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A Conceptual Framework and a Mathematical Equation for Managing Construction-Material Waste and Cost Overruns

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***Abstract*—**The problem of construction material waste remains unresolved, as a significant percentage of the materials delivered to some project sites end up as waste which might result in additional project cost. Cost overrun is a problem which affects 90% of the completed projects in the world. The argument on how to eliminate it has been on-going for the past 70 years, but there is neither substantial improvement nor significant solution for mitigating its detrimental effects. Research evidence has proposed various construction cost overruns and material-waste management approaches; nonetheless, these studies failed to give a clear indication on the framework and the equation for managing construction material waste and cost overruns. Hence, this research aims to develop a conceptual framework and a mathematical equation for managing material waste and cost overrun in the construction industry. The paper adopts the desktop methodological approach. This involves comparing the causes of material waste and those of cost overruns from the literature to determine the possible relationship. The review revealed a relationship between material waste and cost overrun that; increase in material waste would result to a corresponding increase in the amount of cost overrun at both the pre-contract and the post contract stages of a project. It was found from the equation that achieving an effective construction material waste management must ensure a "Good Quality-of-Planning, Estimating, and Design Management" and a "Good Quality- of-Construction, Procurement and Site Management"; a decrease in "Design Complexity" which would reduce "Material Waste" and subsequently reduce the amount of cost overrun by 86.74%. The conceptual framework and the mathematical equation developed in this study are recommended to the professionals of the construction industry.

***Keywords*—**Conceptual framework, cost overrun, material waste, project stags.

I. Introduction

THE construction industry is one of the driving forces behind the socio-economic development of any nation by improving the quality of life and providing the infrastructure, such as roads, hospitals, schools, and other basic facilities. Hence, it is imperative that construction projects are completed within the scheduled period of time, within the budgeted cost, and meet the anticipated quality. However, being a complex industry, it is faced with the severe problems of cost overruns, time overruns, and construction waste [1], [3].

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 [4]. Reference [5] observed that extra construction materials are usually purchased due to the material wastage during the construction process.

Reference [6] established that 10% of the materials delivered to sites in the UK construction industry end up as waste that may not be accounted for. Accordingly, it is noted that for every 100 houses built, there is sufficient waste material to build another 10 houses in Nigeria [7].

Consequently, cost overrun is a common issue in both the developed and the developing nations, which makes it difficult for many projects to be completed within budget. Most developing countries experience overruns exceeding 100% of the initial budget [8]. Reference [9] reported that cost overruns were found across twenty (20) nations and five (5) continents of the world. Cost overruns are a problem, which affects 90% of completed projects [1].

The argument in the construction industry on how to reduce or totally remove cost overruns from a project has been on-going among the built environment professionals, the project owners, and the users for the past seventy (70) years [9], [10]. However, there is neither a substantial improvement, nor any significant solution for mitigating its detrimental effects [9]. Furthermore, studies from different countries have revealed that cost overruns represent a large percentage of the production costs. For instance, 33.33% of the construction project owners in the UK are faced with the problem of cost overruns [1], [11]. The Big Dig Central Artery/Tunnel project in Boston could not be completed within its budgeted cost; and it had an overrun of 500%. The Wembley stadium in the UK had a 50% cost overrun; and the Scottish parliament project, which had a time overrun of more than three (3) years, also experienced a cost overrun of 900% [12].

Reference [7] asserts that material wastage on site leads to an increase in the final cost of the building project. This assertion is supported by [5], who believes that building material wastage on construction sites contributes to project cost overruns. As materials are wasted, more are procured; and this thereby affects the estimated cost.

In the UK, material waste accounts for an additional 15% to construction project cost overruns and also accounts for about 11% of construction cost overruns in Hong Kong. In the same

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vein, a study conducted in the Netherlands revealed a cost overrun of between 20-30% as a result of construction-material wastage [7].

