Onsite Assessment of Material Waste Minimization of Operations on Construction Projects

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Abstract
The minimization effectiveness of any framework can be determined by subjecting it to objective assessment on real-life projects before it can be engaged as a reliable tool for practitioners. This study is an objective validation of a framework for materials waste minimizations (FMWM) on construction sites. The specific objectives are to: refine the structure of the FMWM; assess the FMWM; evaluate its effectiveness; and determine implementation strategies of the FMWM. Cross-sectional survey and pure experimental research designs were used among professionals and construction projects in Lagos State. Data were collected using focus group discussions, interviews and site evaluation; and analyzed with descriptive and inferential statistical tools. The findings reveal that the FMWM is appropriate for material waste minimization with the overall effectiveness of 4.09%, which could be enhanced when the FMWM is used at all stages of construction projects. It implies that construction material waste can be reduced when the FMWM is adequately engaged. It is recommended that professionals should adopt the FMWM for site operations on their projects. This can be done by head offices mandating site teams to apply the FMWM on sites and requesting its inclusion on site reports.

Keywords: *Assessment, Material Waste minimization, Onsite, Operations, Construction Projects.*

Introduction

Construction waste can be categorized as structure or finishing waste (Skoyles & Skoyles, 1987). Waste generated during the builder's work stage are termed structure waste while finishing wastes are those generated at the finishing stage. Construction material waste can also be classified into direct and indirect waste, direct waste is damaged or lost material during the building process; while indirect waste is only a monetary loss in value and not physical loss of materials.

Keys, Baldwin, and Austin (1999) noted that indirect wastes could contribute 10 – 15% of waste volumes when services are being installed. Moreover, the Centre for Research in the Built Environment (CRiBE) (2003) opines that waste types vary according to the stage of the construction project. Poon, Yu, Wong and Cheung (2004) in a study in Hong Kong discovered that high amount of various building materials ended up as waste on sites and different materials have varying generation and waste recovery tendencies.

Similarly, Seydel, Wilson, and Skitmore (2002) reported that plasterboard, timber, and masonry contribute approximately 19.5% of the waste produced on a construction project in Brisbane, Australia, these materials were considered to have high recycling potential. Akanni (2007) also report 13.6% average materials waste on 146 construction projects in Southwestern Nigeria. In a related research, Swinburne, Udeaja, and Tait (2010) conducted a study on a local authority highway project in the United Kingdom.

The study measured on-site wastages of sand, Portland cement, concrete with tarmac and compared them with the 5% material wastage allowance included in the tender documents, and discovered significant differences between the theoretical and actual quantities of the materials. Concrete had an average wastage of +10.9%, Portland cement; +79.7%, tarmac; + 2.2%, while only sand was -5.7% (positive % shows actual materials usage > theoretical usage, while negative % is the reverse case). The negative wastages of sand were attributed to erroneous recording and possible use of the wrong mixing ratio.

Souza and Andrade (1999) also conducted a study on three 15-floor towers and four 17-floor towers in Brazil using sampling approach. The approach involves setting aside specific numbers of blocks marked in the stockpile (A). After a week, the number of blocks used (B) in the wall were counted and the remaining blocks in the stockpile (C) were also counted and recorded.

The waste; Materials Loss in Percentage (*MLP*) is calculated as,

$$MLP = \frac{A - (B + C) \quad x\ 100}{A} \text{ ------------------ (1)}$$

The sites presented *MLP* values of blocks ranging from 3% to 48%.

In addition, Shen, Tam, Tam, and Ho (2000) investigated seven types of projects by interviewing contractors to gather information on wastages of concrete, steel reinforcements, formworks, and brick/block. It revealed that the percentage wastage of these materials vary with project type. All the project type investigated showed unavoidable or natural waste which necessitates setting minimum wastage levels for all materials in projects.

