Optimisation of Construction Waste in the Built Environment
at Selected Sites in Nigeria: Deconstruction Strategy

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ABSTRACT: The focus of this paper is ‘deconstruction as a strategy’ for construction waste reduction in the built environment. Construction waste is becoming a topical issue in the building industry as large percentage of this is being generated annually in developing nations including Nigeria. The economic, political and environmental pressures put on sustainable work practices have led to a renewed emphasis on developing effective waste mitigation strategies in the built environment in Nigeria. Data collection from selected case studies was through interviews and observations conducted among leading professionals in the building industry, owners as well as site managers. The case studies were purposively selected because they exhibited modular design systems and dry construction methods. Variables investigated includes information on name and addresses of projects, types of designs adopted for construction, insitu materials and prefabricated materials used, causes and levels of waste in building construction, availability of materials, techniques of construction, proficiency of labour in handling materials, possibility of deconstruction and materials reuse, design management measures and waste minimisation measure adopted. The study observed that the use of dry construction methods and modular coordination system reduces waste in building construction. The paper suggests a wide range of measures for reduction of wastes on construction sites. These include deconstruction, modularisation of design, standardisation of building components, industrial production of building materials, efficient specification writing, retraining of building professionals, reuse and recycling among others. The paper concludes that there is colossal deficiency in the management of construction waste in the study and recommend ways of ameliorating it.

Keywords: Built environment, Construction waste, Deconstruction, Dry construction, Modularisation of design

INTRODUCTION

Construction waste is all non-hazardous solid waste resulting from construction, demolition and land clearing activities. Waste in the building industry consist of unused blocks, bricks, concrete, wood, metals, glass, paints, porcelain, plastic, film from packaging, cardboard, drywall, can, dirt, asphalt, electrical waste, acoustic materials, insulation and land clearing debris (Ogunsiran and Aluko, 2014).

The generation and disposal of waste is an important part of any developing society just as waste management is an essential part of a built environment. Wahab and Ojolowo (2012) opine that waste generation as an activity is not challenging per se, but subsequent phenomenal collection, storage and disposal in the face of urbanisation pose challenges in many cities in Nigeria. Solid wastes (construction wastes

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inclusive) are those tangible elements of matter that are artificially disposed (by man), which to him is of little or no value but may be valued by others. Waste generation can arise at any stage of the process, from inception, through to the design, construction and operation of the built facility (Faniran and Caban, 1998). Studies have also shown that the three most significant sources of construction waste relate to design changes (usually stemming from over-specification, poor detailing, late variations, changing materials previously ordered and alterations to complete work), leftover materials, waste from packaging and non-reclaimable consumables, poor storage and handling of materials and insufficient protection of the completed works in addition to professional errors such as design errors, poor detailing and over specification of materials (Coventry, Shorter and Kingley, 2001; Dainty, and Brooke, 2004). Pressures on cost and programme delivery also lead to working practices that are not conducive to conserving materials and avoiding damage (Coventry, 2001).

Faniran and Caban (1998) note that levels of waste generated are clearly dependent upon the attitudes of key individuals (in the supply chain) engaged with the project especially the clients, which have the greatest influence over waste issues. This is based on the clients’ responsibility to set the environmental standards to which the project team must comply. Solid waste management involves the storage, collection and transportation of disposed refuse in a manner that is hygienically and aesthetically acceptable to avoid being detrimental to human health (Chukwuemeka, Ugwu and Igwegbe, 2012). The disposal of solid waste generated and the evacuation or accumulation is an index of the degree of the effectiveness of solid waste management in a built environment. Waste management should be properly and equitably exercised in all the corners of the built environment to avoid humanly contagious problems, which thereafter influence property values (Ayanride and Olujimi, 2014).

Adewole (2009) observes that if wastes are not properly managed, they will have negative effects not only on the built environment but can also cause health hazard and loss of aesthetic. The impacts on the environment are diverse ranging from depreciation of aesthetic values, loss of economic value, development of slum, change of property use among others. Efficiency in the management of construction wastes and recycling will enhance reduction in depletion of natural resources such as trees, oil and minerals; reduction of greenhouse gases by using less energy for manufacturing, transportation and generation of less pollution caused by manufacturing of new building materials and transportation-related emissions. This is the focus of this research.

