PREDICTING THE VOLUME OF MATERIAL WASTE: A CASE OF ONGOING BUILDING PROJECTS IN ABUJA, NIGERIA

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While quantification of material waste is crucial for construction waste management, accurate estimation can be accomplished by developing waste quantification model that is applicable for national or regional construction waste generation. This is important for building professionals to properly plan and control their disposal thereof. The purpose of this study was to develop mathematical models for quantifying the volume of building-material waste in Abuja, Nigeria. The methodological approach adopted is the quantitative technique that is rooted in the positivist research paradigm. 31 ongoing building construction projects were investigated, which includes public and private projects using purposive sampling technique (projects to the value of 1.6 billion Naira/8 million USD and above). The data for this research were sourced from the field investigation (measurement of the volume of material waste) and data from the archival records (drawings, project-progress reports, and specifications) on building materials and volume of material waste. Linear-regression analytical tool was used for the analyses. The study revealed a statistically significant relationship between the variables analysed models for predicting the volume of building-material waste in a project were developed from the linear-regression analyses. These models are presented and discussed in this paper. The study recommends the use of this model by construction professionals of the Nigerian construction industry in quantifying volume of waste at an early stage in the life of a project. This in turn, would minimise waste generation, which is in line with the prime objective of waste-management for a building project.

Keywords: building size, building materials volume, material waste, models , waste volume

INTRODUCTION

The rapid urbanisation in developing nations has resulted in a substantial increase in construction activities, which in turn, has led to the generation of a large quantity of construction waste (Chikezirim and Mwanaumo,

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2013: 498). Construction waste is a major source of municipal solid waste in all the megacities around the world, frequently accounting for 10% to 30% of the total waste sent to landfills. For instance, in Hong Kong, construction waste consists of 30% to 40% of the total waste (Li and Zhang, 2013: 142; Begum, 2009: 321)

Material wastage has become a serious problem, which requires urgent attention in the construction industries. This constraint harmfully affects the delivery of many projects in Nigeria (Adewuyi and Otali, 2013: 746). Ameh and Itodo (2013: 748) assert that, for every 100 houses built, there is sufficient waste material to build another 10 houses in Nigeria. Accordingly, Osmani (2011: 209) added that 10% of the materials delivered to sites in the UK construction industry end up as waste.

Nguyen, Gupta and Faniran (nd: 2) emphasise that, despite the studies that have highlighted the future benefits of reducing construction waste, there has been little progress in implementing the waste-management option available, in order to ensure that construction waste is minimised. Wahab and Lawal (2011: 247) suggest that a more effective control of materials on site should be adopted; as the problems of material wastage cannot be fully treated without efficient material control. Hence, Begum, Siwar, Pereira, Jaafar (2007: 191) propose various construction material waste management approaches.

In the last decade, little attention has been paid to the management of waste generated in the Nigerian construction industry (Wahab and Lawal, 2011: 248). This could be as a result of the low level of awareness of the construction workers, a low level of available means of waste disposal, or the slow adoption of environmentally sustainable practices. Yuan and Shen (2011: 670) highlighted that the insufficient attention given to material-waste generation in developing nations during the past decades has meant that the statistical data on the quantity of material-waste generation are not readily available. This is supported by Babatunde (2012: 328), who believes that the situation is not any different in the Nigerian construction industry and these are important for the building practitioners to properly plan and control their disposal thereof.

Moreover, Masudi *et al.* (2012: 269) believe that, while quantification is crucial for construction waste management, accurate estimation can be satisfied by developing waste quantification model that is applicable for regional or nation-wide construction waste generation.

Over the years, research interests in addressing construction and demolition waste management issues across the world have resulted in a large number of publications. However, research evidence has shown that previous studies from different parts of Nigeria centered mostly on waste and waste-management practices in the construction industry; as well as the techniques for their management. Nonetheless, these studies failed to develop models for predicting the volume of material waste for building projects in Nigeria. As this would assist construction professionals in having idea on the probable volume of material waste to be generated for their projects, in order to plan and adopt at an early stage the best material waste management principles and disposal thereof. This led to the development of the problem posed in this study that: data on the quantities of material waste have not been well documented and statistics on the waste generated are minimal in Nigeria (Babatunde, 2012: 328). Hence, this research aims to develop mathematical models for quantifying the volume of building-material waste in Abuja, Nigeria.

LITERATURE REVIEW

Sources and causes of material waste in construction

Construction waste is generated throughout the project lifecycle from the pre-construction stage through to the construction stage, and on to the finishing stage (Nagapan *et al.*, 2012). Waste sources and causes revolve around four factors, namely: procurement, handling, operation and culture (Al-Hajj and Hammani, 2011). Kareem and Pandy (2013) added that construction waste could arise from different sources, depending on the complexity of the project, namely: design stage, procurement stage, operation stage, material management stage, and material storage area.

