Kong. Measurement was made for three months' time and on site sorting at floor level before going to the chutes. The measurement was divided into four typical trades which was concreting, formwork, masonry and plastering. The calculation can be measured using four methods; percentage of material purchase, percentage of material required by design, kg/m^2 of gross floor area and m^3/m^2 of gross floor. The method of survey was done by the composition of volume and mass and the Waste Generation Rates was found between 3.275 – 8.791 kg/m^2.

From the study by Katz and Baum (2011), they found that the amount of waste increased towards the end of the project. The total amount of waste generated in residential construction was 0.2 m^3/m^2. The method of study was site observation in the new residential building (10 high-rise building). They also used the dumpster to get the total volume, degree of filling and the relative volume. The sampling of the total waste from accounting book was done by project activity and construction stages.

Poon et al. (2004) reviewed the amount of waste at five housing projects during superstructure and finishing stages. The methods used in the study were visual inspection, tape measurement and truck load record (truck volume and total no of trucks for waste disposal). They found that the total waste generation rate, 0.176 m^3/m^2. Table 3 summarized the previous study of weighing method.

The regression analysis is one of the most widely used in statistical technique. The study of the regression analysis techniques will also provide certain insights into how to plan the data collected (Draper and Smith, 2014). The variables of a regression model can be tested statistically to select the best number of variables that fit best to the available data (Sahin and Gunduz, 2015). Andrea et al. (2015) stated that the use of multiple linear regressions as a data treatment tool is feasible. The approach can be utilized by decision makers in a pro-active manner with the objective to predict the amount of construction waste and establish a benchmark to reduce waste generation, the key and most effective step in waste management.

Table 3: Summary of weighing method

	Waste Measurement	Method
Lu et al. (2011)	Percentage of material purchase, % of material required by design, kg/m^2 of gross floor area and m^3/m^2 of GF.	Waste sorting and weighing at 4 sites in Shenzhen (building)-3 month monitors
Katz and Baum (2010)	Using Dumpster -Total volume -Degree of filling -Relative volume	Site observation -Using Dumpster -Sampling total waste from accounting book -By project activity New residential building (10 high-rise building) By construction stages
Poon et al., (2004)	The volume m^3 of waste generated per m^2 of gross floor area	-Visual inspection, tape measurement and truck load record At five housing projects during superstructure and finishing stages
Franklin Associates (1998)	-	-Combine national data on construction industry project activity with waste sampling and weighing -Single family residential construction
Bossink and Brouwers (1996)	Weight (of purchasing materials)	-Sorted and weight the waste materials -Five housing projects

Regression analysis is not widely used for the construction waste projection. Previous study by Koshy and Apte (2012) found that through the method of correlation, transit loss, absence of authorities and handling, and over ordering were found to be factors that have high correlation with total cement wastage by chutes, buckets, and pumps, respectively. Their studies focusing on the cement wastage and the causes of waste generated.

Andrea et al. (2015) conducted a study using multiple linear regression and found that the set of these variables was able to predict approximately 69% of the factors involved in the waste generation in high-rise residential buildings of the sample, since the statistical model presented coefficient of determination (R^2) = 0.784 and the adjusted coefficient of determination (adjusted R^2) 0.694. This sampling involved 18 buildings with different company.

2. Methodology

2.1 Site selection

The selected construction sites for study are located in Pulau Pinang, Malaysia. The type of housing examined is a two-story terrace house. According to Mahayuddin and Zaharuddin (2013), similar housing types must be investigated.

The methods employed in this research are site observations, site sampling, and personnel interviews. Site observations involve monitoring concreting activities at the construction site. The researcher visited the area during the performance of bricklaying activities to review site operations. The observation process began during the early stage of bricklaying and ended with the completion of this task. The researcher also interviewed site personnel to obtain information related to these activities. Data on the area, the number of skilled and unskilled workers, and their years of experience were documented as well.