Reference [13] suggests 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, [14] propose various construction material waste management approaches. On this basis, this research seeks to develop a conceptual framework and a mathematical equation for managing material waste and cost overrun in the construction industry.

II. Relationship between Material Waste and Construction Cost Overrun

Construction waste is generally classified into two main classes, namely: the physical waste and the non-physical waste [15].

Physical construction waste is the waste from construction, renovation activities, including civil and building construction, demolition activities, and roadwork. It is, however, referred by some directly as solid waste: the inert waste which comprises mainly sand, bricks, blocks, steel, concrete debris, tiles, bamboo, plastics, glass, wood, paper, and other organic materials [15]. This type of waste consists of a complete loss of materials, due to the fact that they are irreparably damaged or simply lost. The wastage is usually removed from the site to landfills [15]. On the other hand, the non-physical waste normally occurs during the construction process. By contrast with material waste, non-physical waste relates to time and cost overruns for a construction project. Similarly, Reference [16] defines waste as not only associated with wastage of materials, but also to other activities such as repair, waiting time, and delays. Besides that, waste can be considered as any inefficiency that results in the use of equipment, materials, labour, and money in the construction process. In other words, waste in construction is not only focused on the quantity of materials on-site, but also overproduction, waiting time, material handling, inventories, and unnecessary movement of workers [15]. Consequently, Reference [17] added that non-physical waste includes undesired activities, which can cause the physical waste, such as rework, unnecessary material movements, and so forth.

Fig. 1 shows that since construction waste entails both the physical and the non-physical waste, there is a relationship between material waste originating from physical waste and cost overruns from the non-physical waste. Furthermore, the causes of material waste and those of cost overruns identified from the literature are similar. These causes occur as a result of one, or combination of several causes at different stages of a project (the pre-contract and the post-contract stages), and they are very important to identify for effective cost performance and sustainable construction.

TABLE I
Summary of the Relationship between the Cause of Material Waste and Cost Overruns (Pre-Contract Stage of a Project)

Causes of material waste similar to the causes of cost overruns	Material Waste		Cost overruns	
	Ref.	Location	Ref.	Location
Quality of Planning				
Improper planning	[18], [3]	Nigeria; Malaysia	[9], [22]	Ethiopia; Saudi Arabia
Frequent demand for design change by clients	[2], [3]	UK; Malaysia	[1], [22]	Malaysia Ethiopia
Lack of legislative enforcement	[3]	Malaysia	[9]	Saudi Arabia
Inadequate site investigation	[2], [3]	UK; Malaysia	[23], [24]	India; India
Inadequate scheduling	[3]	Malaysia	[23]	India
Quality of design management				
Frequent design changes and material specification	[3], [4]	Malaysia; Nigeria	[1], [9]	Saudi; Malaysia
Error in design and detailing	[18], [19]	UAE; Nigeria	[9], [25]	UK; Saudi Arabia
Lack of design information	[3], [20]	Malaysia; Nigeria	[1]	Malaysia
Inexperience designer or design team	[4]	Nigeria	[1]	Malaysia
Poor communication flow among design team	[2]	UK	[26]	India
Design Complexity				
Designing uneconomical shapes and outlines	[2]	UK; Nigeria	[27]	Ethiopia
Difficulties in interpreting specification	[2]	UK	[9]	Saudi Arabia
Designing irregular shapes and forms	[21]	Geelong, Australia	[28]	Nigeria
Incomplete Drawing	[2]	UK	[28], [29]	Nigeria; Vietnam
Lack of experience	[4]	Nigeria	[26]	India
Quality of Estimating				
Wrong (over/under) estimation and allowance	[21]	Geelong, Australia	[22]	Ethiopian projects
Inaccurate quantity take-off	[3]	Malaysia	[29], [30]	Egypt; Vietnam
Insufficient time for estimate	[3]	Malaysia	[9], [28]	Saudi Arabia; Nigeria
Late engagement of estimator	[21]	Geelong, Australia	[1]	Malaysia
Different methods used in estimation	[3]	Malaysia	[1]	Malaysia

