Minimizing Materials Wastage in Construction- A Lean Construction Approach

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ABSTRACT: *It is commonly acknowledged that a very high level of waste exists in construction. Since construction has a major and direct influence on many other industries by means of both purchasing inputs and providing the products to all other industries, reducing waste in the construction industry could yield great cost savings to the society. This paper aimed at identifying the main sources and causes of materials waste on construction sites arising from storage and handling of high waste generating building materials and employing the Lean Construction approach to reduce such waste. The findings in this paper are based on a structured questionnaire survey of 226 building construction organizations and consultants in the Ghanaian building industry. The findings revealed that materials storage and handling, operational factors, design and documentation factors and procurement factors are the main sources of waste on building construction sites. Among the causes of materials waste are last minute client changes, errors by tradesmen, purchased products that do not comply with specification and lack of onsite materials control. The findings further showed that timber, cement/mortar, concrete and blocks are the four key materials that have the highest level of wastage on building sites. Recycling of some waste materials on site, re-using of surplus materials where appropriate and preventing the occurrence of waste are recommended to reduce waste. Minimizing material wastage would not only improve project performance and enhance value for individual customers, but also have a positive impact on the national economy.*

Keywords: Materials, Waste, Lean Construction, Re-Use, Recycling
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INTRODUCTION

A very high level of waste is assumed to exist in construction[1]. Studies in various countries have confirmed that waste represents a relatively large percentage of production cost although it is difficult to systematically measure all wastes in construction[1].

In pursuing the mission of sustainable development, many countries are working towards maintaining a balance between developing the built environment and protecting the natural environment. This balance can only be achieved by shifting from the traditional linear production process to a cyclic process based on prevention; reuse and recycling of material waste[2-3]. Although solid waste is generated by different household and economic activities, the construction industry has always been considered as one of the major producers of waste. This is clearly reflected in statistical and environmental reports in several countries. One hundred and seventy (170) million tonnes of waste were generated in the USA in 2003 and that 1,900 construction and demolition (C&D) landfills operate in the USA to receive disposed

material waste[4]. About 2 billion tons of waste is generated every year in European Union (EU-15) and the share of construction waste is 31%[2]. In Hong Kong, 3,158 tonnes per day of material waste is disposed of at landfills representing 23% of the total solid waste[5]. The United Arab Emirates (UAE) is considered one of the biggest producers of waste, 75% of which is from construction waste[6] and it is ranked second to USA in waste share per capita among the world countries[7]. The amount of construction waste dumped in Dubai's landfill for the year 2007 reached 27.7 million tonnes, which was almost three times the volume generated in 2006 (i.e. 10.6 million tonnes). The Ghanaian construction industry also experiences severe problems resulting from waste generation. A wide variation in waste rates of between 5% and 27% of total materials purchased for construction projects is identified in the Ghanaian construction industry[8]. As construction is a locomotive sector of the national economy, waste resulting from the construction industry affects the overall national economy. It is important to assess and analyze construction material waste mainly because a cost reduction arising from material waste prevention is of direct benefit to all participants in a construction project. This paper aims at identifying the main sources and causes of materials waste on construction sites in Ghana arising from storage and handling of high waste generating building materials and recommending ways of reducing such wastes.

MATERIALS WASTE

Waste includes both the incidence of material losses and the execution of unnecessary work, which generates additional cost but do not add value to the product[9]. Waste in construction can be classified into three main types; waste of materials, waste of time and waste of machinery[10-11]. This study concentrates mainly on materials waste because materials account for the largest input into construction activities in the range of 50-60% of the total cost of a project[12,13], and the raw materials from which construction inputs are derived come from non-renewable resources and would rarely be replaced once they are wasted[11].

Material waste is defined by the EPD of Hong Kong as comprising of unwanted materials generated during construction, including rejected structures and materials, materials which have been over ordered or are surplus to requirements, and materials which have been used and discarded[5]. Building materials waste can also be defined as the difference between the value of materials delivered and accepted on site and those properly used as specified and accurately measured in the work, after deducting the cost saving of substituted materials transferred elsewhere[14]. Furthermore, materials waste can be defined as "any material, apart from earth materials, which needs to be transported elsewhere from the construction site or used within the construction site itself for the purpose of land filling, incineration, recycling, reusing or composting, other than the intended specific purpose of the project due to material damage, excess, non-use, or non-compliance with the specifications or being a by-product of the construction process"[11].