2.2. Site sampling method

2.2.1. Weighing method

According to Lau (2008), the scattered (random and weigh) waste can be divided into two which is the waste such as broken bricks, cement bricks, roof tiles and cement bags. The second consists of waste with large variation in size, such as off cuts of steel roofing sheet, plastic packaging and off cuts of gypsum or plaster board. Idealizing from his study, the weight method was applied to the bricks. The equipment used for the weight method includes the following: a) buckets, b) a weighing scale, and c) shovels. The weight was obtained in kilogram (kg). The flow of weighing process was shown in Figs. 1, 2 and 3. The weighing procedures follow the procedures suggested by Mahayuddin and Zaharuddin (2013):

- Providing adequate bucket for collection of all types of construction waste. For this study the bucket size is 0.7 x 0.5 x 0.4 m.
- Recording the data in inventory format. The main data recorded is the amount of waste generated, the numbers of skilled and unskilled workers, the block of activities, the structures involved and any matters related to that activity.
- Summation of waste quantity in percentage (%).

The data were analyzed through linear regression to identify the relationship between the dependent variable Y (waste) and the independent variables X. The independent variables were denoted by X_1 = area, X_2 = skilled workers (1), X_3 = skilled workers (2), X_4 = skilled workers (3), X_5 = skilled workers (> 4), X_6 = unskilled workers (1), and X_7 = unskilled workers (2). All analyses were conducted with IBMSPSS statistical software.

Fig. 1: Brick waste generated at construction sites

Fig. 2: Brick waste was collected

Fig. 3: Brick waste was weighed

Muhamad et al. (2015) presented the few stages required to establish an MLR model. In Stage 1, 80% of the data for each variable is randomly selected with MATLAB R2014a. In Stage 2, the classification depicted in Table 1 is used to interpret the obtained correlation coefficient values. The most important variables are derived with IBM SPSS Statistic 22. The final variable selected is X_1 = area. In Stage 3, the variance inflation factor (VIF) is applied to check the multicollinearity test in consideration of the main variables selected. The model is free of multicollinearity problems if VIF value is less than 10. OLS assumptions are checked in Stage 4 (Table 1); then, the models are validated by a performance indicator (NAE, PA, IA, and R2) in accordance with a 20% complete monitoring record. The MLR model is obtained in stage 5.

Performance indicator: Performance indicators are applied to evaluate the prediction capability of performance models. These models (Table 4) consist of accuracy measures (PA, IA, and R^2) and error measures (NAE).

Table 4: Interpretation of the strength of correlation results (Namgolo and Musingwini, 2011)

Correlation coefficient range	Strength of correlation
0.00-0.30	Weak
0.31-0.50	Moderate
0.51-0.80	Strong
0.81-1.00	Very strong

Table 5: Ordinary least square assumption (Chatterjee and Hadi, 2006)

Assumption	Checked by
Residuals follow a normal distribution	Normal P-P plot
Residual has constant variance	Scatter plot (the spread of point)
Residuals are uncorrelated with the Independent variables	Durbin Watson test statistics (no\autocorrelation present in error if close to 2)

Performance indicator: Performance indicators are used to evaluate the performance models for predictions. The performance models (Table 3) consist of accuracy measures (PA, IA and R^2) and error measures (NAE).

Table 6: Performance indicators (Gervasi, 2008)

Performance Indicator (PI)	Notes
Normalized Absolute Error (NAE)	Close to 0, model is appropriate
Index of Agreement (IA)	Close to 1, model is appropriate
Prediction Accuracy (PA)	Close to 1, model is appropriate
Coefficient of determination (R^2)	Close to 1, model is appropriate

Results and discussion

The classifications depicted in Table 1 are generally used to interpret correlation coefficient values statistically. The results are grouped into ranges to define the strength of the correlation among variables, and the correlation coefficient range represents both positive and negative correlations. According to Nangolo and Musingwini (2011), a test that generates an R-value of 0.25 can be interpreted as a sign of a positive but weak correlation between two variables. A test with an R-value of −0.25 can be indicative of a negative but weak correlation.