Similarly, Baytan (2007) determined the wastages of ready-mix concrete, steel rebar, brick, and floor blocks using materials data. Baytan measured the wastages by taking into account the material quantities in the bill of quantities (*b*), progress payment report (*c*) and invoices (*d*).

$$\text{Waste percentage value} = \frac{d - c}{c} \text{ x } 100$$

$$\text{Waste/m}^2 = \frac{d - c}{a} \text{ x } 100 \text{ ------------------(2)}$$

Where, *a* = construction floor area; *c* = materials quantity in progress payment; *d* = materials quantity in invoices.

The highest average waste percentage was recorded in floor blocks (14.6080%), while the least wastage was recorded in ready-mixed concrete (6.1229%). Likewise, Bossink, Brouwers, and Kessel (1996) sorted and weighed the material wastage at five building sites in Netherlands, which resulted in various waste fractions. The study revealed that the largest origin of waste is the use of stone tablets (29%), followed immediately by piles (17%), concrete (13%), sand-lime elements (11%), roof tiles (10%), mortar (8%), packaging materials (7%), sand-lime bricks (3%) and small fractions of metal and wood (2%).

In all, the methodology of Souza and Andrade (1999) is the most appropriate for materials waste evaluation for the Nigerian situation. It involves physical counting or measurement of materials or work done before and after an operation. Hence, the methodology of Souza and Andrade (1999) with some modification was appropriate for the evaluation of wastages of selected materials in this study.

Furthermore, material waste minimization strategies involves the use of practices and processes which reduce the amount of waste produced on construction sites. One way construction waste can be minimized on sites is through the usage of frameworks. A framework is a guide, comprising processes or steps to achieve a desired goal, such as material waste minimization. A set of frameworks for material waste minimization (FMWM) for construction practitioners in Nigeria were developed in a research by Oladiran, Ogunsanmi and Dada (2019).

It was concluded that the FMWM possesses important components and processes on waste issues; and therefore it is applicable and appropriate for minimization of material wastage at every stage of building projects. The frameworks were validated through face validity and scoring approach. Nonetheless, it is necessary to evaluate the FMWM on ongoing projects for material waste minimization.

Therefore, the aim of this research is to objectively evaluate the FMWM on selected projects to establish their applicability, appropriateness and effectiveness for waste minimization on construction projects; with a view to minimize waste on construction sites. The specific objectives are to, refine the structure of the FMWM; assess the logical structure, comprehensiveness, clarity, information flow, practical relevance, applicability, suitability, familiarity and appropriateness of the FMWM; to compare material wastages of projects involving the usage of the FMWM with those without the use of the FMWM; and to determine implementation strategies of the FMWM.

This study focuses on selected construction projects in Lagos, Nigeria and considered only the FMWM proposed for site operation stage in Oladiran (2019). Due to large number of construction materials, this study was limited to measuring the wastages of concrete, steel reinforcements, sandcrete hollow blocks and tiles on sites. This study is significant because it provides a veritable tool for construction practitioners to minimize wastages and assist in the realization of low-cost housing and reduction of damage to the environment in Nigeria.

Method

Cross-sectional survey and pure experimental research designs were used to carry out this study. Cross-sectional survey involves one-time gathering of data from respondents without manipulating or controlling the variables. After-only design with multiple experimental groups and control groups were used to assess the

FMWM (See Figure 1). In this study, experimental groups refer to projects involving the usage of the FMWM, while control groups are projects without the use of the FMWM to determine the effectiveness of the FMWM in terms of material waste minimization.

The research area was Lagos State, it was selected because it has been identified as the primate economic city in Nigeria with a lot of construction sites. The populations of the study were construction professionals of on-going and their on-going projects in the research area. Purposive sampling technique was employed to select a sample from the research area. A total of **33** professionals and **60** projects were used. The projects comprised 27 control projects and 33 experimental projects. The data collection instruments were focus group discussions, interviews, and site evaluation.