Similar to the definition of waste, waste measurement has also been viewed and implemented in different ways. The measurement of waste in terms of embodied energy of materials was suggested by[1]. [16]Reported three case studies where waste of each type of material was measured in different ways:

(1) As a percentage of the total of construction waste;
(2) As a percentage of purchased materials; and
(3) As a percentage of the total waste cost.

These methods are all illustrative of the level of waste generated and they can be used simultaneously. However, in order to calculate these percentages, the identification of waste streams and volume or weight of waste generated for each one is necessary[2]. In addition to the fact that recording and measuring waste is a prerequisite to its management[17], knowing how much waste is generated can be used as a benchmarking tool against other projects, other companies or good practices. The next step is then to explore the gap between what is achieved and good practice[2]. Reducing the gap can be attained by looking at the sources of waste and analyzing the causes of its generation[2].

Sources and Causes of Waste

Many factors contribute to construction waste generation on site. Waste may occur due to one or a combination of many causes. Table 1 shows a summary of the various causes of waste from four sources in construction identified from literature.

Table 1: Sources and Causes of Materials Waste

Design	Operational	Material storage and handling	Procurement
Lack of attention paid to dimensional coordination of products	Errors by tradesmen or operatives	Damages during transportation	Ordering errors (eg., ordering significantly more or less)
Changes made to the design while construction is in progress	Accidents due to negligence	Inappropriate storage leading to damage or deterioration	Lack of possibilities to order small quantities
Designers inexperience in method and sequence of construction	Damage to work done caused by subsequent trades	Materials supplied in loose form	Purchased products that do not comply with specification
Lack of attention paid to standard sizes available on the market	Use of incorrect material, thus requiring replacement	Use of whatever material close to working place	
Designers unfamiliarity with alternative products	Required quantity unclear due to improper planning	Unfriendly attitudes of project team and operatives	
	Equipment malfunctioning		

Source: [2, 9, 1, 18, 19]

MATERIALS WASTE MINIMIZATION

Waste is a shared responsibility between all parties of the supply chain, from the client down to the waste contractor. This guidance focuses on the role of contractors and sub contractors, taking into account the fact that they cannot work in isolation to reduce and manage waste. In order to ensure that everybody works towards a common goal, leadership is required from clients together with effective interaction between main contractors and sub contractors[17]. The building industry uses a considerable amount of resources most of which are wasted because of poor material control on building sites[21,19,1]. The potential for minimizing construction and demolition waste is considerable[20]. Practical waste minimization strategies require a detailed understanding of what causes construction waste[21].

Waste minimization involves any technique, process or activity which avoids, eliminates or reduces waste at its source or allows re-use or recycling of the waste[22]. Materials waste minimization involves surveying the flow of materials into as well as out of the site and assessing what steps could be employed to reduce the quality and range of materials discarded[21]. The minimization of materials wastage in construction is of importance because wastage will have direct impact on cost, time and quality of a construction project[17].

The driver for reducing waste needs to come from the client. As part of the project brief, the client needs to establish waste as an important issue, and challenge the project team to deliver a project that uses materials efficiently. In order to effectively minimize waste, it is important that the following be adhered to[10, 22]:

- Develop an attitude to minimize wastage
- Design to prevent waste
- Use prefabrication instead of in-situ method
- Adopt proper material procurement and handling method and
- Adopt site waste management plan.

