Journal of Contemporary Research in the Built Environment
Volume 1, Number 1, March 2017

PREDICTION OF MATERIAL WASTE GENERATION AT CONSTRUCTION STAGE OF LOW RISE BUILDINGS

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ABSTRACT

Purpose: This research is steered towards developing models for predicting the quantity of material waste generated during construction stage of building projects employing in-situ construction method and the comparison of predicted quantity with the actual waste generated on site.

Design/methodology/approach: The data used for the development of the models were sourced from thirty on-going projects through research assistants for six-month period consisting of one hundred and fifty cases of measurement of material waste. Standard multiple regression was utilised to develop the models. To test the accuracy of the developed models, paired sample t-test was used to compare the actual waste and the predicted quantity of waste.

Findings: The model for concrete work in slab embraced three predictors: the theoretical quantity for work done, building gross floor area and the amount of rainfall accounting for 44.36%, 5.95% and 2.50% of the variance in the waste generated during concrete works in slab respectively. While the model for predicting waste generation during blockwork comprises of theoretical quantity of block for work done, the height from floor and the area of site undeveloped explaining 43.82%, 10.82% and 2.28% of the variance in the waste generation of block work respectively.

Research limitations/implications: The results of this study are limited to new projects adopting in-situ construction method. Practitioners in the building industry within the study area can predict the amount of material waste anticipated in low rise construction with good accuracy using the developed models.

Originality/value: This study revealed that material waste generation on building sites is predictable. There is no significant difference between the actual material waste generated on site and the predicted quantity using the developed models.

Keywords: Actual waste; developed models; low-rise building; material waste; predicted waste

1. INTRODUCTION

Material waste in construction is defined as the difference between the value of those materials delivered and accepted on site and those properly used as specified and accurately

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measured in the work, after deducting the cost-saving of substituted materials and those transferred elsewhere while the loss is expressed as a percentage of deliveries (Enshassi, 1996). Materials in construction are the physical items that are purchased and used to produce the final product (building or road structures) and this does not suggest that materials are the final product. In other words, materials are the parts used to produce the final product. Baily and Farmer (1982) define materials as the goods purchased from sources out of the organisation that are used to produce finished products. Stukhart (1995) defines materials as the items that are used to produce a product and which include raw materials, parts, supplies and equipment items. Chitkara (2008) described materials as a broad term that denotes all purchased items utilised at the project site including constructional materials, supporting plants and equipment, and administrative facilities and stores.

Construction materials constitute a major cost component in any construction project. The total cost of installed materials (or value of materials) may be 50 percent or more of the total cost (Stukhart 1995, Bernold and Treseler, 1991), even though the factory cost may be a minor part of the total, probably less than 20 to 30 percent (Perdomo, 2004). Poor planning and control of materials, lack of materials when needed, poor identification of materials, re-handling and inadequate storage cause waste which can indirectly increase total project cost. Effective management of materials can reduce these costs and contribute significantly to the success of the project.

Cha, Kim and Han (2009) asserted that there are four major impacts of construction phase, namely: construction waste, noise, dust and air pollution. Among these impacts, construction waste has been reported to be one of the most harmful (Bossink & Brouwers, 1996; Teo & Loosemore, 2001). According to Santos (1999), the levels of waste generation in the construction sector remain high despite the economic and social pressures on it. For instance, there is a lower level of productivity when compared with the manufacturing industry and the social pressure of high housing costs.

Many authors, from both developed and developing countries, have consistently shown that the level of material waste generated on site significantly exceeds the estimator’s allowance at the pre-contract stage of construction project. For instance, Formoso, Soibelman, Cesare, and Isatto (2002) observed that the volume of material waste generated from seven materials on five building sites in Brazil and discovered values ranging from 5.06 to 11.62 percent in terms of cost which were above initial allowed values. Reports from Norway indicated that the estimated costs due to nonconformity, errors, alterations and wastage in the course of the building process, were around 10 percent of the total building cost (Adewuyi, 2012). Usually, the range of 5 to 10 percent material wastage is allowed for by the estimator at the preliminary stage of a project, depending on the type of material, but recent studies discovered that the percentage of on-site waste of materials is contrary to the provisional and that the material waste can be as high as 20 to 27 percent in some cases (Formoso, Soibelman, Cesare, & Isatto, 2002; Datta, 2000; Agyekum, 2012; Adewuyi, Idoro & Ikpo, 2014). Formoso, Isatto and Hirota (1999) concluded that the average material wastage was much higher than what was usually assumed in cost estimates for most materials, indicating that waste allowances were nominal figures supported by very little practical evidence.

Hence, the call for waste management plan, effective project’s cost management, mastering or adopting best practices in construction process, effective material management as applicable to construction industry and many other measures that would curtail the magnitude of material waste generation in construction industry. Cha, Kim and Han (2009) stated that stakeholders’ concerns on waste management have increased, therefore, it is not trivial to assess objectively and quantitatively the effectiveness of waste management performance on project basis. It has equally been revealed that excessive generation of material waste can impact on contractor's profit margin (Fellows, Langford, Newcombe & Urry, 2002), project's cost (Adewuyi, 2012) and much more importantly the impact of the generated waste on the environment (Cochran, Townsend, Reinhart, & Heck, 2007; Formoso, Soibelman, Casare & Isatto, 2002). The existing high volume of waste generated during the construction of projects is not only detrimental to construction cost and time but also the productivity of workers, project environment and the society at large. The negative impact of construction waste has prompted several studies on how to minimise it. But no local study, within Nigeria nor the study area, is known to this research to have attempted the prediction of material waste generation. This research therefore, is an effort to predict the anticipated quantity of material waste that can be generated during the construction stage of new projects, especially while employing the common traditional in-situ construction method commonly used in developing countries. This study, therefore, targeted the objectives of:

(i) Developing models for predicting material waste generated on building sites adopting in-situ construction method in the study area; and
(ii) Validating the developed models by comparing the actual and the predicted levels of material waste generation on site;

A null hypothesis for validating the accuracy of the developed models was postulated to ascertain their degree of dependability.