Focus group discussions were employed for initial fine tuning of the FMWM, before proceeding to site evaluations. Interviews were conducted by the researchers while site evaluations were done with the aid of field assistants and site assessors on the selected sites. This was done by construction professionals on the selected projects. The main goal was to study the FMWM and make suggestions on how it could be refined in terms of its structure, content, and clarity. The FMWM was sent to them to study before the discussions. The outcome of the discussions was used to refine, restructure, and improve the FMWM shown in Figure 1.

Moreover, **s**ome site managers of the selected on-going projects were interviewed. Letters of consent, interview schedule and the FMWM were sent to each of them at least two weeks before the interviews. The interview schedule contained questions that centered on assessing the FMWM and other objectives of the study. Finally, observations and measurements on the FMWM were carried out on sites to determine its material waste reduction of selected materials, namely: concrete, steel reinforcements, sandcrete hollow blocks and tiles.

Wastages of these materials were measured and calculated on both the control and experimental projects using the method of Souza and Andrade (1999); and the difference was the waste reduction effectiveness of the FMWM. Descriptive and inferential statistical tools were used to analyze the data and make deductions. Waste reduction of the FMWM = Material wastage of experimental projects - material wastage of control projects.

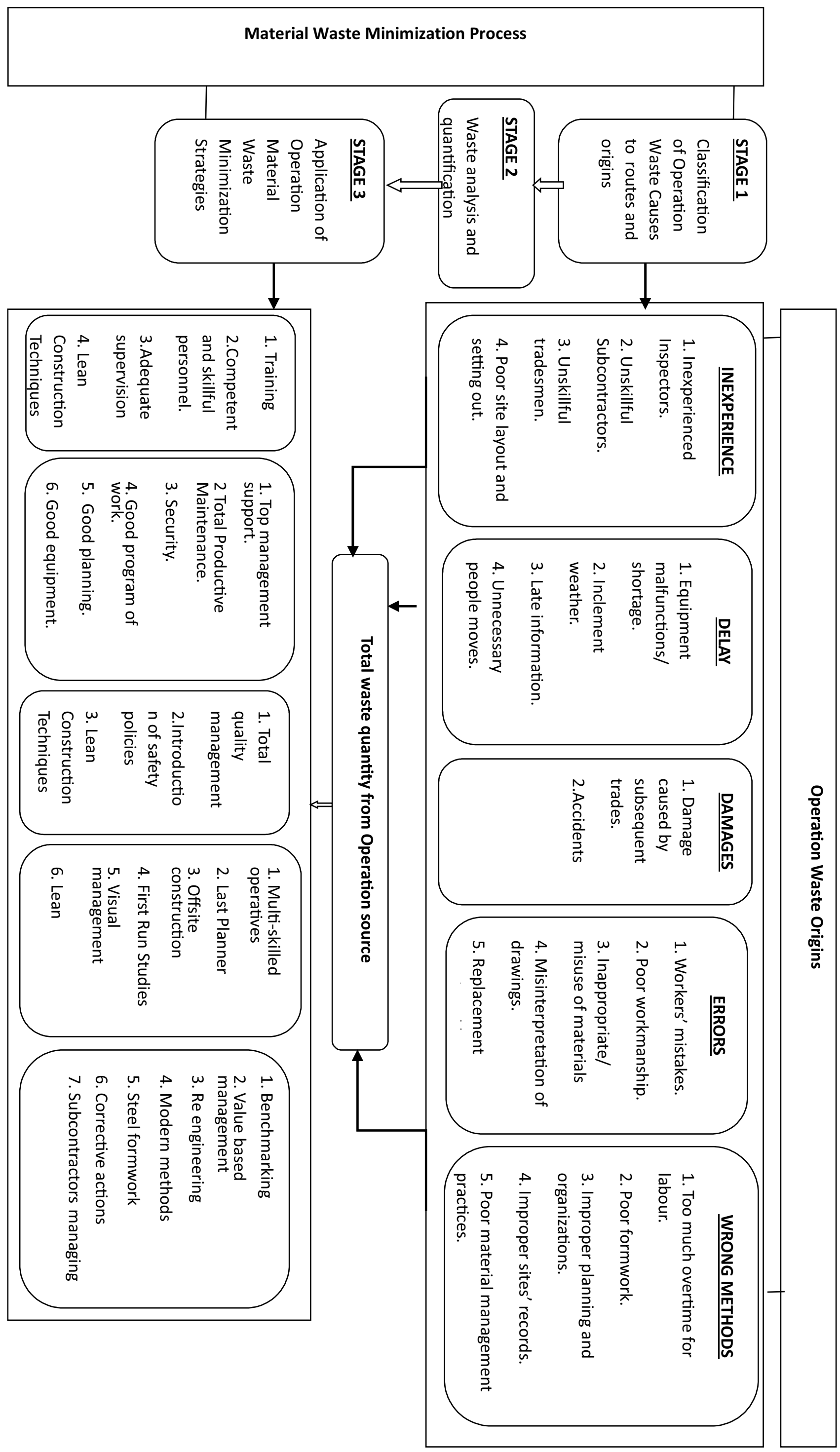

Figure 1: Operation waste minimization subsidiary-level framework for medium and large contracting organizations projects.
Source: Oladiran *et. al.* (2019), p.56

Findings and Discussions

Demographic Information of Interviewees.

Table 1 shows the demographic information of the respondents who participated in the validation exercise. A total of 33 construction professionals were interviewed. Nine percent of them were Project Managers, 46% were Site Managers, 6% were Site Supervisors, 15% were Project Engineers and 24% were Quality Officers. Fifteen percent were Architects, six percent were Quantity Surveyors and 39.5% each were Builders and Civil Engineers. Also, 51.5% have M.Sc degree, 39.5% have B.Sc degree and nine percent have HND. Additionally, 21% have less than 5 years construction experience, 48.5% have from 6 to 10 years and 30.5% have from 11 to 15 years.