LEAN CONSTRUCTION

Lean Construction (LC) is a way to design production systems to minimize waste of materials, time and effort in order to generate the maximum possible amount of value[23-24]. It is also a holistic design and delivery philosophy with an overarching aim of maximizing value to all stakeholders through systematic, synergistic and continuous improvements in the contractual arrangements, product design and method of selection, the supply chain and the workflow reliability of site operations[25]. At the Design for Manufacture Competition, LC was defined as the continuous process of eliminating waste, meeting or exceeding all customer requirements, focusing on the entire value stream and the pursuit of perfection in the execution of a project[26]. In the opinion of[26], lean thinking is lean because it provides a way to do more and more with less and less – less human effort, less equipment, less time and less space – while coming closer and closer to providing customers with exactly what they want.

MATERIALS AND METHOD

In order to investigate the sources and causes of materials waste and to identify high waste generating building materials on construction sites, a structured questionnaire survey employing both closed and open-ended questions was conducted. The survey targeted project managers of construction organizations and senior architects and quantity surveyors of registered consultancy

firms in the Ashanti and Greater Accra regions of Ghana. The questionnaire consisted of three sections. The first section sought information about the respondents' profile. The second section required respondents to identify the main sources and causes of materials wastage on construction sites from a list identified from the literature. The final section sought information on materials which have high levels of wastage on construction sites and how to reduce waste.

Building construction organizations operating within Ghana register with the Ministry of Water Resource, Works and Housing (MWRWH) in four categories: class D, K, E and G, based on the nature of work the organizations engage in - building, civil engineering, electrical and plumbing works respectively. There are four financial sub-classifications within these categories - Class 1, 2, 3 and 4 - which set the limitations for companies in respect of their asset, plant and labour holdings, and the nature and size of the projects they can undertake. Class 1 has the highest resource base, decreasing through classes 2 and 3, to class 4 having the least resource base[27]. Project Managers of D1 and D2 building construction organizations who are registered with the MWRWH as well as Architectural firms fully registered with the Architects Registration Council of Ghana (ARCG) and Quantity Surveying firms fully registered with the Ghana Institution of Surveyors (GhIS) were involved in the study. According to the[27], there are 519 D1 and D2 building contractors in the Ashanti and Greater Accra Regions of Ghana. Records of the[28] indicate that there are 114 fully registered architectural firms in the two regions, whilst the[29] also had 60 fully registered quantity surveying firms. A sample size of 226 Project Managers of D1 and D2 construction organizations was determined in accordance with[30]. A census sampling approach was used to select 174 Architects and Quantity Surveyors from all consultancy firms fully registered with their respective professional bodies in the Ashanti and Greater Accra regions of Ghana. The census sampling approach was used because a census is attractive for small populations of 200 or less as it eliminates sampling error and provides data on all individuals in the population[30].

The questionnaire was administered through a face-to-face session which ensured the participation of 188 out of the 226 project managers of construction firms, representing a response rate of 83%. Out of the 174 questionnaires administered to the consultancy firms, 123 were completed, resulting in a response rate of 71%. On the sources of waste, respondents were asked to score on a Likert scale of 1 to 5 which waste sources contribute highly to the generation of waste on site (where 1 = 'not a source of waste', 2 = 'insignificant source of waste', 3 ='quite a source of waste', 4 = 'significant source of waste', 5 = 'major source of waste'). On the causes of waste, respondents were asked to score on a scale of 1 to 5 various causes of materials waste on site (where 1 = 'not a waste cause', 2 = 'insignificant waste cause', 3= 'quite a cause of waste', 4 = 'significant waste cause' and 5 = 'major waste cause'). Finally respondents were asked to score on a scale of 1 to 5 which key materials are wasted on construction sites (where 1 = 'not severe', 2 = 'less severe', 3 = 'quite severe', 4 = 'severe' and 5 = 'very severe').

Data on the wastage of key building materials and the sources and causes of waste were analyzed using the one sample t-test and mean score rankings.

RESULTS AND DISCUSSION

Company Profile

The average years of experience of the firms surveyed ranged between 10 and 20 years, indicating that the firms have significant experience in the building construction industry. With regards to the number of employees, none of the firms contacted was willing to disclose. The main reason given was that it is confidential. The respondents, however, indicated that they had enough employees and could recruit additional employees when necessary.