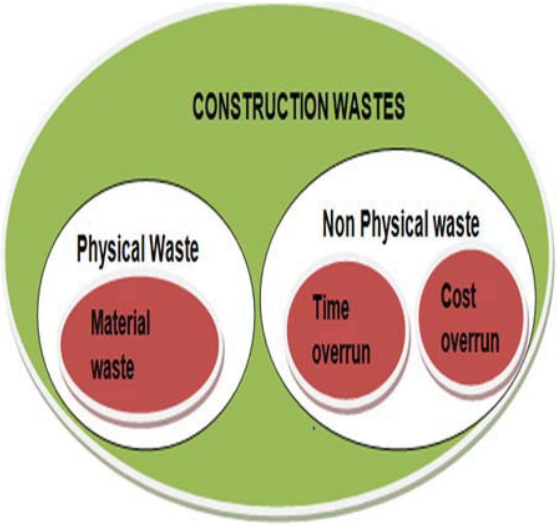

Fig. 1 Classification of construction waste adapted from [15]

A. The Pre-Contract Stage of a Project

The pre-contract stage of a project comprises a lot of activities from inception to the final stage of award of contract. These activities include: the feasibilities, outlined proposal, scheme design, detail design, bills of quantities, and so forth. These activities, if not properly managed and controlled, contribute to the generation of material waste and cost overruns. Hence, it is appropriate to understand the main causes of material waste that relate to the causes of cost overruns at this stage of a project.

The causes of material waste and cost overruns in this stage (pre-contract) are identified in four major phases namely: the quality of planning, the quality of design management, design complexity, and the quality of estimating.

The causes of material waste that are similar to the causes of cost overruns at the pre-contract stage of a project are presented in Table I.

B. Post-Contract Stage of a Project

The activities involved in the post contract stage of a project include the following:

Construction on site, supervision, inspection, approvals, valuations, completion, hand over to client and user occupation, correction of defects, and completion of contract requirements and settlement of the final accounts [31]. However, this aspect of research focuses on construction related issues.

The causes of material waste and cost overruns in this stage (post-contract) are identified in three major phases namely: the quality-of-procurement management, the quality-of-construction management, and the quality-of-site management as presented in Table II.

TABLE II
SUMMARY OF THE RELATIONSHIP BETWEEN THE CAUSE OF MATERIAL WASTE AND COST OVERRUNS AT THE POST-CONTRACT STAGE OF A PROJECT

Causes of material waste similar to the causes of cost overruns	Material Waste		Cost overruns	
	Ref.	Location	Ref.	Location
Quality of procurement management				
Errors/mistakes in material ordering/procurement	[3]	Malaysia	[9]	Saudi Arabia
Procuring items not in compliance with specification	[4]	Nigeria	[9]	Saudi Arabia
Poor estimate for procurement (over/under procuring)	[3]	Malaysia	[9], [30]	Egypt; Saudi Arabia
Wrong material delivery procedures	[3]	Malaysia	[30]	Egypt
Delivery of substandard materials	[3]	Malaysia	[27]	Ethiopia
Damage of material during transportation	[2]	UK	[27]	Ethiopia
Difficulties of vehicles in accessing site	[2]	UK; Malaysia	[22]	Saudi Arabia; Ethiopia
Quality of construction management				
Incorrect scheduling and planning	[2]	UK	[1]	Malaysia; India
Inappropriate contractor's policies	[3]	Malaysia	[30]	Egypt
Lack of awareness	[19]	UAE	[30]	Egypt
Lack of experience	[3]	Malaysia	[34]	Malaysia; Nigeria
Poor site management and supervision	[7]	Malaysia; Nigeria	[29]	Vietnam
Incompetent subcontractor/supplier	[3]	Malaysia	[34]	Nigeria
Lack of training and development	[19]	UAE	[11]	UK
Quality of site management				
Site accident	[32]	Nigeria	[29]	Vietnam
Disputes on site	[4]	Nigeria	[34]	Nigeria; Saudi Arabia; UK
Poor site storage area	[2]	UK; Nigeria	[35]	Reading
Damage by weather	[13]	UK; Nigeria	[3]	Malaysia
Theft, vandalism, sabotage pilferage, and material damage	[2], [7]	UK; Nigeria	[9]	Saudi Arabia
Poor site and unforeseen ground conditions	[13], [33]	Nigeria; Lagos, Nigeria	[30], [34]	Egypt; Nigeria
Lack of environmental awareness	[3]	Malaysia	[36]	Nigeria
Rework	[19]	UAE	[23]	India