Table 1: Demographic information of interviewees.

Respondents' information		Frequency	Percentage
Designation	Project Managers	3	9
	Site Managers	15	46
	Site Supervisors	2	6
	Project Engineers	5	15
	Quality Control Officers	8	24
	Total	**33**	**100**
Profession	Architecture	5	15
	Quantity Surveying	2	6
	Building	13	39.5
	Civil Engineering	13	39.5
	Total	**33**	**100**
Academic qualification	M.Sc	17	51.5
	B.Sc	13	39.5
	HND	3	9
	Total	**17**	**100**
Construction experience	Less than 5 years	7	21
	6 – 10 years	16	48.5
	11 – 15 years	10	30.5
	Above 15 years	0	0
	Total	**33**	**100**
Category of organization	Indigenous	28	85
	Multinational	5	15
	Total	**33**	**100**
Type of organization	Private	27	82
	Public	6	18
	Total	**33**	**100**
Nature of organization	Contracting	17	52
	Consulting	4	12
	Client	4	12
	Developers	5	15
	Multiple	3	9
	Total	**33**	**100**

Moreover, 85% of those interviewed were from indigenous construction organizations while 15% were from multinational organizations. As many as 82% were from private organizations while 18% were from public. Also, 52% are from contracting organizations, 12% each from consulting and client organizations, 15% from Building Developers and 9% were from organizations that were involved in multiple construction jobs. This result shows that those that were interviewed are qualified to validate the proposed FMWM.

Field Validation of the FMWM.

First, the field validation was done by questioning the interviewees on the FMWM on the logical structure; comprehensiveness; clarity; familiarity and appropriateness; information flow; suitability for waste minimization; practical relevance; and applicability on construction projects. They were asked to rate the framework between 'excellent' (5) and 'extremely poor' (1) on the aforementioned issues; after which they were further questioned on the same issues. Their opinions about the FMWM on the issues are presented in Table 2 and additional findings on the issues from the interviews are subsequently presented and discussed.