CONSTRUCTION WASTE PREVENTION

The Building Research Establishment (BRE, 2004) establishes that waste prevention is more beneficial than recycling. This should start early from the inception and design stages. Identifying potential waste early in the design process decreases waste generated during construction. If wastes are not generated, it would be needless planning how to manage, reuse or recycle it. In preventing waste generation, a number of options are available for the designer to adopt. First, design with standard sizes for all building materials. This avoids creating waste when standard sized materials are cut to unusual lengths. Materials are designed to facilitate future materials recovery.

Second, design of spaces to be flexible and adaptable to changing uses. This avoids creating waste during remodels. According to Bradley and Scott (2006), basic principles that can be adopted in order to ensure efficient design for deconstruction include: the sorting out of systems, materials bolted together instead of
glued, a construction and deconstruction blueprint, built-in tie-offs and connection points for workers and machinery, no hazardous materials and highly recyclable materials.

**Deconstruction Concept**

Design for deconstruction is an emerging concept from the subject of design for disassembly, reuse, remanufacturing and recycling in the consumer products industries. Its overall goal is to increase resource and economic efficiency and reduce pollution impacts in the adaptation and eventual removal of buildings, and to recover components and materials for reuse, re-manufacturing and recycling.

Guy and William (2003) put deconstruction as the process of dismantling buildings to safely and responsibly maximise the reuse and recycling of building materials in a cost effective approach. The practice of design for deconstruction will allow existing and new building stock to one day serve as the primary source of materials for replacement construction, in effect harvesting existing building stock rather than the natural environment. Deconstruction is a process of building disassembly in order to recover the maximum amount of materials for their highest and best re-use. Re-use is the preferred outcome because it requires less energy, raw materials, and pollution than recycling does in order to continue the life of the material (Dainty and Brooke, 2004). As a consequence of deconstruction, there are also many opportunities for recycling other materials along the way. Deconstruction combines the recovery of both quality and quantity of reusable and recyclable materials. The re-use of materials can serve a broad set of goals including the provision of low-cost building materials to a community, and the avoidance of demolition debris going to landfills.

Accordingly, Papakyriakou and Hopkinson (2012) state that deconstruction is a process through which future buildings could be ‘zero waste’ as they are designed to be carefully dismantled after the end of its useful life to facilitate the recovery and reuse of its materials without threatening their concurrent value. Sodagar (2008) opines that in order to achieve extended service life, buildings must be designed for disassembly. This would facilitate the new steps in the life cycle and encourage the reuse and recycling of materials and components. Though deconstruction process at the end of building life is highly speculative it is assumed that the process will entail energy consumption and non-recyclable waste production similar to the construction stage. It is likely that the bulk of materials such as the steel frame and the cladding could be reused or recycled. The building foundations could be reused as they have much longer design life than the building itself. At the end of the life of the building a decision will be made to either deconstruct the building or extensively refurbish perhaps also with an alternative use. In the latter case the building will retain a part of its content as useful structural frame and possibly also the envelope which have high embodied asset values (Sodagar, Rai, Murphy and Altan, 2009). Other parts such as windows and services may be deteriorated or can be replaced with much improved technologies to provide a superior operational performance. Retained fabric therefore becomes a useful legacy to the next building user. Deconstructed materials may be reused off-site or on-site, recycled in closed or open loops and remaining portions may go to landfill or be used as fuel depending on the type of material. The relationship between these groups will vary with the type of materials, the level of complexity of fabrication and composite constructions which make it difficult to disassemble into raw materials. BRE (2008) puts it that two other vital factors for efficient design for construction system are the labour costs and speed of the disassembly process itself. The efficiency of the
deconstruction affects the direct costs of labour and equipment and also affects the time costs of a project where building removals are integral to new construction on the same site. Of all of these factors, the efficiency of the deconstruction process and the cost-effectiveness of materials recovery with highest reuse or recycling value are most influenced by the designer, the architect and engineering team that determines how the building is to be assembled (BRE, 2008). These designers must understand how their decisions impact disassembly and reuse. The choices and specific uses of materials, the connections between individual materials or components, the inter-relationships of building elements, the designs of spaces and whole-building structure, and even the ability to “read” the building are within the designer’s control.