Poor site management and supervision, the lack of experience, inadequate planning and scheduling, mistakes and errors in design, and construction were ranked as the top causes of waste in a project (Nagapan *et al.*, 2012; Babatunde, 2012). Furthermore, Al-hajj and Hamani (2011) summarised that design error leading to unnecessary off-cuts, low-quality products, lack of awareness, rework and variations, and temporary works are the major causes of material waste on construction sites. Nagapan *et al.* (2012) conducted a survey on the causes of material waste at three construction sites in Malaysia and revealed that inappropriate storage of materials, poor materials handling, low quality of materials, error in material ordering, mistakes in estimation, and bad attitudes of workers are the major causes of material waste.

Osmani *et al.* (2008) categorised construction waste into: *Contractual waste:* which includes client-driven waste; mistakes in contract documents; and incomplete contract and tender documents. *Procurement waste:* lack of early stakeholders' involvement, poor communication flow, improper co-ordination amongst the parties and trades, and lack of allocated duties for decision making. *Design:* changes in design, complexity in design and specifications, mistakes in design and construction details, insufficient or incoherent specifications; poor co-ordination and communication (late information, last-minute client requirements, slow in drawing revision and distribution).

Adewuyi and Otali (2013) found that, rework, design changes, waste from uneconomical outlines, inclement weather, and bad quality materials contrary to specification were ranked as the top causes of waste in the Rivers State of Nigeria. In Nigeria, the various causes of material wastage identified by Oladiran (2009) are: changes in design, errors and mistakes of workers; improper flow of communication amongst the parties; waste resulting from uneconomical shape; poor specifications; unfamiliarity of designers with alternative products; improper supervision; wrong interpretation of drawings; vandalism; poor site conditions; poor transportation of materials; building failure/defects; loading and unloading of materials; poor setting out; theft of material, use of substandard materials; bulk material delivery; and errors in estimation.

The procedures for construction materials-waste quantification

The quantification of the amount of construction-material waste is important for the building practitioners to properly plan and control their disposal thereof (Jingkuang, Yousong and Yiyong, 2012: 398). Li, Ding, Mi and Wang (2013: 20) highlight that researchers quantify construction-site waste in many ways:

In the Netherlands, construction waste has been measured in three ways: as a percentage of the total amount of waste; the purchased amount of material; and the total material-waste costs. It was also found that the amount of waste for each building material lies between 1% and 10% of the amount purchased (Ekanayake and Ofori, 2004: 852; Liatas, 2011:1263).

The quantification of material waste is based on the volume of stockpiled waste, which is determined either on the basis of a rectangular prism, or in a pyramidal shape (Nagapan, *et al.* 2013: 102)

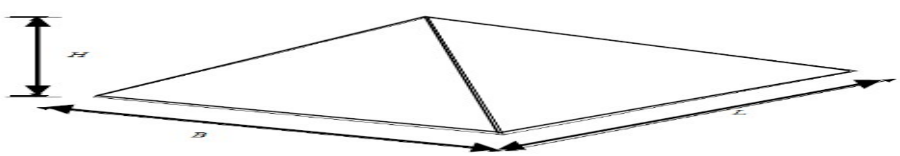

Figure 2.4 The volume method of pyramid shape

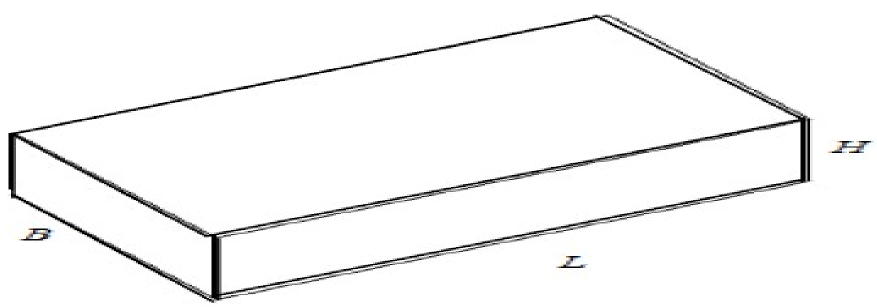

Figure 2.5 The volume method of rectangular shape
(Source: Nagapan et al., 2013)

For the pyramidal shape, the volume= 1/3 (B x L x H); and for the rectangular prism form, the calculated volume is = L x B x H. Where **L** is the length, **B** is the base, and **H** is the height.

Waste Generation Rates (WGRs) are useful variables that lie at the core of many efforts for understanding waste management in the construction sector. WGRs can provide quantitative information for benchmarking different construction waste-management practices (Lu, Yuan, Li, Hao, Mi, and Ding, 2011: 680). This is achieved by measuring the quantity of construction waste generated by weight (tons) for every square metre of normalised floor space at the construction sites (Lachimpadia, Pereira, Taha, and Mokhtar, 2012: 93).