III. Research Methodology

The research employed the desktop methodological approach. This involves comparing the causes of material waste and those of cost overruns from the review of the related literature in order to determine the possible relationship. The relevant secondary source of data for this research include: published materials (books, journals) and unpublished reports, such as: periodicals, conference proceedings, building codes, and policies and guidelines relating to material waste and cost overruns in the construction industry.

The analysis was performed by comparing the causes of material waste and those of cost overrun identified from the literature. The causes of material waste that relate to those of cost overruns are ticked by the author and the results were expressed in percentages as presented in Fig. 2.

A. Comparing the Causes of Material Waste with the Causes of Cost Overruns

The causes of material waste and the causes of cost overruns identified from the literature review were both compared with each other at the pre-contract and post-contract stages of a project; in order to identify the relationship between them.

The comparison revealed that, 31 out of the 32 causes of cost overruns considered at the pre-contract stage of a project also cause material waste, showing a 96.88% relationship (pre-contract stage). This means that all the causes of material waste also causes anticipated cost overrun at the pre-contract stage of a project. But only 96.88% of the causes of cost overrun cause material waste. The remaining 3.12% are not related. This implies that, managing material waste at this stage denotes managing a 96.88% of cost overruns.

At the post-contract stage of a project, 54 out of the 66 causes of cost overruns considered also cause material waste, while the 12 remaining causes are not related. This denotes an 81.8% relationship at the post-contract stage of a project.

Summing all the causes at both the pre-contract and the post-contract stages, 32+66 =98, a total of 85 out of 98 causes of cost overruns also cause material waste showing $\frac{85}{98} \times 100 =$ 86.74% relationship for a complete project. The summary of these findings are graphically represented in Fig. 2.