Ho: There is no significant difference between the predicted and the actual quantity of material waste generated on site in the study area.

The waste generated by construction industry varies and depends on the type of construction works concerned. It includes construction waste generated from new construction, demolition works, reworks, rehabilitation and so on in the Building industry. In the Civil Engineering works, the waste generated may be from road works (new construction, repairs and maintenance) and ancillary facilities associated with these works. This study is limited to the measurement and prediction of material waste generated from new construction on the building sites. In the Building industry, there are various uses of building developments which include commercial, educational, industrial, residential, social, health developments and so on while the development may be of low or high rise. These may be grouped into either public or private developments. The volume of work involved to investigate all these types of works may be too enormous for a study of this nature. Therefore, the work study for this research is limited to wastes generated on on-going public buildings (e. g. Office blocks, Law courts, and so on) and public educational buildings (such as classroom blocks in tertiary institutions, libraries, laboratories, to mention a few) sampled within the study area which were of low rise developments. Additionally, there are several construction techniques/methods which include in-situ construction, semi-prefabrication, comprehensive prefabrication, volumetric prefabrication, lean construction, system formwork, and so on. Observations during the work study for this study is limited to the traditional in-situ construction method.

2. METHODOLOGY

The six States in the South-South geopolitical zone of Nigeria were focused in this study. The data used for the development of the model were collected from thirty (30) on-going projects through research assistants for six-months period using the research instrument described in Adewuyi (2012). The projects were purposively selected in each State of South-South geopolitical zone of Nigeria. The data collected consisted of one hundred and fifty (150) cases of measurement of material waste, with thirty (30) cases from each of the selected projects, for each type of the two selected materials (concrete and block works). Another set of data collected from six (6) projects, different from the aforementioned, were reserved for the purpose of model validation, with five (5) cases of measurement of material waste from each of the project site adding up to make thirty (30) cases. All the selected building projects were low rise and constructed using traditional in-situ construction method involving concrete works in suspended floor slab with floor beams and 225mm thick block works. The data for daily average sunshine and rainfall were obtained from the meteorological centre in each of the States for the period of six months covered by the study. The meteorological centres are close to the project sites. The data set collected for monitoring material waste generated on building sites and the parameters causing the waste as collected during the work study were used to develop multiple linear regression models in the form:

$$Wg = a+b_1X_1+ b_2X_2\ldots\ldots\ldots\ldots\ b_9X_9 \qquad \textit{Equation 1}$$

where:

Wg= Predicted waste generated on site as a dependent variable
a = Regression constant
$b_1, b_2, b_3 + \ldots\ldots + b_9$ = Partial regression coefficient
$X_1, X_2, X_3 \ldots\ldots X_9$ = Parametric independent variables causing waste on site

In this research, standard multiple regression analysis was utilised to develop the models for predicting the generation of material waste on low rise building site employing in-situ construction method. As a preliminary step to establishing the correlation between the dependent and the independent variables, the value of R, which is the coefficient of correlation, was assessed based on Pallant (2007) guidelines such that R-value of 0.10 to 0.29 is regarded as a small correlation, 0.30 to 0.49 as a medium correlation while R-value of 0.50 to 1.0 is judged to be a large correlation. Secondly, the preliminary step of the analysis was espoused to ensure that there is no violation of the rules of normality, linearity, and homoscedasticity and outliers. This was done by inspecting the Histogram of Regression Standardised Residual to ensure that there is no skewness in the data set, the Normal Probability plot (P-P) of Regression Standardised Residual and the Scatterplot. The multicollinearity problem was resolved by the inspection of the "Collinearity Diagnostic" table in the preliminary analysis. If the condition index > 30 and the tolerance value in the "coefficient" table for that variable is less than 0.10 or VIF value is above 10, then it suggests multicollinearity problem (Tabachnick & Fidell, 2007).

The "scatterplot" diagram was inspected to check for outliers. Tabachnick and Fidell (2007) defines outliers as cases that have a standardised residual of more than 3.3 or less than -3.3. Additionally, the Cook's Distance in the residual statistics table was inspected to ensure no major problem is caused by the presence of any outlier. Tabachnick and Fidell (2007) suggested that cases with Cook's Distance of more than 1 are potential threats to the model.

The measure for the goodness-of-fit for the model is the coefficient of determination (R^2), which represents the proportion of dependent variable variance that is accounted for by its linear relationships with the independent variables. To determine whether the model, with its independent variables, is a significant predictor of the dependent variable (that is, significant test for R^2), a statistical significance test is performed using the F-statistic. The R^2 value is statistically significant, or different from zero, if the computed F-statistic is greater than the F-critical value for the defined probability level. For this study, the p-value used was put at 0.05 level. Therefore, for the output interpretation, if the obtained significance level (p-value) associated with the F-statistic is less than 0.05 (at 95 percent confidence), then R^2 is statistically significant.