Lu *et al.* (2011: 681) suggested that different practices can be used to measure waste: either by weight (kg or ton), or by volume (cubic metres/m^3). However, the WGRs are calculated by dividing the waste by either the amount of purchased materials, the amount of materials required by the design, or per square metre/m^2 of Gross Floor Area (GFA). Therefore, the four typical measurements for WGRs are: (1) the percentage of purchased materials (2) the percentage of material required by the design; (3) kg/m^2 of GFA; and (4) m^3/ m^2 of GFA.

$$WGR = \frac{\text{Total construction waste (tons)}}{\text{Total floor space (m2 of normalized floor space)}}$$ (Lu *et al.,* 2011: 682)

Li *et al.* (2013: 21) highlighted that material-waste quantification commences with the following steps: (1) listing the major types of construction material; (2) the purchased amount of major materials; and (3) the actual Material Waste Rate (MWR) of each type of material listed in 1, by dividing the amount of waste by either the amount of purchased material (Tam, Shen and Tam, 2007), or by the amount of material required by the design; and, lastly, (4) estimation of the percentage of the remaining waste.

Major materials account for nearly 90% of the total construction waste. The remaining waste occupies approximately 10 percent of the total waste (Li *et al.,* 2013: 22-23).

Listing the major types of construction materials

Although buildings across the world are varied in building structure and construction techniques, typical construction waste components include: concrete, bricks and blocks, steel reinforcement, timber, cement and mortar, ceramic tiles, plastic and cardboard packaging materials, and so on (Li *et al.,* 2013: 22-23).

Investigating the purchased amounts of the major materials

The amount of material purchased can be determined from the purchasing records of the finished projects, or from the budget documents of ongoing projects. The amount in the budget document generally includes normal material loss during construction, and thus is close to the actual purchased amount (Li *et al.,* 2013: 22-23).

The Table 1 below shows the previous studies from different countries on waste- generation rates.

Table 2.1: Previous studies on waste generation rates

Sn	Author	Country	Measurement of WGRs	Methodology	Conclusions
1	Skoyles (1976)	UK	Percentage by weight (o the amount required according to design)	Direct observation and comparing contractor's record	2-15% by weight account to th amount purchased for 37 materials
2	Mc Gregor e al. (1993)	USA	Weight and percentage of total waste from an individual project	Questionnaire and telephone survey	Varied with construction type and project cost
3	Bossink & Brouwers (1996)	Netherlanc	Percentage by weight (o purchased materials)	Sorted and weighted the waste materials	1-10% by weight of the amoun purchased for seven materials, with an average of 9%
4	Mcdonald & Smithers (1998)	Australia	The volume (m3) of waste generated per m2 of gross floor area	Sort in waste bin and delivery records of bins	Total waste rate: 0.084m3/m2
5	Forsthe and Marsden (1999)	Australia	Waste ordered materials-insitu quantities	Insitu quantities from drawings or site measurement: ordered material from delivery anc order document	Maximal and minimal generation rate for eight materials by percentage in twc projects
6	Poon et al. (2002)	Hong Kong	Percentage by weight oı volume according to different materials	Site observation and questionnair	1-8% for public housing and 1-100% for private housing
7	Morris Specificatior s Inc. (2001)	Canada	NA	NA	WGRs for main construction materials (wood, drywall, metal, concrete, others) are given
8	Formoso et al. (2003)	Brazil	$\boldsymbol{Waste}\ (\%) = \frac{\{\text{Mpurchased}-\text{Inv})-\text{Mdesign}\}}{\text{Mdesigned}}$ where Inv indicates the final inventory of materials	Direct observation and contractors recor	19.1-91.2% by weight accordin to the amount purchased for eight materials
9	Treloar et al (2003)	Australia	Not clear	Consultation wit construction company employer	3-10% for eight materials
10	Poon et al. (2004)	Hong Kong	The volume (m3) of waste generated per m2 of gross floor area	Visual inspection tape measurement, truck load record	The total waste generation rate: 0.17m3/m2; 0.4-0.65m3/m2
11	Lin (2006)	Taiwan	The volume (m3) of waste generated per m2 of gross floor area	The neutral network method	0.85m3/m2; for factory and 0.54-0.66m3/m2 for residential
12	Tan et al. (2007)	Hong Kong	Waste level= (Material purchased-material used)/material used multiplied by 100	Interview with the people involved in the industry	8.9-20% and 4.11-6.62% by weight for five materials according to different sub-contracting arrangements

Investigating the actual material waste rate

MWR is measured by dividing the amount of waste by either the amount of purchased material (Tam, Shen and Tam, 2007), or by the amount of material required by the design. The two possible rates would differ to a very small extent, unless the rate is huge. MWR is evaluated as the ratio of waste material to purchased material, expressed as a percentage (Li *et al.,* 2013: 22-23).

Estimation of the percentage of remaining wastes

In addition to the waste generated from the major materials listed in the first phase, there are also numerous types of small quantities of waste, such as cardboard packaging, plastic pile, iron wire, and so forth. These remaining wastes include numerous categories; but they comprise only a small part of the total waste by weight.

Previous studies have revealed that the waste generated from major materials accounts for nearly 90 percent of the total construction waste. It can be deduced that in this situation, this remaining waste comprise approximately 10 percent of the total waste (Li *et al.,* 2013: 22-23).