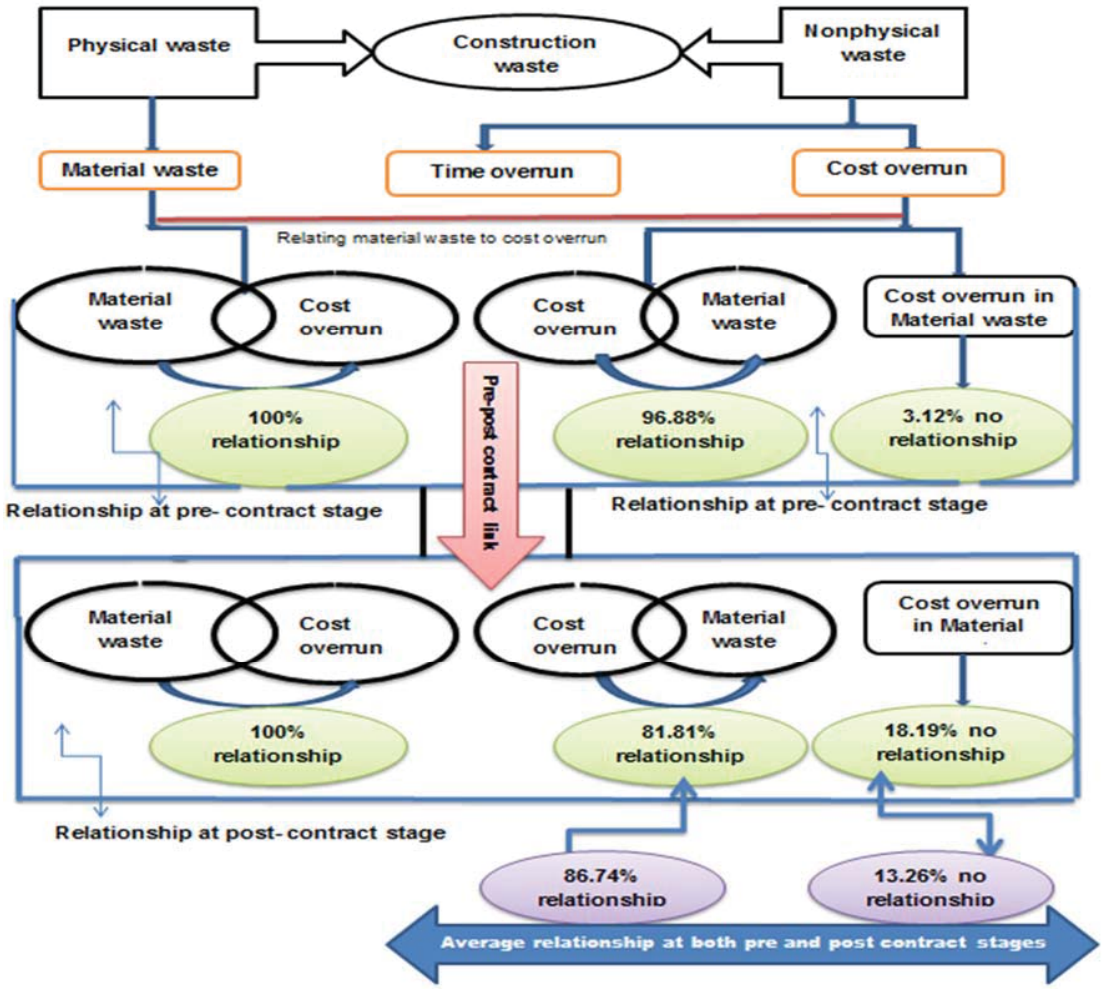

Fig. 2 Relationship between material waste and cost overrun at all stages of a project

IV. The Conceptual Framework for Effective Management of Construction Material Waste and Cost Overrun

A concept is a plan, vision, or a symbolic representation of an abstract idea. A conceptual framework in research shows the researcher's position on the research problem, which gives direction to the study, and further shows the relationships that exist between different constructs that the study intends to investigate. It may be an adoption of a model used in a previous study with modifications to suit the present investigation. Thus, it is referred to as, an organisation, or matrix of concepts that provide a focus for enquiry [37].

The theoretical issues centering on the achievement of effectiveness of construction material waste management are majorly the key pillars of sustainability namely: the environmental, economic, and social construction issues. However, the literature reveals that quality of planning, quality of estimating, quality of design management, and design complexity at the pre-contract stage, and quality of construction management, procurement management, and quality of site management at the post-contract stage of a project all have a major influence on effective construction material waste management. The interrelationships between these issues are important for an effective construction material waste management. Furthermore, the Venn-diagram of effective construction material waste management concept is therefore, located at the boundary line (universal set of the effective construction material waste management), which borders the intersection of the variables that constitute the project stages, material waste, and coefficient of cost overruns.

Fig. 3 presents a conceptual framework to guide the method of the research for the management of material waste and cost overrun in the Nigerian construction industry.

