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Critical design factors for minimising waste in construction projects: A structural equation modelling approach

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ABSTRACT

Notwithstanding that efforts made at the design stage of building construction projects have significant impacts on project outcome, most waste management efforts are usually focused on construction stage. This is albeit the understanding that construction waste could be significantly reduced through design activities. This study investigates the underlying design measures that are capable of minimising waste generated by construction and demolition activities. Using exploratory sequential mixed method research, the study employs focus group discussions and thematic analysis at the exploratory phase, while questionnaire and structural equation modelling were used at the explanatory stage of the study.

The study suggests that construction waste could be significantly reduced by designing for standard materials size and by designing for modern method of construction, thereby minimising waste due to breakage, materials leftover and other major causes of waste. The study further suggests that the design process and design documentation are key underlying measures for mitigating waste in construction projects. This could be enhanced through such critical success factors as a collaborative delivery process, which is characterised by early involvement of contractors and adequate coordination of design between various disciplines involved. Findings of this study would assist designers and other construction stakeholders in understanding the significant measures for designing out waste in construction projects.

1. Introduction

Waste generated by the construction and demolition activities is estimated at 44% of total waste to the UK landfill (DEFRA, 2013). This is more than double the proportion of waste generated by each of commercial, household, mining and industrial activities, which are estimated to contribute 14%, 13%, 9% and 13% respectively (DEFRA, 2013). This trend is similar to the patterns in other nations, as evidence suggests that the proportion of construction and demolition waste is up to 29% in the US (Yu et al., 2013), 25% in Canada (Yeheyis et al., 2013) and 25% in Hong Kong (Lu and Tam, 2013). Apart from cities running out of landfill site, waste landfilling has significant environmental impacts. While some wastes will finally decompose, others could provide various forms of pollution such as leaching into land and water as well as emission of various gaseous substances.

In addition to the negative impacts of waste generation, evidence suggests that reducing waste in construction projects has significant economic benefits. This would result in savings in forms of the cost of wasted materials, cost of storage, landfill tax, and cost of disposal (Coventry and Guthrie, 1998; Ajayi et al., 2015), which are usually shifted to the clients (Guthrie et al., 1999). A study by the UK's Building Research Establishment (BRE) suggests that up to £130million could be saved by reducing just 5% of its construction waste (BRE, 2003). Owing to the requisite of waste minimisation to the sustainable economy and the global sustainability agenda, the EU has introduced various legislative provisions to target waste reduction, minimisation, re-use and recycling. For instance, the EU Waste Framework Directive (2008/98/EC) currently sets a target of re-using, recycling and/or recovering 70% of construction and demolition waste by 2020. The Circular Economy Package of the EU also sets a new target for recycling other forms of waste, with a binding landfill reduction target of 10% by 2030; thus, there is an increasing need to focus on waste mitigation.

Due to these significant benefits of waste minimisation, there has been a large body of knowledge on construction waste (e.g. Faniran and Caban, 1998; Formoso et al., 2002; Dainty and Brooke, 2004; Osmani et al., 2008; WRAP, 2009b, etc.). These sets of studies suggest that waste is caused by, and could be minimised through, activities ranging throughout the whole project lifecycle, including design, materials

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procurement and construction activities. Accordingly, there is an increasing awareness that rather than concentrating on site effort to reduce and manage waste during building construction activities waste minimisation should be considered throughout all stages of the building process – design to completion (Ekanayake and Ofori, 2004). This is especially as a single stage-based measure would produce less waste minimisation outcome when compared to a holistic effort at the design, material procurement and construction stages of project delivery processes (Ding et al., 2018).

However, most construction waste management studies have largely focussed on the actual construction stage, resulting into the strategies for achieving the 3Rs – reduce, reuse and recycle (Osmani, 2012; Ajayi et al., 2017a). This is notwithstanding that waste management efforts at the construction stage is belated if the design and the whole design process is not waste-efficient, especially as up to 33% of building construction waste could be prevented through design activities (Innes, 2004). In line with this, the widely referred McLeamy curve recognised design stage as being a decisive stage with multiple implications for project outcome (McLeamy, 2004). It has critical impacts on key project performance indicators such as cost, time and quality, among others. In addition, the cost of change is cheaper if such change is made at the design stage of project delivery process (McLeamy, 2004). It is, therefore, important that construction waste management is approached from a design perspective, so as to corroborate the efforts made at the later stage of the project delivery processes. Such measures would provide the cheapest option for minimising waste generated by construction activities.

The overall aim of the study is to establish the key and underlying design measures for mitigating waste generated by the construction industry. The study seeks to explore and confirm a set of design measures that are capable of minimising waste generated by construction and demolition activities. The study fulfils its aim through the following sets of objectives.