Calculation of waste generation per gross floor area (wga)

In the first step, the total construction waste generated on site is calculated using Eq (1):

WG= $\sum_{i=1}^{n}(Mi\ (ri) + wo)$……………………………………………………1

where WG refers to the total construction waste generated from the project by weight (kg), Mi means the purchased amount of major material i in the identified list by weight (kg); ri is the MWR of major material i; W0 is the remaining waste; n is the number of major material types.

In the second step, the total WGA is calculated using Eq. 2

$WGA = \frac{WG}{GFA},$ ……………………………………………………………………2

Where GFA is the gross floor area of the building project in meter square (m^2) (Li *et al.,* 2013: 22-23).

Summary and literature gap

It is obvious from the literature that past research on material waste quantification focused on direct on site measurement of waste (for instance, measuring waste as a percentage of the total amount of waste or based on the volume of stockpiled waste) and by measurement of waste generation rates. However, none of this research focused specifically on using parameters such as estimated volume of materials from the bill of quantities or building size (length by width by height) from the drawing to predict material waste. Hence, the need for this research as the project manager or other professionals do not need to go to site or wait until the waste is generated on site before the volume of waste can be known.

RESEARCH METHODOLOGY

The research employed the quantitative method that is rooted in the positivist research paradigm. It is quantitative because, the data were generated from the numeric measurement of the volume of on-site material waste; the designed quantities of the building materials, all converted to cubic metre (volume); the volume of materials used for projects; the building volume (length*width*height); the estimated cost of projects; the estimated time for projects, the actual time (time now); and the percentage of work completed. The table containing these details is presented in Appendix 1 of this study.

The study population is public and private on-going building construction projects within Abuja, the Federal Capital Territory of Nigeria, from which a sample of 31 projects was selected. Only building projects with value of 1.6 billion Naira (8 million UD) and above, were selected using the purposive sampling techniques. As at the period of data collection, only 31 of such projects were noticeable. The rationale for this selection is that, building-construction projects of this value and above are likely to generate large quantities of material waste when compared with projects of less value (Saidu & Shakantu, 2016: 104).

Abuja as a geographical case study area was selected because; it has the highest population of professionals within the built environment, and has many on-going building-construction projects.

This study focused mainly on primary data, which included: the field investigation on the on-site material waste and data from the archival records (drawings, bills of quantities, project progress reports, and specifications). The structural components of the buildings are mostly of reinforced concrete/steel structures with hollow but filled solid/solid sandcrete blocks.

The research is designed to answer the following research questions:

1. What are the parameters, constant and coefficient values for predicting the volume of onsite material waste for a building project?
2. What are the parameters, constant and coefficient values for predicting the volume of materials to be used for a project?

Archival records:

The designed volume of materials for each building project were generated from the measured quantities of each material from the priced/unpriced bills of quantities (BOQ) prepared for the project. The measurement units of each material, as contained in the BOQ (linear, square and cubic metre, number, kilogram, tonne, and so on) were converted to a common standard unit (volume/cubic metre). The converted volumes were summed up to achieve the Total Volume of Materials for each Building (TVoMB).

Where access to BOQ was denied, the volume of material was generated by taking direct measurements of the quantities from drawings, and by making the necessary adjustment (for openings, plastering, finishes, and so forth), in accordance with the rules of the Standard Method of Measurement (SMM) for building works, in order to determine the net volume of materials for the buildings.

The volume of material used for each project was determined from the **'% of WC'** and the '**TVoMB'.** The 'building volume (L*B*W)', was measured from the design/working drawing. This involves measuring and multiplying the length, width, and the height of the building.

The data on Time Now (TN), the Percentage of the Work Completed ($\% \, of \, WC$), for different projects were generated from the records of projects compiled by the Quantity Surveyor

Field investigations:
The data on the volume of on-site material waste was generated by physical on-site measurements with the aid of measuring instruments, such as tape and measurement rule. The volume of the stockpiled waste is determined by the shape it created on site, for instance, rectangular prism, pyramidal shape, and so forth.

Where the generated on-site material waste has already been disposed and removed from site, a request was made to allow the researcher to access the total volume (material waste) disposed/removed from the project's onsite records (number of truck- load record).

Analyses of the data:
The inferential analysis of the data was employed in this study and the results were presented in Tables and Figures.

Regression analyses are used to describe data and to explain the relationship between one dependent variable and one or more independent variables. They are also used as a basic predictive analysis. The simplest form is with one dependent and one independent variable. (Morenikeji, 2006).

The linear-regression equation was used to develop the statistical models. For a linear regression equation:

$$\boldsymbol{y = a + bx}; \quad \boldsymbol{x = a - \frac{y}{b}}; \quad \textit{and} \quad \boldsymbol{b = \frac{n\sum xy - (\sum x)(\sum y)}{n\sum x^2 - (\sum x)^2}}.$$

Where "y" is the dependent variable (volume of material waste); "x" is the independent variable (building volume); "b" is the coefficient of "x; and "a" is a constant.

This study was conducted between December 2014 to March 2015 and the approximate conversion rates as at November 2014 were: Nigerian Naira to US dollar = ₦200 = 1USD.

Since the projects considered were on-going, the average percentage completion for the entire projects was 52.4% as at the period of data collection.