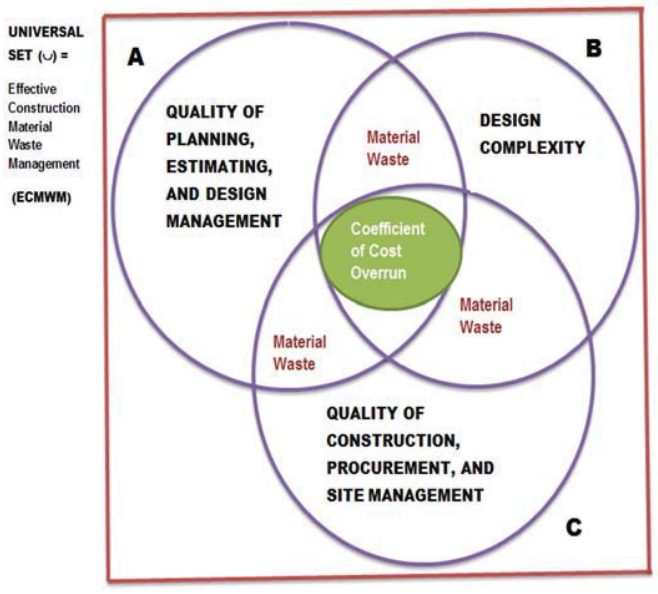

Fig. 3 The Venn diagram conceptual framework for effective construction material waste management

The interrelationships of the variables in the conceptual framework above are summed up in a mathematical equation for achieving an effective waste management in a project using the Venn diagram SET theory.

Fig. 3 shows a relationship between "Quality of Planning, Estimating, and Design Management ($\boldsymbol{QPEDM}$)"; "Design Complexity ($\boldsymbol{DC}$)"; and Material Waste($\boldsymbol{MW}$). This means that a negative change in ($\boldsymbol{QPEDM}$) or positive change in ($\boldsymbol{DC}$) will lead to Material Wastage ($\boldsymbol{MW}$) which will in turn result into Cost Overruns ($\boldsymbol{Co}$). The same applies to "Quality of Planning, Estimating, and Design Management ($\boldsymbol{QPEDM}$)"***and*** "Quality of Construction, Procurement, and Site Management ($\boldsymbol{QCPSM}$)". A negative change in any of these results in Material Waste ($\boldsymbol{MW}$) which also results in cost overrun ($\boldsymbol{Co}$). There is also a relationship between "Design Complexity ($\boldsymbol{DC}$)"; "Quality of Construction, Procurement and Site Management ($\boldsymbol{QCPSM}$)"; and Material Waste ($\boldsymbol{MW}$). This means that a negative change in ($\boldsymbol{QCPSM}$) or a positive change in ($\boldsymbol{DC}$) variable will lead to material wastage ($\boldsymbol{MW}$) which will in turn result into Cost Overrun ($\boldsymbol{Co}$).

A. Mathematical Equation for Managing Material Waste and Cost Overruns

Based on the issues originating from the conceptual framework of material waste and cost overruns, the steps for developing a mathematical equation for managing construction material waste and cost overrun are presented as:

$\cup$= Effective Construction Material Waste Management ($\boldsymbol{ECMWM}$)
$\boldsymbol{A}$= Quality of Planning, Estimating, and Design Management ($\boldsymbol{QPEDM}$)
$\boldsymbol{B}$= Design Complexity ($\boldsymbol{DC}$)
$\boldsymbol{C}$= Quality of Construction, Procurement and Site Management ($\boldsymbol{QCPSM}$)
$\boldsymbol{x}$= Material Waste ($\boldsymbol{MW}$)
y= Cost Overrun ($\boldsymbol{Co}$)
$\boldsymbol{a}$= Coefficient of cost overrun = (*0.87)*
$\boldsymbol{i}$= Lower limit
$\boldsymbol{n}$= Number of designs

Therefore,

Poor "$\boldsymbol{A}$" (-) ==>Leads to==>"$\boldsymbol{x}$"; Poor "$\boldsymbol{C}$" (-) Leads =>to==>="$\boldsymbol{x}$"
Increased "$\boldsymbol{B}$" (+) = (Leads to=== "$\boldsymbol{x}$"; *and*
"$\boldsymbol{x}$"==========$\boldsymbol{0.87y}$.

To reduce letter "x" to negative (-), then, Good "$\boldsymbol{A}$" (+) leads to negative x $(-\boldsymbol{x})$; Good "$\boldsymbol{C}$" (+) leads to a negative x $(-\boldsymbol{x})$ *as well*; ***and*** Reduced "$\boldsymbol{B}$" (-) leads to a negative x $(-$ x).