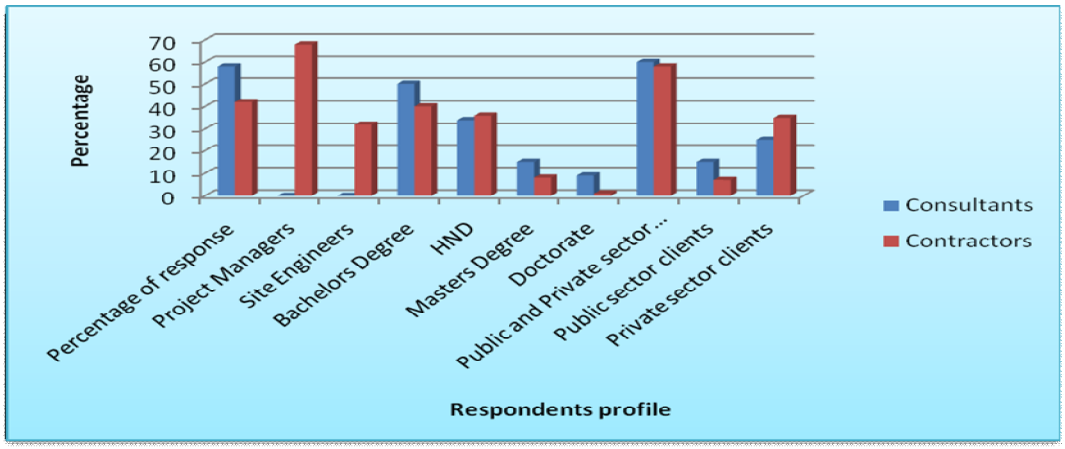


Fig. 2 Respondent Profile

Architects constituted 58% and quantity surveyors 42% of the respondents from the consultancy firms. Sixty-eight percent (68%) of the respondents from the construction firms were project managers and 32% were site engineers. Forty percent of the contractor-respondents and 50% of the consultant-respondents had bachelors' degree, and 36% of the contractors and 34% of consultants had Higher National Diploma (HND). The results further showed that 15% of consultants and 8% of the contractors had Master's degree. Nine percent of the contractors and 1% of the consultants had doctorate degree. The results also showed that majority of the firms (58% of contractors and 60% of consultants) had both public and private sector clients. Seven percent of contractors and 15% of consultants had public sector clients and 35% of contractors and 25% of consultants had private sector clients.

Sources of Material Waste

Mean scores of all the sources of material waste evaluated by the consultant-respondents except 'operational factors' are significantly greater than the neutral score of 3.00. Thus, in the opinion of the consultant-respondents, 'design and documentation', 'procurement' and 'materials storage and handling' contribute significantly to materials waste generation on Ghanaian construction sites (Fig.3). In the opinion of the project managers, however, all the four sources of waste contribute significantly to the generation of materials waste on construction sites in Ghana (Fig. 3). The

results further show that whereas the consultants identified 'design and documentation' as the major source of material waste (Fig. 3), the project managers identified 'materials storage and handling' as the major source of material waste on construction sites in Ghana (Fig. 3). Previous works grouped the sources of material waste under six categories: design, procurement, handling of materials, operation, residual related and others[11, 16]. According to[11], waste may occur due to one or combination of the above sources.