Reliability and Validity of the research:

Reliability in research is generally the ability of a collected data, and the interpretation or the analysis to be dependable, trustworthy, uniform and repeatable (Miller, 2008). Validity determines whether the research truly measures that which it was intended to measure, or how valid the research results are (Golafshani, 2003).

All information presented in this research are factual, substantiated by the collection of the relevant data. All the feedbacks are incorporated in the study instrument in the research report. There, the results can be trust worthy.

RESULTS

Table 2 shows that 31 valid construction projects were visited in the study area. The projects' values ranged from ₦1.635 billion to ₦63 billion (R102.3 million to R3.94 billion) with a mean average of ₦7.864 billion (R491.31million), which are above the target of ₦1.6 billion (R100 million) stated in section 3 of this study. The projects had attained between 5 to 100% completion with a total average completion of **52.4%.** The '**estimated time'** for the projects ranged from 16 to 68 months, with an average of 27 months; while the **'actual time'** (time now) ranged from 3 to 96 months, with an average of 25.8 months.

The measured **'Buildings Volume' (L*W*H)** ranged from 17,486.6 to 5,181,480.0 cubic metres with an average of 387,600.8 cubic metres. The **'volume of materials used'** for the projects ranged from 4,982.4 to 673, 592.4 cubic metres, with an average of 45,468.1 cubic metres. The **'generated volume of onsite material waste'** ranged from 36.0 to 4,005.2 cubic metres, with an average of 455.6 cubic metres.

The collected data from which this summary was drawn is presented in the appendix 1 of this study.

Table 2. Summary of the archival record and field investigations for the data collected

Descriptive Statistics	Valid number of projects	Minimum	Maximum	Mean	Standard Deviation
Estimated Cost of Project (EC) (₦)	31	1,635,000, 000.0	63, 000, 000, 000	7,864, 085 426.0	13,009, 813, 196.0
Estimated Time for the Project (Month)	31	16.0 month	68.0 month	27.0 month	12.1
Time Now (Month)	31	3.0 month	96.0 month	25.8 month	23.0
Building Volume (L*W*H)	31	17486.6 m^3	5181480.0m^3	387600.8 m^3	1, 061, 644.6
Estimated volume of materials for Project (M^3)	31	4982.4 m^3	673592.4 m^3	45468.1 m	122, 643.0
Volume of materials used (M^3)	31	1146.0 m^3	190723.1 m^3	14972.4 m	33, 437.7
Generated volume of onsite material waste (M^3)	30	36.0 m^3	4005.2 m^3	455.6 m^3	721.3
Transformed 100% Volume of waste	30	156.6 m^3	14145.4 m^3	1273.9 m^3	2, 584.0

Regression analyses and mathematical models

This section presents the results of the linear-regression analyses performed and the mathematical models developed from the analyses.

Relationship between the Volume of Materials Used for Projects (VMUP) (52.4% average projects completion) and the Building Volume (L*W*H)'

Table 3 shows the result of the regression analysis between the Building Volume (L*W*H) and the VMUP (52.4% completion). The result depicts a linear and a strong correlation with the R-square (R^2) value of 61.62%. The probability value (0.0002) is less than the 5% significance level; and the hypothesis was tested at the 95% confidence level.

Therefore, the relationship is statistically significant; and the alternative hypothesis is accepted; while the null hypothesis is rejected.

The result shows that any change in the either of the variables (X and Y) would lead to a corresponding change in the other.

Table 3: Result of regression analysis between building volume (L*W*H) and the VMUP (52.4% completion)

S/n	Variables X	Variables Y	Type of model	Observation Regression Equation	R square	Probability value	Inference Strength of relationshi	Remarks	Action on Hypothese
1	Building volume (m3) (L*W*H	Volume of materials used for project (m3) 52.4%	Linear regression	Estimated volume of materials used =7449.7315+ 0.0194*(x)	61.62%	0.0002	Strong	Statistically significant	Accept Hi and reject Ho

Therefore, to predict the VMUP (52.4% project completion) using the Building Volume (L*W*H) for that project will be determined by: adding the constant value (7449.7315) to the coefficient value of the Building Volume (0.0194), and multiplied by the value of the 'Building Volume (L*W*H)' as shown in Figure 1. This result is in line with the findings of Nagapan *et al.* (2013) who concluded that the quantification of waste is based on the volume of stockpiled waste and that of Lu *et al.* (2011) who concluded that waste could be quantified using different practices, one of which is by volume. This result quantifies material waste by volume.