Design for deconstruction offers possibilities for the design of buildings that will tighten the loop of materials-use in building, and help make the transition towards minimal virgin materials use, and a cradle-to-cradle building industry instead of the dominant paradigm of cradle-to-grave. Goldstein and Neuman (2010) advocate “Doubling the life span of the building and thus reduces the environmental impact by half. This is achievable through renewal and reuse. He advocates that renovation creates 30 to 50 percent less green house gases than new construction, produces less construction waste, and utilizes existing resources - buildings”.

**Recovering and Reuse of Building Materials**

There are two ways to recover materials for salvage and reuse. First, deconstruct the building and second conduct a selective salvage operation prior to demolition. Deconstruction involves the careful dismantling of a whole structure in reverse order of assembly, usually by hand, to re-harvest materials for reuse. Salvage is the removal of certain valuable reusable building materials before demolition (ERM, 2006).

According to BREEAM Offices (2003), to choose the best option for managing a project’s waste, consider the value of the various materials. For instance, there may be materials on a project that have a greater value “as is” for salvage compared to their value as material for recycling. Some of these materials may be valuable to reuse on-site; others may be donated or sold to a used building material retailer or charitable organization. The initial costs for deconstruction services may be offset by returns from salvaged materials or reduced purchasing costs. In developed countries, some deconstruction services also may give a tax deduction for materials that are donated. In some cases, reused materials may also provide functional or aesthetic features not available in new materials. For example, salvaged wood is often of a quality and a variety of species that is difficult to find in the market place (WRATE, 2008).

**Modular Coordination, Design and Dry Construction**

Adedeji, Taiwo, Fadairo and Olotuah (2013) point out that modular coordination and mass production of building components are important features of dry construction system. This refers to simplifying the process of assembly through industrialisation, modularisations, standardisation, and continuous flow processes. The reduction of operations required for a production process means less chance of the occurrence of errors, waste and rework. This follows the same logic that the fewer the number of operations, the higher the quality of the product and a predictive timeline, resulting in cost savings. This is the fundamental principle that ensures that is the most cost effective affordable housing building construction technology and will continuously improve by simply eliminating waste and rework.

Conventional methods of designs and constructions contribute to waste generation on site in the built environment. Adedeji (2007) opines that modular design and standardisation of
spaces to improve buildability and reduce the quantity of off-cuts are strategies to significantly reduce construction waste resulting from the conventional methods of designs. Buildability comprises of three main principles. These include simplicity, standardisation and independence for ease of access. Buildability is also connected to modularity, prefabrication and standardisation of assemblies and sizes which are principles for design for deconstruction (Papakryiakou and Hopkinson, 2012). Crowther (2002) noted that: “If buildings were initially designed for deconstruction, it would be possible to successfully recover much more materials for reuse (and recycling) to prevent loss of valuable energy vested in existing materials, preserve virgin/new resources/energy and prevention (or reduction) of pollution of disposal of building materials”.

Similarly, the application of standardised components has the potential of regularising dimensional units of spaces in a modular form. Professionals and stakeholders in the building industry can easily visualise with clearer perception their proposed building projects, thus, making materials and cost planning easier.

**RESEARCH METHODOLOGY - CASE STUDIES**

A survey research design using interview and observations schedules were administered on professionals in gathering data through visits to purposively selected case studies. A total number of two hundred buildings were observed. Major materials investigated are interlocking blocks and prefabricated panels used for construction of housing projects and other buildings. These materials were used extensively in Elizade University, Ilara-Mokin; Federal University of Technology, Akure; Obasanjo Housing Estates, Ado-Ekiti; Ambrose Ali University, Ekpoma; University of Lagos and University of Abuja. The selection of these sites was based on the fact that they exhibited the use of interlocking blocks and prefabricated panels in building constructions. The selected buildings are Students’ hostels in Elizade University; E-Test building in Federal University of Technology, Akure, and Housing Estate at Obasanjo Housing Estates, Ado-Ekiti; all constructed with interlocking blocks. The choice of stabilised earth interlocking is based on its merits over the conventional types. Interlocking blocks are locally sourced, eco-friendly materials, cost-efficient and frequently used in dry construction in many parts of the world including Nigeria.