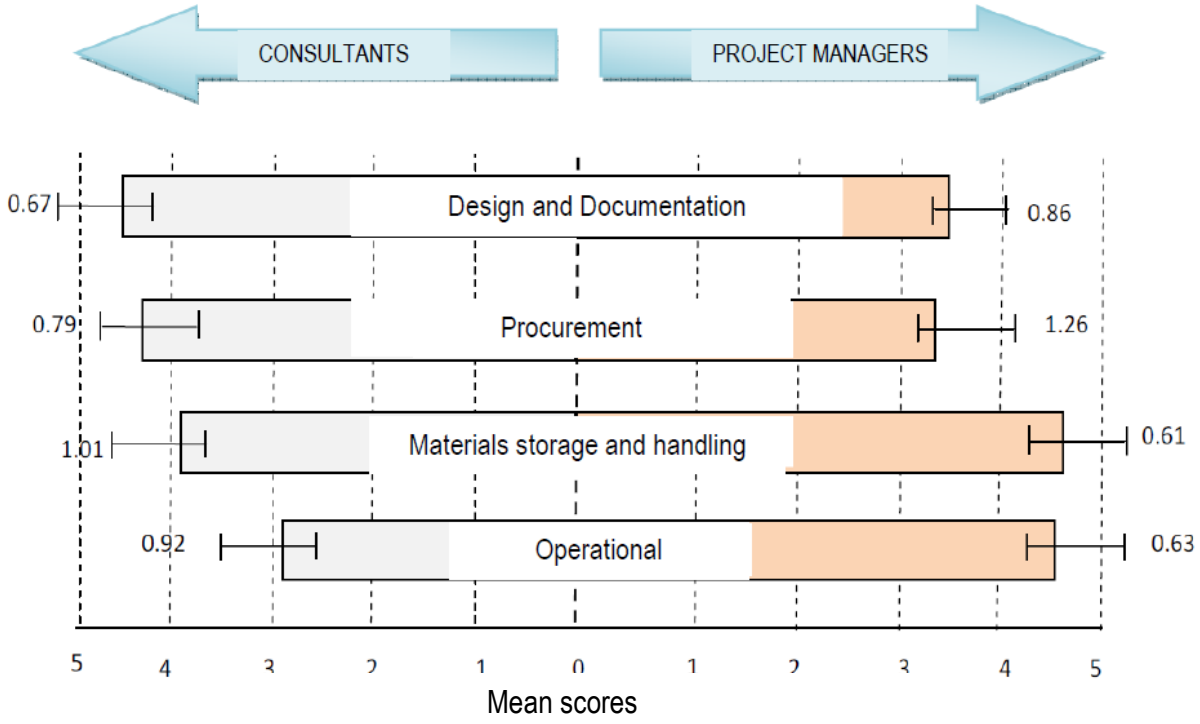


Fig. 3 Respondents Evaluation of the Sources of Waste

Causes of Waste

The various causes of material waste are discussed under each of the four sources as follows:

Design and Documentation

Respondents were asked to score factors considered to be causes of waste arising from design and documentation. The evaluation of the various causes was based on their mean scores. Comparison of the mean scores of all the causes of material waste arising from design and documentation showed no significant differences between the responses of the project managers and the consultants at 5% significance level. Responses of both groups of respondents were then pooled together and presented in Table 2. Table 2 shows that mean scores of all the 15 causes of waste evaluated by the two groups of respondents are greater than the neutral value of 3.0. Thus, in the opinion of the respondents, all the fifteen factors are considered as causes

of waste arising from design and documentation. The results further show that 'last minute client requirement (resulting in rework)', 'poor communication leading to mistakes and errors', 'selection of low quality products', 'designer's inexperience in method and sequence of construction' and 'poor or wrong specifications' are the five major causes of waste resulting from design and documentation.

Table 2: Causes of Design and Documentation Waste (Consultants and Project Managers)

Design and Documentation Waste	Mean Scores of Waste Causes	Standard Deviation	Ranking
Last minute client requirement (resulting in rework)	4.95	0.214	1
Poor communication leading to mistakes and errors	4.88	0.324	2
Selection of low quality products	4.84	0.370	3
Designer's inexperience in method and sequence of construction	4.69	0.464	4
Poor/ wrong specifications	4.14	0.850	5
Lack of knowledge about construction techniques during design activities	4.07	0.867	6
Lack of attention paid to dimensional coordination of products	4.02	0.861	7
Lack of information in the drawings	4.02	0.871	8
Poor site layout	3.81	0.938	9
Lack of attention paid to standard sizes available on the market	3.71	1.064	10
Complexity of detailing in the drawings	3.68	1.002	11
Variations in the design while construction is in progress	3.61	1.005	12
Designer's unfamiliarity with alternative products	3.83	1.080	13
Incomplete contract documents at commencement of project	3.58	0.939	14
Overlapping of design and construction	3.51	0.992	15

Operational Factors

The respondents were asked to score the causes of wastes arising from operational activities on construction sites. Comparison of the mean scores of all the causes of material waste arising from operational activities showed no significant differences between the responses of the project managers and the consultants at 5% significance level. Responses of the two groups of respondents were then pooled together and presented in Table 3.