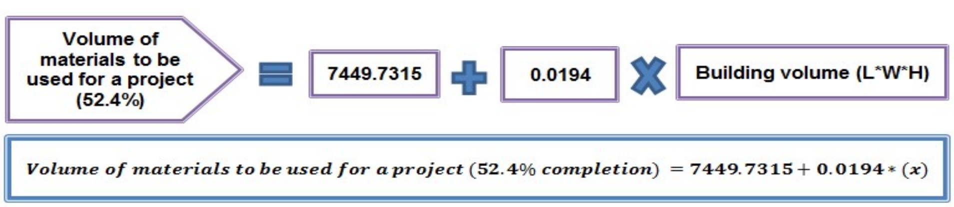

Figure 1: Mathematical model for predicting the volume of materials to be used for a proposed building project (52.4% completion)

Relationship between the VMUP 100% completion and the Building Volume (L*W*H)

The results in Table 4 depicts that, if the project is 100% completed, the regression analysis between the Building Volume (L*W*H)' and the VMUP (100%) also reveals a linear and a very-strong correlation with the (R-square) value of 96.3%. The probability value (0.000) was less than the 0.05 (5%) level of significance; and the hypothesis was tested at the 95% confidence level.

The relationship is statistically significant; and the alternative hypothesis is accepted; while the null hypothesis is rejected.

Table 4: Result of regression analysis between the Building Volume (L*W*H) and the VMUP (100% completion)

S/n	Variables		Type of model	Observation			Inference		
	X	Y		Regression Equation	R2	Probabi ity valu	Strength of relationship	Remarks	Action on Hypotheses
2	Building volume (m3) (L*W*H)	Estimated volume of materials	Linear regression	Estimated volume of materials=2334.7586+0.1113*(*x*)	96.3%	0.000	Very strong	Statistically significant	Accept Hi and reject Ho

To predict the VMUP 100% completion using the Building Volume (L*W*H) for that project is determined by, adding the constant value (2334.7586) to the coefficient value of the building volume (0.1113), and multiplied by the building volume (L*W*H) as shown in the Figure 2. This result is in line with the findings of Nagapan *et al.* (2013) who concluded that the quantification of waste is based on the volume of stockpiled waste and that of Lu *et al.* (2011) who concluded that waste could be quantified using different practices, one of which is by volume. This result quantifies material waste by volume.

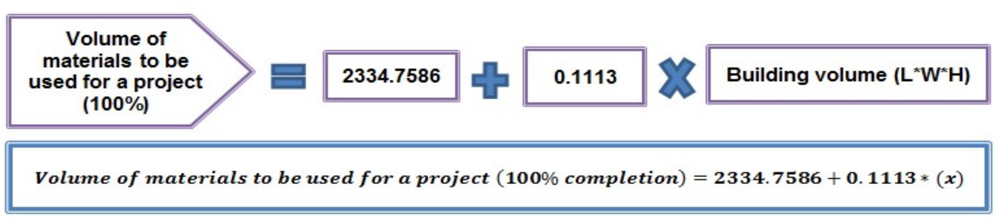

Figure 2: Mathematical model for predicting 100% VMUP for a proposed building project

Relationship between the Generated Volume of On-site Material-Waste (GVOMW), (52.4% completion) and the Building Volume (L*W*H)

Table 5 shows the result of the linear-regression analysis between the Building Volume (L*W*H) and the GVOMW (52.4% completion). The results indicate a strong correlation between the variables with an R-square value of 55.43% and a probability value of 0.0015, which is less than the 5% significance level at the 95% confidence level.

It is inferred that a statistically significant relationship exists between the variables; and the alternative hypothesis is accepted; while the null hypothesis is rejected.

To predict the volume of onsite material waste (52.4% completion) using the Building Volume (L*W*H) for that project, is determined by adding the constant value (333.5738) to the coefficient value of Building Volume (L*W*H), (0.0004), and multiplied by the Building Volume (L*W*H), as shown in Figure 3. This result is not in line with the findings of Lin (2006), Poon *et al.* (2004), and McDonald and Smither (1998) who both concluded that the volume of waste is generated based on the gross floor area. But this result uses building volume as a benchmark

Table 5: Result of regression analysis between the Building Volume (L*W*H) and the GVOMW (52.4% completion)

S/n	Variables X	Y	Type of model	Observation Regression Equation	R2	Probabili y value	Inference Strength of relationship	Remarks	Action on Hypotheses
3	Building volume (m3) (L*W*H	Generated volume of onsite material waste (52.4% completion)	Linear regression	Volume of material waste recorded =333.5738+0.0004*x	55.43%	0.0015	Strong	Statisticall significant	Accept Hi & reject Ho

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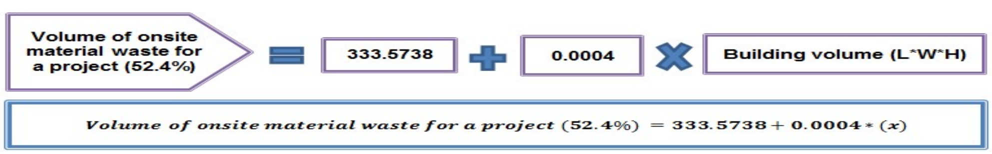

Figure 3: Mathematical model for predicting the volume of material waste for a proposed project

Relationship between the Building Volume (L*W*H) and GVOMW (100% completion)

The 52.4% GVOMW in Table 5 above was upgraded to 100%, in order to determine a relationship at project completion.

The result is presented in Table 6 and shows a very-strong correlation between the variables with an R-square value of 95.2% and a probability value of 0.000.