Table 2: Assessment of FMWM by Construction Professionals.

	Extremely Poor 1	Below Average 2	Average 3	Above Average 4	Excellent 5
Logical Structure of the Frameworks	0 (0%)	0 (0%)	0 (0%)	28 (85%)	5 (15%)
Comprehensiveness	0 (0%)	0 (0%)	1 (3%)	13 (39%)	19 (58%)
Clarity	0 (0%)	0 (0%)	1 (3%)	18 (55%)	14 (42%)
Familiarity and Appropriateness	0 (0%)	0 (0%)	2 (6%)	14 (42.5%)	17 (51.5%)
Information Flow	0 (0%)	0 (0%)	1 (3%)	20 (61%)	12 (36%)
Suitability for waste minimization	0 (0%)	0 (0%)	0 (0%)	24 (73%)	9 (27%)
Practical Relevance	0 (0%)	0 (0%)	1 (3%)	13 (39%)	19 (58%)
Applicability	0 (0%)	0 (0%)	0 (0%)	10 (30%)	23 (70%)

a. Logical Structure of the Frameworks: Table 2 sheds light that 85% of those interviewed agreed that the structure is above average, while 15% opined that it is excellent. Additionally, seven of them agreed that 'it is very logical', five agreed 'it is good', while 21 agreed that 'it is well organized. It can be inferred that the arrangements, linkages, and presentation of the FMWM are good and can be understood by construction professionals who are to use it on projects.

b. Comprehensiveness: as many as 58% of the interviewees said that the comprehensiveness is excellent, 39% opined that it is above average and 3% said it is average. Moreover, 15 of them said that 'it is very comprehensive'. It can be inferred that all the issues that are required to minimize materials wastage are included in the FMWM.

c. Clarity: about 42% of those interviewed said that the clarity of the FMWM is excellent, 55% opined that it is above average and 3% said it is average. Moreover, close to 14 of them submitted that the FMWM can be 'easily understood and it is very clear'. Eighteen of them said 'it is not difficult to interpret'. However, a respondent noted that 'language barrier could be a difficulty for operatives in interpreting the FMWM'. It is noteworthy that the people to actually interpret and implement the frameworks are construction professionals, who are expected to have some level of education such that language will not be a barrier. The professionals are to involve operatives in the application of the frameworks.

d. Familiarity and Appropriateness: as many as 51.5% of the interviewees said that the familiarity and appropriateness are excellent, 42.5% opined that they are above average and 6% said they are average. Moreover, 14 of the interviewees said that 'there are no unpopular and inappropriate items in the FMWM', while another person said 'everything in the frameworks are okay and known'. Since the items of the framework are known, using it won't be a problem.

e. Information Flow in the frameworks: about 36% of the interviewees said that the information flow in the framework is excellent, 61% opined that it is above average and 3% said it is average. Additionally, 12 of the interviewees further opined that 'there are no disruptions in information flow in the frameworks', while 14 said that 'there is proper linkage of information in the frameworks' and that 'the processes are well arranged and sequenced'.

f. Suitability for waste minimization: as many as 73% of the interviewees said that the suitability of the frameworks for waste minimization above average, 27% opined that it is excellent. Furthermore, five of the interviewees said that the suitability can be achieved by 'following the procedures' in the frameworks. Other opinions by the interviewees on how the suitability can be achieved or enhanced include 'adopting central dumps, good layouts, monitoring to prevent double handling, communication among project team, training of artisans and consciousness of materials used and wasted'.

g. Practical Relevance: about 58% of the interviewees said that the practical relevance of the frameworks to waste minimization is excellent, 39% opined that it is above average and 3% said it is average. Additionally, 15 of them said the FWMW can be applied on all project types, 12 further opined the relevance can be improved by 'strictly following the procedure in the FWMW'. It was also noted that the relevance can achieved by 'applying certain strategies specific to a project and improved communications.

h. Applicability of frameworks: as many as 70% of the interviewees said that the applicability of the frameworks on construction projects above excellent, 30% opined that it is above average. All the interviewees submitted that if the 'processes are followed, the FMWM is applicable'. However, someone noted that one way the frameworks may not work in the Nigerian construction projects is due to low mechanization. Most indigenous projects favours more of manual labour to mechanization due to affordability. The FMWM advocates mechanization to achieve waste minimization.