Standard multiple linear regression was used to assess the abilities of the parametric causes of waste generation of concrete work in floor slab and blocks. Preliminary analyses were performed to ensure that assumptions of normality, linearity, homoscedesticity and outliers not violated. The preliminary regression model for the selected building materials were developed, thereafter, the factors that did not significantly contribute to the model were dropped one after the other according to their level of insignificance. The p-value of the factor in the regression model, comparison of closeness of fit (error measures), and prediction accuracy of the models with and without the factor were the criteria used to determine the significance of the factor in the model. One error measure: Mean Square Error (MSE) and two prediction performance measures: R^2 and index of agreement (I.A.) were used to compare the closeness of fit and prediction performance of the models. The index of agreement (I.A.) was computed with the expression in Equation 2 in consonance with the studies of Ujene and Idoro (2015).

$$I.A. = 1 - \frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}(|P_i - \bar{O}| + |O_i - \bar{O}|)^2} \qquad Equation\ 2$$

where:

Pi = predicted value of case i;

Oi = observed value of case i;

Ō = mean values of O

To test the accuracy and validity of the developed models, paired sample t-test was carried out to confirm if there is any significant difference between the actual (observed) waste and the predicted quantity of waste expected to be generated on building sites. To validate the models, paired T-test was used at $p \geq 0.05$ (95% level of significance). The rule for the rejection of the hypothesis is that when the p-value > 0.05, the test fails to reject the hypothesis, however, when the p-value ≤ 0.05, the test rejects the hypothesis. The test was carried out on each of the two models developed.

3. VARIABLES SELECTED FOR MODEL DEVELOPMENT

Based on reviewed relevant literatures on causes of construction material waste on building sites, parametric significant factors (variables) from past studies which are associated with the height of the active work, cross-sectional area of building element, distance from material storage point to the active usage point, the *i*th number of floor level, total area of site, area of site developed and area of site undeveloped and the number of storey levels of the building were used in the construction material waste estimation models. In addition, parameters associated with building's gross floor area were also identified as being significant.

Amount of rainfall and amount of sunshine were also identified as significant parameters to be considered in construction material waste prediction model. The fact remains that if these parameters were not reckoned with, then the weather and storage factors effects will not be reflected and one is bound to digress from very good results. To produce a successful construction waste estimating model, the amount of rainfall and sunshine in project location must be considered in the model development.

The first step to multiple regression analysis was the selection of the variables to be used in the analysis. Multiple regression analysis is a dependence technique; therefore, the variables to be used as the dependent variable and the independent variables must be specified. The selection of both types of variables should be based principally on conceptual or theoretical grounds (Phaobunjong, 2002). As in all functional models, there must be logical relationships of the independent variables to the dependent variable.

For this study, the selection of the parameters to be used in the model development was based on the available project data and the significant relationship between the independent variables and the dependent variable. In addition, since the intent of the model is not only for the identification and explanation of the parameters affecting construction waste, but also for use in estimating the construction waste, the quantitative characteristics or measurability of the values of the variable; availability with reasonable accuracy in the early project stages when conceptual construction waste estimation is required were considered.

In this study, the data were derived from projects located in South-South of Nigeria, for the six-month period of field survey. However, their distributions are not even, with most projects concentrated in major cities. In addition, a major portion of the projects were also derived from projects under construction during the data collection period. Due to this unevenness in distribution, and the very limited representations of the data for most cities and year, the time and location influences on the waste data are accounted and adjusted for through the data normalisation process during model development. Figure 1 shows the conceptual relationship between the dependent variable (Quantity of waste generated) and the independent variables. The measurable factors causing construction waste generation, described as parametric measurable factors in Figure 1, were considered appropriate and suitable as independent variables for this study and hence, were selected as follows:

1. Theoretical quantity for work done (Q_2)
2. The building gross floor area of the project (Ag)
3. The height of the active work (H)
4. Distance from material storage point to the active usage point (D)
5. The height of floor, measured from the general ground level, at which the active work is being carried out (Fn)
6. Total area of site (At)
7. Area of site developed (Ad)
8. Area of site undeveloped (Au)
9. Amount of rainfall for the day the work is carried out (R)
10. Amount of sunshine for the day the work is carried out (S)

These building and construction process parameters selected are quantitative measures of the building and construction process characteristics that are well established with clear definition. These parameters are also usually the first few parameters identified for the building and location of construction project. Building gross floor area and number of floor levels are measures of the scale of the project. These variables have been shown to significantly affect the building construction waste, and are thus considered in this study. The amount of waste generated is the dependent variable for the models which is designated Wpc and Wpb for predicted concrete waste and blocks respectively.