Also, twenty students’ hostels (10% of the sample frame) were selected purposively from the data obtained through case studies and interviews of professionals at the institutions. The housing projects were low-rise buildings constructed with prefabricated panels. In these institutions, design of these hostels was of modular system. While the construction of the sub-structure up to Damp Proof Course (DPC) level followed the same procedure for wet masonry system, super structures were of framed prefabricated panels. The frames were demountable steel frames bolted to concrete pad foundations. The over site concrete floors were composed of cement, sand and palm kernel shells (aggregates) of 1:3: 5 ratio.

Schedules prepared as questionnaires were administered on professionals and site supervisors by the authors to collect data on the causes of waste observed on sites. The schedule collected information on name and addresses of projects, types of designs adopted for construction, insitu materials and prefabricated materials used, availability of materials, techniques of construction, cost of materials for walling, proficiency of labour in handling materials, waste minimization in the use of materials, number of labour involved in masonry
optimisation of Construction Waste in the Built Environment: Deconstruction Strategy

operation, number of hours expended on masonry works, possibility of deconstruction and materials reuse, design management measures and waste minimisation measure adopted. Many of the surveyed projects, in various stages of completion were observed to be littered with unused and leftover building materials together with others to be disposed after use.

FINDINGS AND DISCUSSION OF RESULTS

The hostels selected in Elizada University, Ilara-Mokin were observed to be of modular coordination system and dry construction. Similarly, modular design system was adopted for E-Test centre in Federal University of Technology, Akure, and Obasanjo Housing Estates, Ado-Ekiti. Stabilised earth interlocking blocks were used for the walling of the selected buildings. The choice of modular coordination system was not unconnected with its efficiency in terms of materials, time, labour and cost savings in construction. Similarly, researches have shown that dry construction systems carried out either with prefabricated panels or stabilised earth interlocking blocks reduce waste and cost effective as compared with conventional cement-sand masonry (Anand and Ramamurthy, 2003; Adedeji, 2007). The list of buildings in Table 1 reveals designs of similar sizes and rates paid to workmen for construction of masonry works but with the use of different materials and methods for construction. For example, in Project No.1 with a masonry size of 384 m², it took one mason and one helper eight days to erect the masonry work, while one mason and one helper will require thirty days to complete a similar operation using sandcrete blocks. It can be observed that cost savings of masonry works using interlocking blocks is N307, 200 or 55% of cost of using conventional sandcrete blocks for the same project. Besides, while fewer men were engaged in carrying out the masonry operation, the productive man-hours observed are much higher (4: 1) with the use of interlocking blocks as compared with sandcrete blocks. Similar results were obtained for other projects given in Table 1.

E-Test Centre, Federal University of Technology, Akure, constructed with Stabilized Earth Interlocking Blocks.
Source, Field Survey (2011)
Table 1: Selected Data from Executed Project Sites

<table>
<thead>
<tr>
<th>S/N</th>
<th>Area (m²)</th>
<th>Rate (₦)</th>
<th>Cost (₦ in 1000)</th>
<th>Labour (No per gang)</th>
<th>Pro. Hr. (m³/h)</th>
<th>Cost (₦ in 1000)</th>
<th>Labour (No per gang)</th>
<th>Pro. Hr. (m³/h)</th>
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</table>

Source: Field survey (2007)

A comparative analysis of outcome of field survey shows that buildings constructed using dry construction methods and modular coordination system (stabilized earth interlocking masonry) exhibited lower cost of construction, less number of workmen engaged and higher productive hours as against those constructed with sanderete blocks. Besides, professionals attest that the left-over and waste materials on sites with dry construction methods were far lesser than those of wet construction methods.

Also, it was observed in some of the projects that site managers were appointed to monitor the ordering of materials and deliveries to sites were done according to specifications. In some of the sites, site manager held regular meetings with workmen and materials suppliers on modes of deliveries to sites and reuse of materials. This helps in reducing waste levels that could have resulted from over ordering of materials and leftovers. Usually, stabilised earth interlocking blocks are assembled without mortars and differ from conventional blocks in that the units are assembled together using geometrical features incorporated in the unit without the aid of mortar. Prefabricated wall panels were used for the framed masonry walls of hostels at Ambrose Ali University, Ekpoma. The projects were supervised to ensure solid bases for the buildings. In the case of the super structure, masonry works were carried out through the assemblage of prefabricated panels produced from the agro-allied product using agro-waste composite panels, a constituent of cement reinforced with palm kernel fibre, a by-product of oil palm. The panels composed of cement-bonded particle boards using palm kernel fibre with Portland cement binder after hot water treatment (Adedeji, 2011).