It is inferred that a statistically significant relationship exists between the variables and the alternative hypothesis is accepted; while the null hypothesis is rejected.

Table 6: Results of the regression analysis between the building volume (L*W*H) and an 100% generated volume of material waste

S/n	Variables X	Y	Type of model	Observation Regression Equation	R square	Probabilit value	Inference Strength of relationship	Remarks	Action on H
4	Building volume (m3) (L*W*H)	100% Generated volume of onsite material waste	Linear regressio	100% volume o material waste =361.9173+0.0023*x	95.2%	0.000	Very strong	Statisticall significant	Accept Hi & reject H

To predict the 100% volume of onsite material waste for a proposed building using the Building Volume (L*W*H) for that project is determined by adding the constant value (361.9173) to the coefficient value of building volume (0.0023), and multiplying the result by the building volume (L*W*H), as shown in Figure 4. This result is in line with the findings of Nagapan *et al.* (2013) who concluded that the quantification of waste is based on the volume of stockpiled waste and that of Lu *et al.* (2011) who concluded that waste could be quantified using different practices, one of which is by volume. This result quantifies material waste by volume.

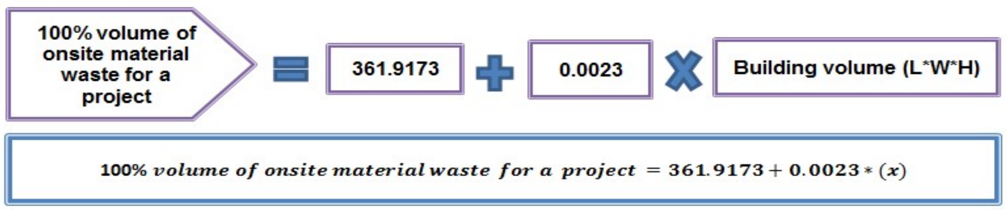

Figure 4: Mathematical model for predicting the total volume (100%) of on-site material waste for a proposed building project

Results of the relationship between the Estimated Volume of Materials for Projects (EVMP) and the GVOMW (52.4% completion)

Table 7 shows the results of the relationship between the EVMP and the generated volume of on-site material waste for the projects.

The result shows a non-statistically significant relationship; because the probability value (0.0698) is greater than the significance value (0.05); and the hypothesis was tested at the 95% confidence level. The R-squared value of 33.57% was weak. The alternative hypothesis was rejected in favour of the null hypothesis.

Table 7: The results of regression analysis between the estimated volume of material for the project (m³) and the volume of on-site material waste recorded

S/n	Variables		Type of model	Observation			Inference		
	X	Y		Regression Equatio	R2	Probability value	Strength of relationship	Remarks	Action on Hypothes
5	Estimate volume of material for projec	Generated volume of material waste (52.4% completion)	Linear	Volume of onsit material waste recorded =390.8538+0.009*x	33.57%	0.0698	Weak	Not statistically significan	Accept Hi & reject Ho

To predict the volume of onsite material waste to be generated for a proposed building project (52.4%) using the EVMP if the volume of materials is known.

This is determined by adding the constant value (390.8538) to the coefficient value of the volume of materials for the proposed project (0.0019), and multiplied by the volume of materials for the proposed project as shown in Figure 5. This result is not in line with the findings of Lin (2006), Poon et al. (2004), and McDonald and Smither (1998) who both concluded that the volume of waste is generated based on the gross floor area. But this result uses building volume as a benchmark.

Figure 5: Mathematical model for predicting the volume of on-site material waste for a proposed project (52.4% completion)

Results of the relationship between the EVMP and a 100% GVOMW

The results in Table 8 show how the 52.4% onsite material waste volume in Table 7 is upgraded to 100%. The result shows a very strong correlation between the variable with an R-squared value of 99.29% and a probability value (0.000) less than the significance level (0.05). The hypothesis was tested at the 95% confidence level.

The relationship is statistically significant; and the null hypothesis was accepted and alternative was rejected.

Table 8: The results of the regression analysis between the EVMP (m^3) and the100% GVOMW

S/n	Variables		Type of mod	Observation			Inference		
	X	Y		Regression Equation	R2	Probability value	Strength of relationship	Remarks	Action on Hypotheses
6	Estimated volume of material for project	100% material waste volume	Linear	Volume of waste =309.4626+0.0206*x	99.29%	0.000	Very strong	Statistically significant	Accept Hi & reject Ho

To predict the **100%** volume of onsite material waste for a proposed project using the estimated volume of materials for that project is determined by adding the constant value (309.4626) to the coefficient value of the volume of materials for a proposed project (0.0206), and multiplied by the volume of materials for the proposed project as shown in Figure 6. This result is in line with the findings of Nagapan *et al.* (2013) who concluded that the quantification of waste is based on the volume of stockpiled waste and that of Lu *et al.* (2011) who concluded that waste could be quantified using different practices, one of which is by volume. This result quantifies material waste by volume.