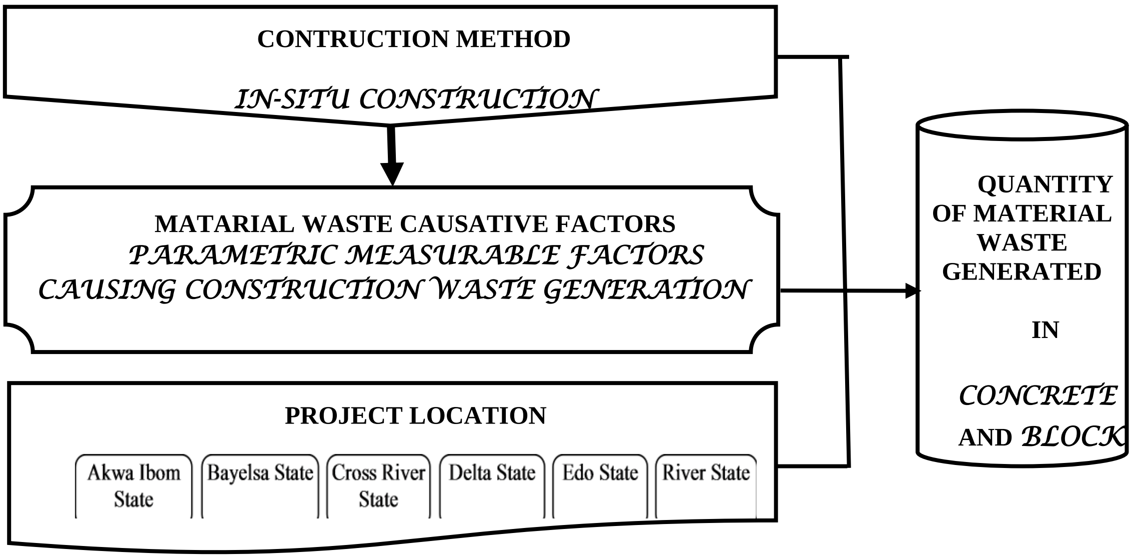

Figure 1: A Conceptual Model for Predicting Quantity of Construction Material Waste Generation on Low-rise Building Site

4. DEVELOPMENT OF MODEL

4.1. Development of Model for Predicting Concrete Waste Generation in Slab with Floor Beams

Standard multiple regression analysis was used to assess the ability of nine (9) parametric variables to predict the amount of unit cubic meter (m^3) of concrete wasted during concrete work in 150mm thick slab with associated floor beams. Preliminary analysis was carried out to ensure no violation of the assumption of normality, linearity, homoscedesticity, independence of residuals and to mitigate the effect of outliers as shown in Table 1.

The initial result indicates unacceptable multicollinearity problems with condition index of 36.723 > 30 (see Table A in the Appendix attached as an example of the output of the regression analysis). The total area of site (At) and the Area of site developed (Ad) are excluded from the model due to singularity problem between them and the area of site undeveloped. The tolerance value of Building's gross floor area (Ag) and Area of site undeveloped (Au) are 0.010 and 0.008 < 0.1 respectively and their corresponding VIF of 101.782 and 119.242 > 10 respectively (Table E of Appendix). This suggest multicollinearity problem. Despite this initial problem, Building's gross floor area (Ag) was retained because its condition index of 5.13 < 30 (Table A of Appendix) and the Area of site undeveloped (Au) is dropped. This action resolved the multicollinearity problem as indicated by the condition index of 18.615 < 30, tolerance values > 0.1 and VIF < 10 for the first regression model for concrete work in slab (MRS-1) as indicated in Table 1. However, the assumptions of normality, linearity, homoscedasticity were not violated as indicated in the normal probability plots, histogram, and scatter plot. Maximum Cook's Distance = 0.118 < 1 indicating that the little cases of outliers existing are within acceptable limits that will not influence the regression analysis. The sample size (N) is 150 cases > (50+8m) as suggested by Tabachmick and Fidell (2007) for a standard multiple regression is satisfied, where m is the number of independent variables involved in the model. The summary of the steps through the development of the model for material waste generation in concrete slab MRS-1 to MRS is presented in Table 1 which also shows the highest condition index, the least tolerance and the highest VIF of each of the models, indicating the improvement and hence the preference of each successive model to the preceding one.

Table 1: Preliminary Analyses of Modelling Material Waste in Concrete Work in Floor Slab

		Closeness of fit	Prediction Performance		Significance Check			Condition Index	Tolerance	VIF
Step	Model	MSE	R^2	I.A.	Operation	Term	P-value			
1	MRS-1	7.478	0.494	0.9171	drop	Fn	0.853	18.615	0.201	4.967
2	MRS-2	8.971	0.494	0.9170	drop	S	0.495	12.208	0.203	4.937
3	MRS-3	11.177	0.492	0.9167	drop	D	0.303	10.480	0.204	4.907
4	MRS	14.78	0.489	0.9159	All remaining variables are significant			9.168	0.981	1.020

MSE = Mean Square Error; R^2 = Coefficient of determination; I.A. = Index of Agreement

The height of floor, measured from the general ground level, at which active work is being carried out (Fn), becomes the variable with the highest p-value of 0.853. Removing this variable from MRS-1 produced model MRS-2 which is preferred to MRS-1. The next variable in model MRS-2 with the highest p-value (0.495) is the Amount of sunshine (S). This variable was expunged to give model MRS-3 which has a better prediction performance. Model MRS-3 is preferred to MRS-2 for the same reason. Distance from material storage point to the active point of usage (D) is the next variable with the highest p-value (0.303). Hence it was removed from MRS-3 to give MRS which has p-values of all the remaining independent variables < 0.05 as shown in Table 2 with R^2 value of 0.478 as reflected in Table 3. The multiple linear regression model for concrete work in slab (MRS) presented in Table 2 with all its attributes can be reproduced as in Equation 3.