Table 3: Causes of Operational Waste (Project Managers and Consultants)

Operational factors	Mean Scores of Waste Causes	Standard Deviation	Ranking
Errors by tradesmen or operatives	4.971	0.168	1
Use of incorrect materials that require replacement	4.926	0.296	2
Required quantity unclear due to improper planning	4.760	0.471	3
Delays in passing of information to the contractor on types and sizes of products to be used	4.295	0.592	4
Poor interaction between various specialists	4.253	0.792	5
Unfriendly attitudes of project team and labors	4.202	0.786	6
Choice of wrong construction method	4.087	0.732	7
Damage to work done caused by subsequent trades	3.994	0.680	8
Inappropriate placement of the material	3.919	1.008	9
Accidents due to negligence	3.426	0.863	10
Equipment malfunctioning	3.420	1.076	11
Inclement weather	3.397	1.228	12
Poor technology of equipment	3.391	0.949	13
Effects of political and social conditions	3.365	1.043	14
Shortage of tools and equipment required	3.285	0.952	15
Frequent breakdown of equipment	3.237	1.152	16
Difficulties in obtaining work permits	3.103	1.271	17

The results show that mean scores of all the factors evaluated as possible causes of material waste resulting from operational activities on construction sites are greater than 3.0 (Table 3). The results further show that 'errors by tradesmen or operatives', 'use of incorrect material that requires replacement', 'required quantity unclear due to improper planning', 'delays in passing of information to the contractor on types and sizes of products to be used' and 'poor interaction between various specialists' are considered as the first five major causes of waste resulting from operational activities on construction sites in Ghana.

Procurement Factors

Comparison of the mean scores of all the factors evaluated as possible causes of material waste arising from procurement activities showed no significant differences between the responses of the project managers and the consultants at 5% significance level. Responses of the two groups of respondents were then pooled together and presented in Table 4. The results show that the mean scores of all the 4 factors evaluated are greater than the neutral value of 3.0.

Table 4 Causes of Waste Arising from of Procurement (Project Managers and Consultants)

Procurement waste	Mean Scores of Waste Causes	Standard Deviation	Ranking
Purchased products that do not comply with specification	4.218	0.824	1
Unsuitability of materials supplied to the site	4.096	1.231	2
Ordering errors	3.606	1.140	4
Changes in material prices	3.574	1.330	5

Thus, 'purchasing products that do not comply with specification', 'unsuitability of materials supplied to the site', 'ordering errors' and 'changes in material prices' are the major causes of waste that result from procurement activities.

Materials Storage and Handling

Comparison of the mean scores of all the fourteen factors evaluated as possible causes of material waste arising from materials storage and handling showed no significant differences between the responses of the project managers and the consultants at 5% significance level. Both responses were then pooled together and presented in Table 5. Table 5 shows that the mean scores of all the factors evaluated are greater than the neutral value of 3.0.

Table 5: Causes of Waste Arising from Materials Storage and Handling

Materials Storage and Handling Waste	Mean Scores of Waste Causes	Standard Deviation	Ranking
Lack of onsite materials control	4.256	0.793	1
Damage to materials on site during transportation	4.250	0.607	2
Poor handling of materials	4.218	0.654	3
Waste resulting from cutting uneconomical shapes	4.180	0.814	4
Using excessive quantities of materials than required	4.128	0.659	5
Overproduction/ production of a quantity greater than necessary	4.051	0.906	6
Theft	4.026	0.921	7
Poor method of storage on site	3.878	0.971	8
Manufacturing defects	3.801	0.889	9
Unnecessary inventories on site leading to waste	3.782	0.895	10
Use of whatever material close to working place	3.744	1.069	11
Insufficient instructions about handling	3.718	0.994	12
Use of wrong method of transport	3.717	0.941	13
Overloading of transport equipment	3.385	1.192	14

Thus, 'lack of onsite materials control', 'damage to materials on site during transportation', 'poor handling of materials', 'waste resulting from cutting uneconomical shapes' and 'using excessive quantities of materials than required' are the

five major causes of waste arising from materials storage and handling.