The Site managers appointed for each of the projects ensured that prefabricated wall panels
and other building materials were ordered to site according to specifications on the drawings. This prevents over ordering of materials that could have amounted to wastes on sites. Also, the materials brought to sites were in standard sizes fabricated to designers’ specification. Since materials were prefabricated off-site, assembled on a modular design and standardised spaces to improve construction process, the construction waste were significantly reduced in comparison with convention methods of design and construction. By designing spaces, walling heights and ceiling materials in multiples of standard sizes, a substantial reduction in off-cuts was achieved. This corroborates the idea that dry construction and standardisation of building components reduce wastes in the built environment as observed by Coventry, et al. (2001).

The adoption of interlocking blocks and standardised building materials will facilitate modular design and construction in the building industry. This is because of the geometric nature of interlocking blocks that helps to ensure structural stability and uniform load transfer between the layers. Similarly, the application of standardised prefabricated components has the potential of regularising dimensional units of spaces in a modular form. The use of dry construction methods with appropriate standardised components to reflect the designer’s specification would reduce or completely eliminate wastages, reduce labour to be engaged, cost as well as the time for construction, if the building operation is professionally handled. In view of this, dry construction method is therefore more cost-effective and preferred above the conventional method.

RECOMMENDATIONS

In line with the major findings of this research, it is necessary to propose strategies for wastes minimisation on construction sites in order to ensure financial savings and improved environmental standards in the built environment. To achieve this, the following recommendations are proffered:

1. Prevention of over specification of materials through efficient project management was identified as offering considerable window for financial savings on all of the cases studied projects. The appointment of dedicated project managers with a brief to minimise waste was seen as a proactive and effective step in ensuring waste reduction. Architects and allied building professionals are to ensure accurate dimensions of spaces and building components together with efficient specification of materials for construction in order to avoid over ordering of materials to the site. Allowing more time for value engineering design solutions was also seen as important for more complex projects.

2. Stock control measures to avoid the over ordering of materials emerged as a particularly significant area of site management leading to materials conservation. Tighter stock control measures coupled with the careful monitoring of on-site progress had helped to reduce the amount of unnecessary waste.

3. Education of clients on measures to reduce waste levels. Most respondents expressed that many clients remain under informed about the severity of construction waste or the potential for the reuse and recycling of materials. Seminars, public enlightenment and other Educational programmes on social media could be very helpful to ensure that clients understand the need for process and attitudinal change and that would encourage them to influence waste conscious design and construction practices from the inception of projects.

4. Increased use of off-site prefabrication to control waste and damage. Off-site
prefabrication and industrial production of building materials and components are advocated for in order to minimize waste in the building industry. Prefabrication should be strictly based on designers’ specification and standard sizes recommended in the industry. Also, the use of standardised prefabricated components to reflect the designer’s specification reduces loss of time and resources considerably in construction.

5. Standardization of design and building components should be explored beyond the accessibility to materials only, but the assessment of baseline for the continuous initiatives for designs and intelligent use of available materials for construction.

Prefabrication uses the factory environment to provide greater control over construction processes. This has provided benefits in work quality and the ideology can be introduced to control waste and ensure tangible reductions in waste levels. Also, it reduces the amount of on-site damage, re-work and waste. The increased use of prefabricated components demands the careful modularisation of the building design, which had been successfully demonstrated in many of the cases studied.

CONCLUSION

This paper appraises deconstruction strategy as an option for optimisation of construction waste in the built environment. Survey of selected construction sites in The Federal University of Technology, Akure; Ambrose Ali University, Ekpoma; Elizade University, Ilara-Mokin; University of Lagos and Obasanjo Housing Estate, Ado-Ekiti were used as case studies to appraise the use of dry construction, modularisation and standardisation of designs, efficient specification and monitoring of materials on site and consequent reduction of waste generation observed and the implications on the built environment. Intelligent application of design for deconstruction strategy in the built environment will effectively reduce construction waste in the building industry.

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