Table 2: Coefficients[a] Table of the Regression Model for Concrete in Slab (MRS)

	Unstandardised Coefficients		Standardised Coefficients	t	Sig.	95.0% Confidence Interval for B		Correlations			Collinearity Statistics	
Model	B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
(Constant)	.065	.187		.351	.726	-.303	.434					
Q_2	.111	.010	.670	11.246	.000	.091	.130	.641	.681	.666	.987	1.013
Ag	-1.257E-7	.000	-.244	-4.084	.000	.000	.000	-.157	-.320	-.242	.981	1.020
R	.013	.005	.159	2.674	.008	.003	.022	.132	.216	.158	.993	1.007

a. Dependent Variable: Waste generated

Q_2 = Volume of quantity for effective work done; Ag = Building's gross floor area;

R = Amount of Rainfall

$$Wcs = 0.065 + 0.111Q_2 - 1.257E\text{-}7Ag + 0.13R \qquad \textit{Equation 3}$$

where:

Wcs = Waste generated in concrete work in slab

Q2 = Theoretical quantity of concrete for work done

Ag = Building's gross floor area

R = Amount of rainfall

The variance of waste generated in concrete work in slab explained by the model is 47.8% as reflected in Table 3 which has Theoretical quantity for work done (Q_2), Building's gross floor area (Ag) and Amount of rainfall (R) as independent variables as shown in Table 2. The p-value for the model is 0.000 < 0.05, therefore, it can be concluded that the quantity of waste generated during concrete work on building sites is predictable. Variables in the model listed with their beta and part correlation values in descending order of their unique contributions to the variance in the dependent variable are: Theoretical quantity for work done (beta = 0.670, part = 0.666), Building gross floor area (beta = -0.244, part = -0.242) and Amount of rainfall (beta = 0.159, part = 0.158).

Theoretical quantity of concrete for work done (Q_2) makes the strongest unique contribution to explaining the variance in waste generation during concrete work in slab when the variance explained by all other variables in the model is controlled for. This implies that the theoretical quantity for work done uniquely accounted for 44.36% of the variance in the waste generated during concrete works in slab. In the same vein, Building gross floor area and Amount of Rainfall uniquely accounted for 5.95% and 2.50% of the variance in the waste generation of concrete works in slab respectively. The properties of model MRS is presented in Table 3.

Table 3: Summary of Regression Model for Concrete work in Slab (MRS)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	F	Sig.
1	.699[a]	.489	.478	.56392	46.505	.000[a]

a. Predictors: (Constant), Amount of Rainfall, Theoretical quantity for work done, Building's gross floor area

b. Dependent Variable: Waste generated in Concrete work

4.2 Development of Model for Predicting Block Waste Generation in Walls using 225mm Thick Blocks

Standard multiple regression analysis was used to assess the ability of the nine (9) parametric variables to predict the amount of number of blocks wasted during blockwork activities on building sites. As checked for the model of concrete work in slab, preliminary analysis was also carried out to ensure no violation of the assumption of normality, linearity, homoscedesticity, independence of residuals and to mitigate the effect of outliers. These conditions were checked as explained above under the model of concrete work in slab. The summary of the results is presented in Table 4. The same process as explained in the development of model for concrete work in floor slab was followed and the results are presented in Tables 5 and 6.

Table 4: Preliminary Analyses of Modelling Material Waste in Blockwork in 225mm Thick Wall

Step	Model	Closeness of fit	Prediction Performance		Significance Check			Condition Index	Tolerance	VIF
		MSE	R^2	I.A.	Operation	Term	P-value			
1	MRB-1	3289.870	0.538	0.9867	drop	H	0.686	17.492	0.615	1.625
2	MRB-2	3834.679	0.540	0.9867	drop	D	0.693	14.677	0.615	1.625
3	MRB-3	4597.639	0.543	0.9866	drop	R	0.354	12.676	0.615	1.625
4	MRB-4	5719.786	0.543	0.9866	drop	Ag	0.276	12.051	0.618	1.619
5	MRB	7576.071	0.552	0.9864	All remaining variables are significant			11.503	0.970	1.031

MSE = Mean Square Error; R^2 = Coefficient of determination; I.A. = Index of Agreement

Table 5: Coefficients[a] of the MLR analysis for Waste Generation in blocks (MRB)

Model	Unstandardised Coefficients B	Unstandardised Coefficients Std. Error	Standardised Coefficients Beta	t	Sig.	95.0% Confidence Interval for B Lower Bound	95.0% Confidence Interval for B Upper Bound	Correlations Zero-order	Correlations Partial	Correlations Part	Collinearity Statistics Tolerance	Collinearity Statistics VIF
(Constant)	-11.253	4.891		2.301	.023	-20.918	-1.587					
Q_2	.108	.009	.662	11.917	.000	.090	.126	.637	.702	.660	.995	1.005
Fn	2.912	.498	.329	5.846	.000	1.928	3.897	.306	.436	.324	.970	1.031
Au	1.206E-6	.000	-.151	-2.695	.008	.000	.000	-.197	-.218	-.149	.975	1.025

a. Dependent Variable: Waste generated; Q_2 = Theoretical quantity for work done; Fn = The height of floor measured from the general ground level at which the active work is being carried out; Au = Area of site undeveloped

Table 6: Regression Model for Blockwork (MRB)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	F	Sig.
1	.743[a]	.552	.543	11.24075	59.959	.000[a]

a. Predictors: (Constant); Area of site undeveloped; Theoretical quantity for work done; The height of floor measured from the general ground level at which the active work is being carried out

b. Dependent Variable: Waste generated in Block work

The multiple linear regression model for block work in is written as in Equation 4.

$$W_b = -11.253 + 0.108Q_2 + 2.912Fn - 1.206E\text{-}6Au \qquad \textit{Equation 4}$$

where:

W_b= Waste generated in block work

Q_2 = Theoretical quantity of block for work done

Fn = The height of floor, measured from the general ground level, at which the active work is being carried out

Au = Area of site undeveloped

The variance of waste generated in blockwork explained by the model is 54.3% which has Theoretical quantity for work done (Q_2), The height of floor, measured from the general ground level, at which the active work is being carried out (Fn) and Area of site undeveloped (Au) as independent variables as shown in Table 6. The p-value for the model is 0.000 < 0.05, therefore, it can be concluded that the level of waste generated during block work on building sites is predictable. Variables in the model listed with their beta and part correlation values in descending order of their unique contributions to the variance in the dependent variable are: Theoretical quantity for work done (beta = 0.662, part = 0.660), The height of floor, measured from the general ground level, at which the active work is being carried out (beta = -0.329, part = -0.324) and Area of site undeveloped (beta = -0.151, part = -0.149).