Therefore, correlation strength was defined as indicated in Table 7 to interpret the R-values of the statistical analysis conducted in this study. Only very strong correlations variables are considered in this study. In line with this regulation, the correlation value of the sole area selected to determine the main variables associated with generated brick waste is 0.881.

Table 7: Correlation result

Variables	Correlations value (R)
Area	0.881
X_1	-0.709
X_2	0.136
X_3	0.426
X_4	0.526
X_5	-0.364
X_6	0.635

To investigate the correlation between waste and independent variables (area), a regression analysis was conducted based on the correlation coefficient value (R^2). The R^2 value of the developed model is 78.1%, thus implying that 78.1% of the variations in the amount of brick waste generated are explained by the regression model that covers this area.

According to Montgomery et al. (2012), the model is subject to a multicollinearity problem if the VIF value is larger than 10. Therefore, the proposed brick waste prediction model is free from multicollinearity because the VIF value (1) is lower than 10.

Multiple linear regression analysis establishes several key assumptions, one of which is that the residuals are normally distributed with zero mean and constant variances. Residual analyses are important in determining the adequacy of statistical models. The criteria for normal distribution refer to the degree to which the plot of the actual values coincides with the line of expected values. The plot of the residuals was shown in Fig. 4 for this problem fits the expected pattern well enough to support the conclusion that these residuals are normally distributed with zero mean.

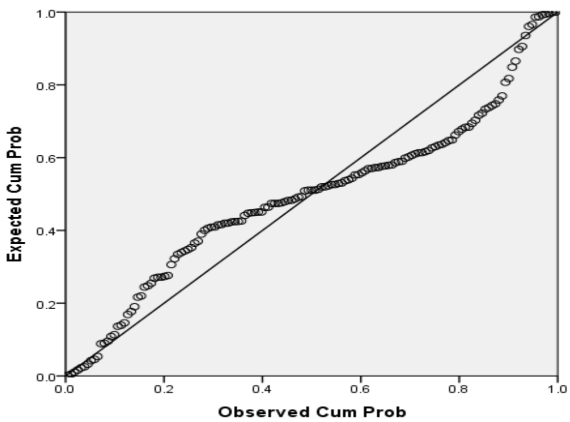

Fig. 4: The plot of the residuals

This residual plot exhibits a random scatter; as such, no obvious pattern can be observed in Fig. 4. The assumption that the residual displays a constant variance is satisfied when the scatter plot exhibits an equal spread and approach to the regression line (homoscedacity). Moreover, the assumption that the residuals are uncorrelated with the independent variables is satisfied because the Durbin–Watson value (2.3) is close to 2. In summary, the analysis described above verifies that the developed model can be used to predict the brick wastes generated by housing construction projects.

Table 8: Multiples linear regression and performance indicator

Model	BW = 1.7 area +3.285
Normalized Absolute Error (AE)	0.3283
Index of Agreement (IG)	0.88
Prediction Accuracy (PA)	0.8
Coefficient of determination (R^2)	0.6

Table 8 shows the performance indicators for brick waste, which were obtained from the multiple linear regression models. The predicted values of the accuracy measures IA, PA, and R^2 are 0.88, 0.8, and 0.6, respectively, for brick waste. Furthermore, the predicted average error value (NAE) is 0.3283. The values of PA, IA, and R^2 are close to 1; thus, the model is suitable for predicting brick waste generation. Furthermore, the NAE value is close to zero.

4. Conclusions

This study recommends the use of multiple linear regressions to investigate the amount of brick waste generated from brick laying activities in housing construction sites. The analyses were only conducted from the construction stages and only considered the brick laying activities. The projected amount may be utilized for future improvement in brickwork activities. The limitation of this study is that the dataset used is small because of the limited time and the challenge involved in brick activities. The coefficients can be predicted more accurately by using a larger data set.

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