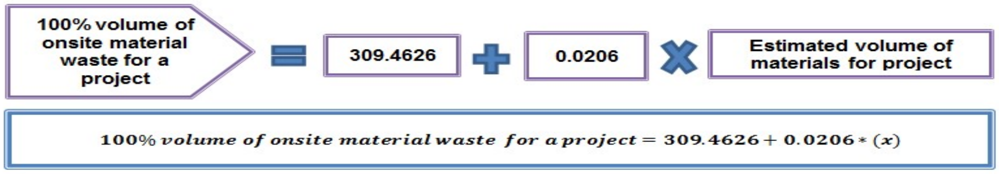

Figure 6: Mathematical model for predicting 100% volume of on-site material waste for a proposed project

To gain a general insight into the mathematical models for quantifying the total volume of materials and material waste for a proposed project, Figure 6 presents the general summary.

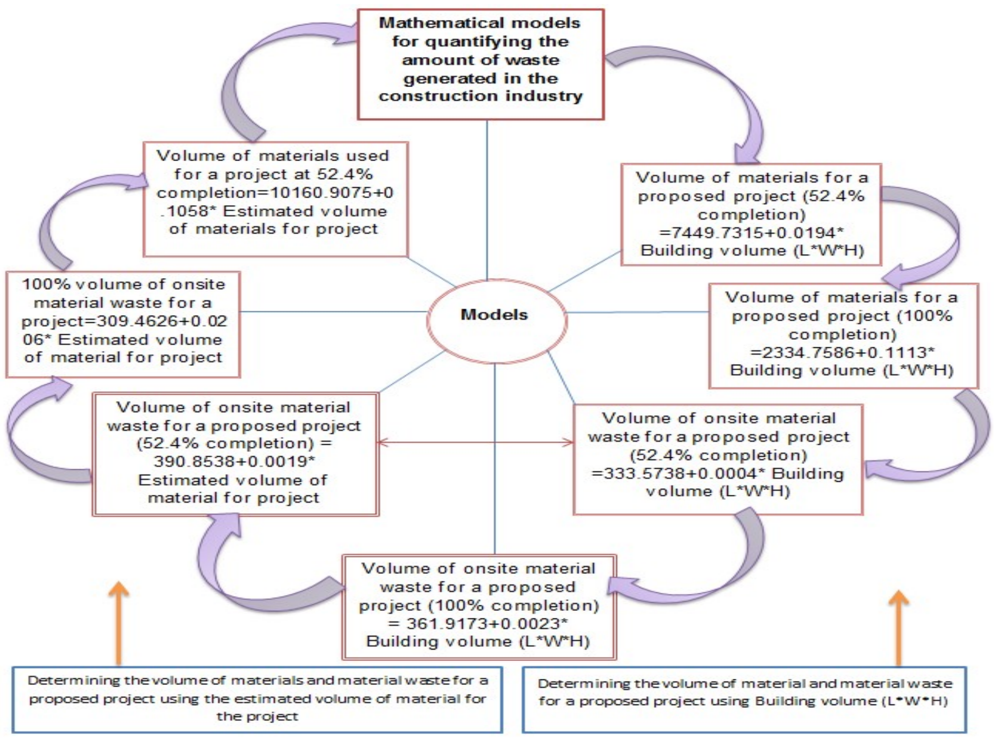

Figure 7: Summary of mathematical models for quantifying the amount of material waste on construction site

Merits, limitations, practicability and basic assumptions of the model

The model can be used to determine the volume of onsite material waste to be generated from drawing, using the building size (length by width by height). It is also easier to determine the entire volume of materials to be used in lump for a proposed building using this model.

However, the volume of material waste predicted by this model comes in lump (combination of waste from different building materials), as it does not consider segregation/separation of waste for individual material.

The model was developed at the level of 52.4% average project completion, since the projects considered were ongoing as at the period of data collection. However, adjustment has been made to the volume of the 52.4%

waste to accommodate 100% project completion, as shown in the last column of the appendix.

The research assumes that the generated volume of waste has pass through re-using process, but not recycled; because only one out of the 31 construction projects visited was involved in material waste recycling.

The practicability of this model is that it gives the professionals the idea of the likely volume of material waste to be generated for projects, as well as the idea on how to plan the waste minimisation and disposal processes.

This research is limited to building construction projects that use hollow filled solid blockwork commonly used in the Nigerian context. The research did not consider other similar building materials, such as burnt bricks, precast unit walling and other paneled building.

CONCLUSION AND RECOMMENDATIONS

The study concludes that; a statistically significant relationship exists between the variables considered in the study. (Building Volume (L*W*H) and the estimated volume of materials used for projects; the Building Volume (L*W*H) and the 'generated volume of on-site material waste'; and 'the estimated volume of material for building projects' and the 'volume of material waste generated'). This implies that any change in the either of the variables would lead to a corresponding change in the other.

The linear-regression analyses revealed the mathematical models for quantifying and predicting both the 'volume of building-material waste' and the 'volume of materials for a building'.

The mathematical models for the quantification of onsite-material waste developed in the study are recommended to the Nigerian construction industry. This should enable the construction professionals to have some idea of what amount of waste is generated, and to evaluate the extent to which it could be minimised, in order to meet the required waste-management objectives for a project.

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