Difference Among Professionals on the Assessments of FMWM.

A hypothesis was postulated to test if the professionals differ statistically in their opinion about the structure of the FMWM:

$H0_1$: There is no significant difference between construction professionals on the assessment of the FMWM.

Analysis of Variance (ANOVA) in statistical package for social sciences (SPSS) was employed to test for the difference in the opinion of the professionals on the assessment of the FMWM and the outcome is presented in Table 3. The result reveals that there is no significant difference in the construction professionals' opinion because all the p-values are higher than 0.05, the null hypothesis ($H0_1$) is therefore supported for all the assessments parameters. The implication is that the results obtained in Table 2 are sustained regarding the FMWM.

Table 3: Analysis of Variance (ANOVA) of difference among professionals on the assessments of FMWM.

		Sum of Squares	df	Mean Square	F	p-values
Logical Structure of Framework	Between Groups	.512	3	.171	1.326	.285
	Within Groups	3.731	29	.129		
	Total	4.242	32			
Comprehensiveness of Framework	Between Groups	1.720	3	.573	1.965	.141
	Within Groups	8.462	29	.292		
	Total	10.182	32			
Clarity of Framework	Between Groups	.925	3	.308	.999	.407
	Within Groups	8.954	29	.309		
	Total	9.879	32			
Familiarity and appropriateness of framework	Between Groups	.828	3	.276	.705	.557
	Within Groups	11.354	29	.392		
	Total	12.182	32			
Information flow of the Framework	Between Groups	.679	3	.226	.759	.526
	Within Groups	8.654	29	.298		
	Total	9.333	32			
Suitability of the framework	Between Groups	1.077	3	.359	2.042	.131
	Within Groups	4.923	28	.176		
	Total	6.000	31			
Practical relevance of the framework	Between Groups	1.220	3	.407	1.316	.288
	Within Groups	8.962	29	.309		
	Total	10.182	32			
Applicability of the framework	Between Groups	.624	3	.208	.950	.429
	Within Groups	6.346	29	.219		
	Total	6.970	32			

Relationship Between Suitability and Applicability of the FMWM.

A hypothesis was postulated to determine the relationship between the suitability and applicability of the FMWM on construction projects:

$H0_2$: There is no significant relationship between the suitability and applicability of the FMWM.

The relationship between the suitability and applicability of the FMWM was examined using the Pearson correlation and the result is presented in Table 4. The result indicates a positive relationship (0.234) though it is weak and insignificant because the p-value is higher than 0.05. The implication of this is that there is weak tendency that professionals will adopt the FMWM if they consider it suitable. If their suitability is improved, it could lead to increase in the usage of the FMWM.

Table 4: Correlation between suitability and applicability of the FMWM.

n	Correlation value	p-value
32	.234	.198

Effectiveness of FMWM on Construction Projects.

Table 5 shows the effectiveness of the FMWM, which is the waste difference between the material wastages of projects involving the usage of the FMWM and those without the use of the FMWM. The results shown in Table 5 indicate that the FMWM is effective in minimizing materials wastages, but it varies for different materials. The highest percentage effectiveness is steel reinforcement (5.75%), followed by sandcrete hollow block (4.76%), concrete (3.25%), and tiles (2.58%).

Table 5: Effectiveness of FMWM on construction projects.