1 To understand the key design measures for driving waste minimisation in construction projects.
2 To evaluate whether there are differences in perception of different professionals on design strategies for waste minimisation
3 To explore, model and establish the underlying sets of design strategies for waste–efficient construction projects.

The study adopts exploratory sequential mixed method approach, combining qualitative data collection and analysis at its first stage with quantitative data collection and structural equation modelling at its later stage. The first stage avails the study an opportunity to carry out an in-depth exploration of waste efficient design measures while the second stage of the study provides an opportunity for rigorous confirmation of the established strategies, using confirmatory factor analysis.

The next section of the paper provides a review of the literature on design strategies for construction waste mitigation. This is then followed by a section on the methodological approach to the study, justifying and explaining the data collection and analytical procedures for the qualitative and quantitative study. The conclusion and implication for practice section is preceded by the discussion of findings from statistical analysis and structural equation modelling. Findings of this study would assist designers and other stakeholders in understanding the measures for designing out waste in construction projects.

2. Reducing waste through design

The cost of making changes in construction projects is evident to be cheaper if such change is made at the design stage of project delivery process (McLeamy, 2004). In line with these benefits, evidence suggests that waste could be significantly reduced by taking waste preventive measures at the design stage. For instance, Osmani (2012) and Faniran and Caban (1998) suggest that most waste management studies tend to concentrate on construction stage while evidence shows that construction waste could be significantly reduced by taking care of several design factors that tend to impact waste (Ekanayake and Ofori, 2004). Innes (2004) also claimed that dedicated measures to reduce waste through design process could reduce total waste by up to a third. The earlier a change is implemented in a project lifecycle, the more its positive impact, and the less the cost of such change. This concept is similarly applicable to dedicated effort towards waste management. The earlier such effort, the more likely it would prevent waste occurring at a later stage.

Meanwhile, the attributes, competencies and dedication of designers and design management team are important in achieving low waste construction projects. Apart from design stage being a crucial stage for waste preventive effort, adverse environmental impacts of construction activities have been widely blamed on designers (Mansikkasalo et al., 2014). Technical capabilities of designers in terms of error-free design, dimensional coordination and the use of standard detailing are recognised as pre-requisite for waste minimisation (Ekanayake and Ofori, 2004). Designers' knowledge of construction materials could also help in preventing early replacement of materials, which could, in turn, result in waste generation (Esin and Cosgun, 2007).

Design documentation has impacts on the effectiveness of the build process and waste generation (Gann et al., 2003). This is because, the design document could affect buildability of the projects while its accuracy and attention to detail could influence design error that could otherwise lead to reworks (Formoso et al., 2002). Ajayi et al. (2017b) suggest that the quality of design document for waste effectiveness could be described in terms of both the accuracy of information as well as completeness of the information provided. Specification of materials in devoid of over ordering and adequate coordination of designs from different professionals would determine the accuracy of the information (Begum et al., 2007). Design document such as deconstruction plan, waste management plan and bar bending lists, among others have also been suggested as additional drivers of waste minimisation in construction projects (Oyedele et al., 2013; Akinade et al., 2015).

The effectiveness of the whole design processes and coordination have effects on waste generated at the construction stage of project delivery (Osmani et al., 2008). This is in terms of the extent to which various specialities are coordinated, level of communication between parties as well as stakeholders' meetings, all of which are found to be important to waste prevention (Ikau et al., 2013; Al-Hajj and Hamani, 2011). Oyedele et al. (2013) suggest the need for an early involvement of contractors as well as design freeze before actual construction. However, it is not always possible to freeze the design before actual construction as design change is often initiated by the client who pays for both the project and the waste. Nonetheless, implementation of sustainable design appraisal system such as BREEAM means that attention would be paid to waste minimisation (Tam, 2008).

Improved buildability of design has been recognised as one of the key strategies for waste minimisation (Lovell, 2012). By adopting a modern method of construction such as prefabricated and dimensionally coordinated elements, buildability of design could be enhanced. In line with this, Formoso et al. (2002) suggest the use of preassembled components and modular coordination of building elements as means of reducing waste due to offcut and materials leftover. Standardisation and dimensional coordination of building elements such as the use of standard door and window, coordination of structural grid and planning grid designing for standard dimensions and units, and optimisation of tiles layout were found to reduce waste generated by construction activities (Dainty and Brooke, 2004; WRAP, 2009a).

Akinade et al. (2017) suggest that demolition waste contributes up to 50% of waste generated by the construction industry. As a means of reducing demolition waste to landfill, it is important that design and construction technique is responsive to change, while