Theoretical quantity of blocks for work done (Q_2) makes the strongest unique contribution to explaining the variance in waste generation during blockwork when the variance explained by all other variables in the model is controlled for. This implies that the theoretical quantity for work done uniquely accounted for 43.82% of the variance in the waste generated during block work. In the same vein, the height of floor, measured from the general ground level, at which the active work is being carried out and Area of site undeveloped uniquely accounted for 10.82% and 2.28% of the variance in the waste generation of block work respectively.

4.3 Validating the Developed Models

One of the most important steps in developing a regression model is to test its accuracy and validity (Dysert, 2001). This process is also referred to as the model validation; it involves the testing and evaluating of the developed model with some test or validation data. The validation data should be some representative data from the target population. These data are not used in the model development, but are used specifically for testing the developed model. For this study, the validation data is extracted from the data collected from the selected site as briefly discussed in the methodology. The following subsections elaborate the model validation process by first discussing the details of the validation data set. The validation methodology is then presented. Finally, the discussions on the validation results are provided.

Validation Data Set: The reserved data mentioned in the methodology, meant for model validation, were collected from various projects in each of the six states of South-South and consist of thirty (30) cases of material waste measurement. This was purposively done to have a broad base data spread all over the study area to avoid biasness of the validating data.

Prediction Process: After each of the models was developed, to use the model to calculate waste involves merely the substitution of the new parameter values into the equation to calculate the estimated waste that may be generated in the work activity involved. An example of this computation can be seen in the use of the derived model in Equations 4 for the first case of the cases presented in Table 7 for predicting the expected quantity of waste in concrete work in slab measured in m^3. The predicted waste computed was compared with the observed waste generated (or actual waste recorded). Based on this methodology, the predicted wastes for all the cases in the validation data set can be computed. The results of the computations are presented in Table 7.

$$W_{pc} = 0.065 + 0.111Q_2 - 1.257E\text{-}7Ag + 0.13R \qquad \textit{(from Equation 3)}$$

where: W_{pc} = Predicted waste in concrete work in slab

Q_2 = Theoretical quantity of concrete for the work to be done

Ag = Building's gross floor area

R = Amount of rainfall

Substituting the values of the independent variables gives:

$$\begin{aligned} W_{pc} &= 0.065 + 0.111(15.61) - 1.257E\text{-}7(976.26) + 0.13(0) \\ &= 0.065 + 1.733 - 1.227E\text{-}4 + 0 \\ &= 1.7979 \text{ m}^3 \\ &= 1.80 \text{ m}^3 \text{ (approximately)} \end{aligned}$$

Secondly, the above described process was repeated for predicting the expected quantity of waste in block work measured numerically. The predicted waste computed was compared with the observed waste generated (or actual waste recorded). Based on this methodology, the predicted wastes for all the cases in the validation data set can be computed. The results of the computations are presented in Table 8.

$$W_{pb} = -11.253 + 0.108Q_2 + 2.912Fn - 1.206E\text{-}6Au \qquad \textit{(from Equation 4)}$$

where: W_{pb} = Predicted waste in blockwork

Q_2 = Theoretical quantity of block for the work to be done

Fn = The height of floor, measured from the general ground level, at which the active work is being carried out

Au = Area of site undeveloped

An example of the derivation of the results presented in Table 8 for the first case for predicting the expected quantity of waste in block work measured numerically is presented as follows:

$$
\begin{aligned}
W_{pb} &= -11.253 + 0.108Q_2 + 2.912Fn - 1.206E\text{-}6Au \\
&= -11.253 + 0.108\,(370) + 2.912\,(7.9) - 1.206E\text{-}6\,(462.78) \\
&= -11.253 + 39.96 + 23.0048 - 5.5811E\text{-}4 \\
&= 51.7112 \\
&= 52 \text{ (approximately)}
\end{aligned}
$$

4.4 Comparison between the Predicted Quantity of Material Waste Generated and the Actual Value on Site

Using the data set reserved for the validation of the developed models, the various quantities of material waste that could be generated in the two selected work trades were computed and compared with the actual quantities of waste. The results obtained for waste in concrete work is presented in Table 7 while that of block work is reflected in Table 8. It was revealed through the results that the predicted quantities favourably compared with the actual material waste generated on site. Conclusions were therefore reached that the quantity of material waste generation at the construction stage of a building project is predictable.