Wastage of Key Construction Materials on Site

When the responses of the professionals (consultants and project managers) on the level of contribution of key construction materials to wastage were compared, the results showed no significant difference at 5% significance level. Hence, all the data were pooled together (Table 6). The mean scores of all the materials evaluated are significantly greater than the neutral score of 3.00 (Table 6). The results further show that the first four key materials which are wasted on construction sites are 'timber', 'cement/mortar', 'concrete' and 'blocks' (Table 6). The t-test results (Table 6) also show that mean scores of all the materials evaluated, except pipes, are significantly greater than the neutral value of 3.0 ($p = 0.05$) . Thus, in the opinion of the respondents, all the key materials evaluated significantly contribute to the generation of waste on construction sites.

Table 6: Level of Contribution of Key Construction Materials to Wastage on Construction Sites

Material	Mean	Standard deviation	t-value	Sig	Ranking
Timber	4.289	0.860	26.462	0.000	1
Cement/mortar	4.205	0.902	23.607	0.000	2
concrete	3.888	0.880	17.812	0.000	3
Blocks	3.843	0.910	13.701	0.000	4
Steel	3.721	0.940	13.553	0.000	5
Quarry chippings/coarse aggregate	3.612	0.860	12.572	0.000	6
Paint	3.561	0.854	11.601	0.000	7
Sand	3.471	1.054	7.893	0.000	8
Tiles	3.337	0.760	7.821	0.000	9
Pipes	3.093	1.031	1.593	0.112	10

This result confirms findings in literature which list concrete, cement/mortar, timber, blocks and steel as the major materials wasted on construction sites[14, 1, 8].

Recommended Ways of Storing and Handling Key Materials

The study further assessed how poor storage and handling led to wastage of the four key materials on construction sites. The photographs in Figures 4 to 9 show poor storage and handling practices and recommended ways of storing and handling each of the four key materials on construction sites in Ghana.

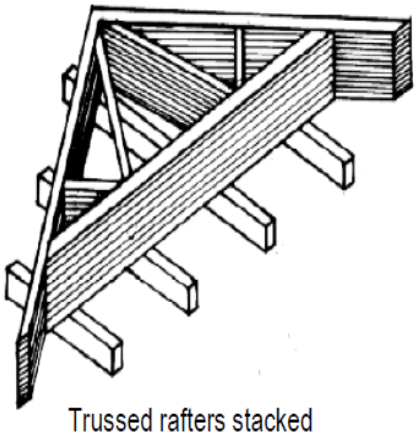
a) Dismantled formwork boards

b) Dismantled formwork left on site

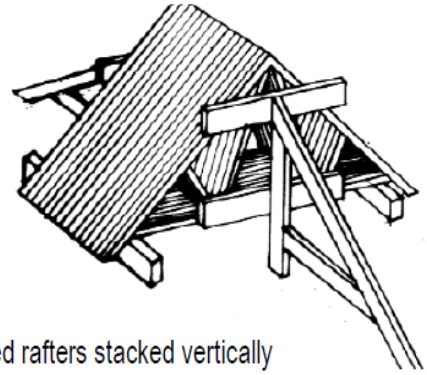
c) Timber pieces left to decay on site

d) Pieces on timber left on site to decay

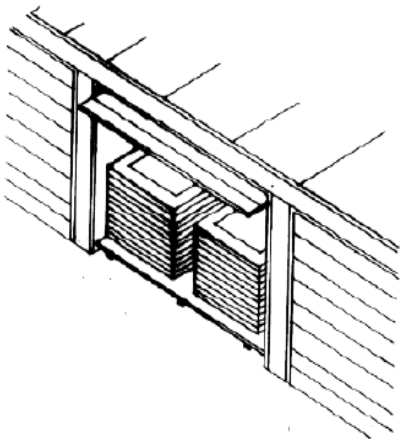
Fig 4: Ways in Which Timber is Wasted on Construction Sites