Negative variables =$\boldsymbol{X, Y,}$ ***and*** $\boldsymbol{B}$. They have to be negative because practically, material waste, cost overrun and design complexity have to be reduced to achieve the 'Effective construction material waste management' ($\boldsymbol{ECMWM}$) ***or*** ($\cup$) ***or*** ($\boldsymbol{A}$ ($\boldsymbol{B}$ ($\boldsymbol{C}$). Therefore, since "$\boldsymbol{x}$" "material waste" for a complete project is shared between all the intersections showing a relationship between the main variables in the SET and "$\boldsymbol{x}$" which is negative, that is $(-\boldsymbol{x})$ can be equal to:

$$\left(-\frac{\mathbf{1}}{\mathbf{3}\boldsymbol{x}}\right)+\left(-\frac{\mathbf{1}}{\mathbf{3}\boldsymbol{x}}\right)+\left(-\frac{\mathbf{1}}{\mathbf{3}\boldsymbol{x}}\right)=-\boldsymbol{x}$$

This means that, a complete material waste is found at the completion of all the required stages of a project. Therefore, from the Venn diagram of SET theory in mathematics,

$$(A\cup B\cup C)=n(A)+n(B)+n(C)+n(A\cap B)+n(A\cap C)+n(B\cap C)+n(A\cap B\cap C) \quad (1)$$

Substituting the variables:

$$(A\cup B\cup C)=A+(-B)+C+\left(-\tfrac{1}{3x}\right)+\left(-\tfrac{1}{3x}\right)+\left(-\tfrac{1}{3x}\right)+(-0.87y) \quad (2)$$

$$(A\cup B\cup C)=A+C-B-x-0.87y \quad (3)$$

Substituting the original variables to (3):

$$ECMW=\ QPEDM+QCPSM-DC-MW-0.87Co \quad (4)$$

The final equation will be:

$$\boldsymbol{ECMWM=\sum_{i=1}^{n} QPEDM+QCPSM-DC-MW-0.87Co} \quad (5)$$

This equation means that: To achieve an effective construction material waste management (from one to any number of projects), there must be "Good Quality of Planning, Estimating, and Design Management ($\boldsymbol{QPEDM}$)" and "Good Quality of Construction, Procurement and Site Management ($\boldsymbol{QCPSM}$)"; there must be a decrease in "Design Complexity ($\boldsymbol{DC}$)" which will reduce "Material Waste ($\boldsymbol{MW}$)" and subsequently reduce the amount of "Cost overrun ($\boldsymbol{Co}$)" by 0.87 (87%).

V. Conclusion and Recommendations

It has been established from this research that a relationship exists between material waste and cost overruns at the pre-contract and post-contract stages of a project. This implies that an increase in material wastage on site leads to a corresponding increase in cost overruns, regardless of the percentage allowed for material waste in the process of the bill preparation.

The study concludes from the literature that 100% of the causes of material waste also cause cost overruns at the pre-contract and the post-contract stages of a project, while 96.88% and 81.81% of the causes of cost overruns also cause material waste at the pre-contract and at the post-contract stages respectively.

There was an 86.74% relationship between material waste and cost overruns at both the pre-contract and the post-contract stages of a project. The study also concludes that to achieve an effective construction material waste management, there must be a "Good Quality-of-Planning, Estimating, and Design Management" and a "Good Quality- of-Construction, Procurement and Site Management"; a decrease in "Design Complexity which would reduce "Material Waste" and subsequently reduce the amount of cost overrun by 87%.

The conceptual framework and the mathematical equation for managing material waste and cost overruns developed in this study are recommended to the construction industries. This would enable the construction professionals to evaluate the extent to which material waste and cost overrun could be minimised, in order to meet the required effective waste management and cost overruns objectives for projects.

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