Table 7: Comparison of Predicted Concrete Waste and the Actual Waste

Case	a	Q_2 (m^3)	Ag (m^2)	R (cm)	Wac (m^3)	Wpc (m^3)
1	0.065	15.61	976.26	0	2.18	1.80
2	0.065	12.11	589.36	0	1.35	1.41
3	0.065	14.49	803.71	13.6	2.36	3.44
4	0.065	20.04	3886128	0	2.15	2.29
5	0.065	7.4	1261.59	0	0.73	0.89
6	0.065	12.3	1490.5	13.6	1.84	3.20
7	0.065	25	3497515	0	2.25	2.84
8	0.065	20.9	982.4	13.6	2.84	4.15
9	0.065	17.79	1108.59	1.3	1.95	2.21
10	0.065	7.1	1419.33	0	1.16	0.85
11	0.065	7.09	1622.02	32.9	0.38	5.13
12	0.065	16.45	909.86	0	2.6	1.89
13	0.065	20.74	1251.16	0	2.93	2.37
14	0.065	16.02	1419.33	0	3.12	1.84
15	0.065	13.92	1622.02	32.9	0.77	5.89
16	0.065	11.33	909.86	0	1.79	1.32
17	0.065	23.28	3972486	16.4	2.74	4.78
18	0.065	18.81	982.4	13.6	2.2	3.92
19	0.065	13.96	976.26	0	3.03	1.61
20	0.065	16.51	753.81	1.3	2.63	2.07
21	0.065	16.72	1371.2	0	2.25	1.92
22	0.065	17.6	1700.49	0	2.2	2.02
23	0.065	21.34	1675.85	8.5	1.74	3.54
24	0.065	16.07	711.55	16.4	1.52	3.98
25	0.065	18.85	3972486	0	1.47	2.16
26	0.065	22.86	1911.34	0	1.72	2.60
27	0.065	13.56	1823.1	0	2.38	1.57
28	0.065	16.06	1108.59	1.3	1.77	2.02
29	0.065	22.3	589.36	0	3.53	2.54
30	0.065	12.95	995.61	0	1.57	1.50

a = constant = 0.065; Q_2 = Theoretical quantity of concrete for the work to be done; Ag = Building's gross floor area; R = Amount of rainfall; Wac = Actual waste generated in concrete work in slab;
Wpc = Predicted waste in concrete work in slab;

Table 8: Comparison of Predicted Block Waste and the Actual Waste

Case	a	Q_2	Fn (m)	Au (m^2)	Wab	Wpb
1	-11.253	370	7.9	462.78	46	52
2	-11.253	259	3.47	527.92	32	27
3	-11.253	379	6.75	458.13	36	49
4	-11.253	470	7.9	333.08	40	63
5	-11.253	468	4.4	5527917	50	45
6	-11.253	285	8	396.23	18	43
7	-11.253	311	3.79	511.78	30	33
8	-11.253	263	7.9	6427811	23	32
9	-11.253	478	3.5	215.39	65	51
10	-11.253	501	6.65	333.08	48	62
11	-11.253	402	4.4	4756580	71	39
12	-11.253	588	7.9	581.42	80	75
13	-11.253	296	3.79	458.71	40	32
14	-11.253	381	3.43	467.81	54	40
15	-11.253	393	6.65	512.4	27	51
16	-11.253	542	4.4	323.99	37	60
17	-11.253	433	3.79	882.9	55	47
18	-11.253	406	6.32	527.92	45	51
19	-11.253	358	7.9	4820858	53	45
20	-11.253	302	3.5	259	44	32
21	-11.253	366	6.65	658.71	31	48
22	-11.253	363	7.9	427.61	45	51
23	-11.253	457	3.5	1018.47	66	48
24	-11.253	378	3.4	6620645	27	31
25	-11.253	368	6.65	458.71	43	48
26	-11.253	303	8	527.92	33	45
27	-11.253	240	7.9	491.66	30	38
28	-11.253	294	3.79	215.39	43	32
29	-11.253	354	6.32	315.42	48	45
30	-11.253	478	7.9	538.86	56	63

a = constant = -11.253; Q_2 = Theoretical quantity of block for the work to be done; Fn = The height of floor, measured from the general ground level, at which the active work is being carried out; Au = Area of site undeveloped; Wac = Actual waste generated in concrete work in slab; Wpc = Predicted waste in blockwork in slab

4.5 Test of Null Hypothesis (Statistical test for Model Validation)

To explain further the accuracy and validity of the developed models, the proposed null hypothesis (Ho) was tested using paired sample t-test to confirm if there is any significant difference between the actual (observed) waste and the predicted quantity of waste expected to be generated on building sites. To validate the models, paired T-test was used at $p \geq 0.05$ (95% level of significance). The rule for the rejection of the hypothesis is that when the p-value > 0.05, the test fails to reject the hypothesis, however, when the p-value ≤ 0.05, the test rejects the hypothesis. The test was carried out on each of the two models developed. The results are summarised in Table 9.

The results of the test of significant difference between the actual wastes generated on site and the predicted quantities for both concrete and block works presented in Table 9 shows that the p-values of 0.06 and 0.42 respectively are greater than the critical p-value (0.05), therefore the test accepted the null hypothesis and concluded that there is no significant difference between the actual waste and the predicted value.

Table 9: Results of Paired t-Test for Test of Significant Difference Between Actual Waste Generated on Site and the Predicted Quantity

Paired Samples Test

			Paired Differences								
						95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)	Decision
			Mean	Std. Deviation	Std. Error Mean	Lower	Upper				
Pair 1	Wac – Wpc	30	-.55333	1.54856	.28273	-1.13157	.02491	-1.957	29	.060	Accept
Pair 2	Wab – Wpb	30	-2.06667	13.84877	2.52843	-7.23788	3.10455	-.817	29	.420	Accept

Wac – Wpc = Actual waste generated in concrete - Predicted waste in concrete;
Wab – Wpb = Actual waste generated in blocks - Predicted waste in blocks.