Trussed rafters stacked horizontally before covering



Trussed rafters stacked vertically before covering



Joinery secured in completed garages

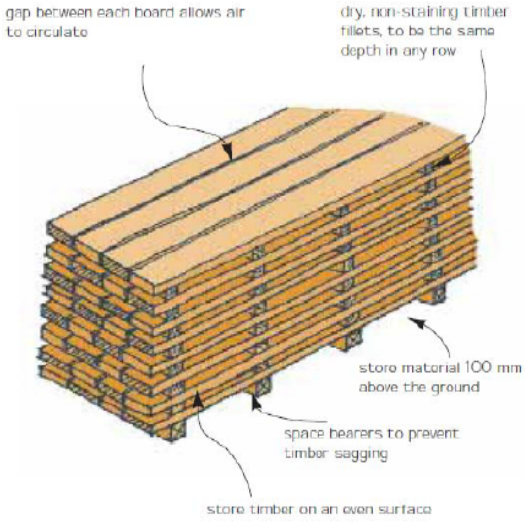


Fig 5: Recommended Ways of Storing Timber on Site

Cement/Mortar

Fig 7a: Ways in which Cement is Wasted on Construction Sites

Fig 5b: Recommended Ways of Storing Cement on Site

Concrete Making Materials

Fig. 8a: Ways in which Materials for Concrete Production are Wasted on Site

Fig. 6b: Recommended Ways of Storing Materials for Concrete Production on Site

Blocks

Fig. 9 a: Wastage of Blocks on Construction Sites

Fig. 7 b: Recommended Ways of Storing Blocks

Recommended Ways of Reducing Wastage of Key Materials

Table 7 suggests various ways of reducing the wastage of key materials on construction sites

Table 7: Ways of Reducing Wastage of Key Materials

Key Materials	Re-Use	Recycle	Reduction
Timber	If reusing timber on site one should always check it first to ensure it is of suitable quality and fit for purpose for intended use. Timber can be reclaimed from numerous sources on site including floorboards, rafters, doors, window frames and fencing. Temporary formworks can be reused several times before disposal.	Any timber which cannot first be reused on site should be sent to a recycling depot for cleaning, de-nailing and re-sizing. Timber can be recycled into among other things landscaping pellets, mulching and chipboard to create new kitchen units.	Timber can be substituted with other materials e.g. Using bamboo for formworks; Prefabricated building components, drywall partition and standard wooden panels can be adopted; Alternative construction Methods can also be adopted.
Cement/ Mortar	Developing plans for an on-site reuse, recovery and recycling systems for cement/mortar wastes; and Instructing workers to adopt the reuse and recycling of cement/mortar wastes on site		Using purchase management, material control and material management
concrete	Concrete waste can be reused for temporary work	Concrete can be recycled as aggregate for concrete production	Accurately calculating and ordering the right quantity of concrete; Using prefabricated building components; and Using alternative construction methods
Blocks	Offer the customer left over (full) blocks; Take block left-overs away to use as aggregate or landscaping cover:	Include a clean- up payment in the scope of the block layer's subcontract to assist recycling and to discourage wasteful site practices	Order blocks more accurately using best take-off practice; Ensure bottom layers of blocks remain useable by preventing soil contamination; Store blocks in a stable flat area to avoid breakages from fall overs; Determine a means for cutting blocks more accurately so that both halves can be used and breakages avoided

CONCLUSION

The study has identified materials storage and handling, operational factors, design and documentation factors and procurement factors as the main sources of material waste on construction sites in Ghana. The study also identified last minute client requirement, errors by tradesmen or operatives, purchased products that do not comply with specification and lack of onsite materials control as the main causes of materials waste. Timber, cement/mortar, concrete and blocks are the four key materials with high level of wastage on Ghanaian construction sites. The paper recommends proper storage and handling practices and re-use and recycling of waste materials to reduce wastage on sites.

Minimizing materials waste would improve project performance, enhance value for individual customers and have a positive impact on the national economy.

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