Materials	Waste generated on projects without FMWM (control group – C) (mean)	Waste generated on projects with FMWM (experimental group – E) (mean)	FMWM's Effectiveness (C - E)
Block	12.45%	7.69%	4.76%
Concrete	8.03%	4.78%	3.25%
Tiles	14.80%	12.22%	2.58%
Steel	17.31%	11.56%	5.75%
Overall(average)			**4.09%**

Previous works revealed that material waste in Nigeria is above 5% (Adewuyi & Otali, 2013; Proverbs and Olomolaiye, 1995; Odusami et. al., 2012). Tam *et. al.* (2007) discovered wastage levels of 4.48% to 8.99% for concrete, 5.87% to 8.90% for block and 6.62% to 15.58% for tile in Hong Kong and this depended on the sub-contracting arrangement employed. Al-Moghany (2006) also assessed the mean weight of concrete and block in Gaza Strip to be 5.4 each while tile is 4.4. Similarly, Poon *et. al.* (2004) recorded 3% to 5% ready-mixed concrete in 22 Hong Kong sites where 80% of the concrete is ready-mixed. The wastage level of concrete, block, and tile in Malaysia are 0% to 10.2%, 3.45% to 5.23% and 3.2% to 8.00% respectively, depending on the type of projects and method of construction (Masudi *et. al.*, 2011). In the same vein, Bossink and Brouwers (1996) reported overall average waste of 9% in the Netherlands; and 5% to 27% in Ghana by Agyekum (2012). Bossink and Brouwers (1996) also stated that in the Brazilian construction industry, 20 – 30% of purchased materials that were not used end up as waste. It can be observed that this study has shown the effectiveness of the FMWM since waste generation is less than 5% for the materials investigated except steel reinforcements. Infact, the average overall wastage for the four materials investigated is 4.09%. This value is lesser compared to the results obtained for many countries aforementioned: Hong Kong, Gaza Strip, Malaysia, Netherlands, Ghana and Brazil. Thus, the implementation of the FMWM will reduce materials waste.

Difference Between Waste of Projects With and Without FMWM.

A hypothesis was also postulated to test if the waste generation of projects that use FMWM and projects without FMWM differ statistically:

$H0_3$: There is no significant difference in the waste generation of projects that use FMWM and projects without FMWM.

The difference in waste generated between the two categories of projects were investigated using paired sample t-test and the result is presented in Table 6. The result shows significant difference between the two sets of projects because the p-value (0.011) is less than 0.05. The null hypothesis $H0_3$ is therefore rejected. It implies that the waste generation on any projects that employed the FMWM will be significantly lesser than those where it was not used.

Table 6: t-test between waste of projects with and without FMWM.

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	%Mean Waste on projects without FMWM. - %Mean Waste on projects with FMWM.	4.08500	1.43644	.71822	1.79930	6.37070	5.688	3	.011

Implementation Strategies of the FMWM.

The following implementation strategies were suggested by various respondents:

1. Engagement of competent and requisite professionals for site works.
2. There is the need for usage of skilled labor.
3. Proper monitoring and coordination of material procurement.

4. Training and education on movement and storage of materials.
5. There is the need to allow suppliers manage the storage of materials.
6. Adequate planning for handling and good materials packaging.
7. Teamwork.
8. Educating workers on correct placement of materials.
9. Good material packaging and changing construction methods.
10. Mechanization or increasing crew on sites.
11. Total quality management.
12. Achievable objectives must be clearly stated for achievable goals.
13. Usage of waste audit.

The Nigerian building industry requires a framework to forestall the incidence of material waste on building projects. Previous works on the issue of waste in Nigeria have not attempted to evolve a framework, which can be used by construction practitioners to prevent and reduce material waste.

Additionally, Wahab and Lawal (2011) indicate that there are no policies that mandate contractors to minimize material waste on projects. The introduction of policies will not be efficient, if there are no frameworks that synergizes the key issues about waste, especially as it relates to the Nigerian context. The proposed FMWM in this study depicts factors that are germane to waste incidence and processes for their minimization on sites. A major highlight in the framework for waste minimization apart from identifying routes of waste and minimization strategies is the analysis and evaluation of waste, which is seldom practiced in Nigeria.