5. Conclusion and Recommendations

Standard multiple regression analysis was utilised to develop models for predicting the generation of material waste on low rise building site. As a preliminary step to establishing the correlations between the dependent and the independent variables, the value of R, which is the coefficient of correlation, was assessed such that R-value of 0.10 to 0.29 is regarded as a small correlation, 0.30 to 0.49 as a medium correlation while R-value of 0.50 to 1.0 is judged to be a large correlation. The model for concrete work in slab involved three predictors: the theoretical quantity for work done, building gross floor area and the amount of rainfall accounting for 44.36%, 5.95% and 2.50% of the variance in the waste generated during concrete works in slab respectively. The p-value for the model is $0.000 < 0.05$, therefore, it was concluded that the quantity of waste generated during concrete work on building sites is predictable. While the model for predicting waste generation during blockwork comprises of theoretical quantity of concrete for work done, the height from floor and area of site undeveloped accounted for 43.82%, 10.82% and 2.28% of the variance in the waste generation of block work respectively. The predicted material wastes computed, using the developed models, were compared with the observed wastes (actual waste recorded) generated on sites different from the ones used for the development of the models. The test accepted the null hypothesis and concluded that there is no significant difference between the actual waste and the predicted value. Conclusions were therefore reached that the quantity of material waste generation at the construction stage of a project is predictable. The study recommended the use of developed models by the building practitioners the study area. The implication for research of this study is that the developed models will assist practitioners in the building industry within the study area to predict the amount of material waste anticipated in low rise construction with good accuracy or acceptable precision.

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APPENDIX

RESULTS OF MULTIPLE LINEAR REGRESSION ANALYSIS FOR WASTE GENERATION OF CONCRETE IN SLAB

Table A: Collinearity Diagnostics[a] of the preliminary MLR analysis for Waste Generation in concrete Slab (MRS, 150mm thick)

Model Dimension	Eigenvalue	Condition Index	Variance Proportions							
			(Constant)	Q_2	D	Ag	Fn	R	S	Au
1 Constant	5.132	1.000	.00	.00	.00	.00	.00	.00	.00	.00
Q_2	1.672	1.752	.00	.00	.01	.00	.00	.00	.01	.00
D	.833	2.482	.00	.00	.00	.00	.00	.30	.03	.00
Ag	.194	5.137	.00	.00	.00	.00	.16	.21	.23	.00
Fn	.091	7.495	.00	.04	.78	.01	.00	.00	.01	.01
R	.060	9.264	.00	.65	.04	.00	.25	.12	.18	.00
S	.013	19.506	1.00	.31	.02	.00	.57	.37	.53	.00
Au	.004	36.723	.00	.00	.15	.98	.00	.00	.01	.99

a. Dependent Variable: Waste generated

Theoretical quantity for work done (Q_2), Distance from material storage point to the active usage point (D), Building's gross floor area (Ag), The height of floor measured from the general ground level at which the active work is being carried out (Fn), Amount of Rainfall (R), Amount of Sunshine (S), Area of site undeveloped (Au)

Table B: Excluded Variables[b]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics		
						Tolerance	VIF	Minimum Tolerance
1	Total Area of site	949.648[a]	1.354	.178	.113	6.850E-9	1.460E8	6.850E-9
	Area of site developed	173.750[a]	1.355	.178	.113	2.047E-7	4884810.605	2.047E-7

a. Predictors in the Model: (Constant), Area of site undeveloped, Amount of Rainfall, Theoretical quantity for work done, The height of floor measured from the general ground level at which the active work is being carried out, Amount of Sunshine, Distance from material storage point to the active usage point, Building's gross floor area

b. Dependent Variable: Waste generated

Table C: Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.720[a]	.519	.495	.55459

a. Predictors: (Constant), Area of site undeveloped, Amount of Rainfall, Theoretical quantity for work done, The height of floor measured from the general ground level at which the active work is being carried out, Amount of Sunshine, Distance from material storage point to the active usage point, Building's gross floor area

b. Dependent Variable: Waste generated

Table D: ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	47.120	7	6.731	21.886	.000[a]
	Residual	43.674	142	.308		
	Total	90.794	149			

a. Predictors: (Constant), Area of site undeveloped, Amount of Rainfall, Theoretical quantity for work done, The height of floor measured from the general ground level at which the active work is being carried out, Amount of Sunshine, Distance from material storage point to the active usage point, Building's gross floor area

b. Dependent Variable: Waste generated

Table E: Coefficients[a] of the preliminary MLR analysis for Waste Generation in Concrete Slab

Model		Unstandardised Coefficients		Standardised Coefficients	t	Sig.	95.0% Confidence Interval for B		Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)	-.110	.335		-.329	.743	-.773	.553					
	Volume of quantity for effective work done	.111	.010	.670	11.384	.000	.092	.130	.641	.691	.663	.978	1.023
	Distance from material storage point to the active usage point	.005	.002	.324	2.224	.028	.001	.010	-.131	.183	.129	.159	6.279
	Building's gross floor area	6.067E-7	.000	1.178	2.006	.047	.000	.000	-.157	.166	.117	.010	101.782
	The height of floor measured from the general ground level at which the active work is being carried out	.002	.025	.007	.086	.931	-.047	.051	-.088	.007	.005	.594	1.683
	Amount of Rainfall	.016	.007	.202	2.378	.019	.003	.029	.132	.196	.138	.468	2.135
	Amount of Sunshine	.014	.028	.047	.495	.622	-.042	.070	-.049	.041	.029	.382	2.620
	Area of site undeveloped	-6.184E-7	.000	-1.720	-2.707	.008	.000	.000	-.170	-.222	-.158	.008	119.242

a. Dependent Variable: Waste generated