For instance, designs are not evaluated for waste in Nigeria. Thus, a lot of waste that can be prevented occurs on site. Ekanayake and Ofori (2004) developed and recommended Building Waste Assessment Score (BWAS) model to evaluate designs for potential to generate waste, so as to produce designs that are less likely to generate waste. Contractors are also enjoined to employ the model to select site management techniques which help them to face the waste challenge at the design stage. Designs should also be subjected to 'buildability and maintainability analysis', which will reveal among other things, the inherent waste tendency in designs.

Additionally, a major advocate in the framework is the application of Lean Construction (LC) techniques in building projects in Nigeria. Ballard and Polat (2005) recommend the application of tools and techniques of LC to prevent waste from occurring by identifying the root-causes of waste and eliminating them at all stages of construction.

However, Oladiran (2008) reveals that LC is alien to the Nigerian building industry; while the study also indicates the barriers and implementation strategies for LC in Nigeria, of which is education and skill development on LC. Thus, there has been growing interest, research and development on LC in Nigeria; hence its inclusion in the framework.

Furthermore, the validation exercise reinforces the need, relevance and appropriateness of the framework. The validation exercise highlights various implementation strategies for it. The practical relevance of the framework can be seen in the evaluation and comments of the potential end users. The following comments were made on the framework by some of the respondents:

I. *If the frameworks are fully implemented on site, waste will be minimized on construction sites.*
ii. *The framework is implementable on construction sites and must be effectively practiced.*
iii. *It is a good framework.*
iv. *The information and the flow are self-explanatory.*
v. *There is thorough research and comprehensive details about the framework. The report is understandable and obtainable.*
vi. *It is satisfactory.*

Conclusion and Recommendations

Material waste minimization is germane to low cost and affordability of housing. This study argues that it can be achieved through the usage of appropriate frameworks. It then assessed a framework on life projects to validate its effectiveness in terms of waste minimization. The empirical investigation was carried out and the following conclusions were made based on the findings of the study:

1. The FMWM can be easily implemented on construction projects to minimize materials wastages due to its features, but the operators must fully understand it to deliver maximally. This implies that some level of literacy is required by site workers to ensure the intended result in minimizing materials wastages.
2. Although the FMWM's effectiveness varies between 2.58% to 5.75% during

site operations for different , the effectiveness could further be enhanced when the FMWM is used at all stages of construction projects. The implication of this is that the readiness of construction professionals to holistically embrace the FMWM is pivotal to high reduction of material waste on construction sites.

3. Although the FMWM is well implementable on construction projects, successful implementation requires certain strategies, including competent and requisite professionals, skilled workers, and training. It implies that attaining waste minimization from the FMWM is premised on the amount of investment put into its implementation.

The following recommendations are made based on the findings of the study:

1. Professionals should adopt the FMWM for construction site operations. This can be done by head offices mandating site teams to apply the FMWM on sites and requesting its inclusion in site reports.
2. Site teams should take cognizance of the specific features of the FMWM when implementing it. This can be done by familiarizing themselves repeatedly with these features before and during each project.
3. Site professionals should set targets of waste minimization for each material and engage the FMWM to achieve them. This can be done at the beginning of each operation and an evaluation at the end.
4. The proposed strategies should be considered for the implementation of the FMWM. This can be achieved via trainings and inclusion in management decisions.

Further Area of Research

The proposed frameworks by Oladiran *et. al.* 2019 were five in number covering the entire stages of a construction project, namely: client, design, purchase/supply, handling and operation. This present study validated just the operation stage framework for material waste minimization. Future researches are therefore proposed to explore the applicability and validation of the frameworks for client, design, purchase/supply and handling stages in real-life projects.

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