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Design for Deconstruction (DfD): Critical success factors for diverting end-of-life waste from landfills

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ABSTRACT

The aim of this paper is to identify Critical Success Factors (CSF) needed for effective material recovery through Design for Deconstruction (DfD). The research approach employed in this paper is based on a sequential exploratory mixed method strategy. After a thorough review of literature and conducting four Focus Group Discussion (FGDs), 43 DfD factors were identified and put together in a questionnaire survey. Data analyses include Cronbach's alpha reliability analysis, mean testing using significance index, and exploratory factor analysis. The result of the factor analysis reveals that an underlying factor structure of five DfD factors groups that include '*stringent legislation and policy*', '*deconstruction design process and competencies*', '*design for material recovery*', '*design for material reuse*', and '*design for building flexibility*'. These groups of DfD factor groups show that the requirements for DfD goes beyond technical competencies and that non-technical factors such as stringent legislation and policy and design process and competency for deconstruction are key in designing deconstructable buildings. Paying attention to the factors identified in all of these categories will help to tackle impediments that could hinder the effectiveness of DfD. The results of this study would help design and project managers to understand areas of possible improvement in employing DfD as a strategy for diverting waste from landfills.

1. Introduction

In recent times, the Architecture, Engineering, and Construction (AEC) industry has taken conscious effort to understand the concept of sustainable construction and to reduce the long-term effects of construction activities on the environment (Ajayi et al., 2015). This need requires that the usage and end of life impact of construction activities on the ecosystem are to be accessible at the design stage. In the same way, design activities must be beneficial to the ecosystem during building usage and end-of-life (Jrade and Jalaei, 2013; Oyedele and Tham, 2007). Owing to accrued economic benefits accruable from sustainable construction, the focus of AEC practitioners has shifted from the traditional methods of end-of-life building disposal to modern methods such as deconstruction. This is because design capabilities on reducing end-of-life impacts of building activities are limited in traditional methods of building disposal such as demolition and landfilling. It has also been argued that deconstruction, which is the disassembly of buildings piece by piece, allows the recovery of building materials and components after the end of life of buildings (Addis, 2008; Guy et al., 2006) in order to reduce waste through reuse (Crowther, 2005). Accordingly, deconstruction results in numerous benefits such as preservation of embodied energy, reduced carbon emission, reduced cost, and reduced pollution.

The paradigm shift from demolition to deconstruction is imperative because evidence shows that demolition generates up to 50% of the waste stream worldwide (Kibert, 2008). This volume of waste is about 18 million tonnes of waste in the UK alone. If this amount of waste is properly diverted from landfills, over £1.5 billion could be saved in terms of landfill tax and other costs. In addition to cost reduction, deconstruction eliminates potential health hazards and site disturbances caused by demolition. These aforementioned among others justify deconstruction over demolition as a strategy for economic and ecological sustainability. Despite the increasing awareness of deconstruction, little consideration has been given to Design for Deconstruction (DfD) due to lack of technical knowledge and supporting tools (Addis, 2008). In addition to the lack of tools, there is a general belief that the end-of-life of buildings may not occur for a long period

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(Guy et al., 2006). Understandably, the value of the building and its components after its end of life is not guaranteed, thus defeating the cost and purpose of ensuring deconstruction. Still, the current building methodology and material choice may become obsolete in decades considering the current trend in building and material engineering. Despite these challenges, the benefits of deconstruction outweigh the cost if the value of buildings components is retained after their end-of-life (Oyedele et al., 2013).

Despite efforts marshalled by all stakeholders in the AEC industry in mitigating Construction and Demolition Waste (CDW) and the evidence that deconstruction could drive waste minimisation initiatives (Akinade et al., 2015; Phillips et al., 2011), there has not been a progressive increase in the level of DfD. According to Dorsthorst and Kowalczyk (2002), less than 1% of existing buildings are fully demountable. Although the principles of DfD have been in practice for the past three decades, existing practices (Crowther, 2005; Guy, 2001; Kibert, 2003; Tingley, 2012) show that DfD is still far from reaching its waste minimisation potentials.

It is on this premise that this study seeks to explore and discuss critical success factors needed to ensure effective material recovery through DfD. Accordingly, the study will help to uncover functional requirements in maintaining a cost effective material recovery right from the design stages. After a review of extant literature in the research area of sustainable construction, construction waste reduction strategies, and modern methods of construction, an explorative qualitative study was conducted using Focus Group Discussions (FGDs). The purpose of the FGIs is to verify factors from the literature and to identify other factors that could influence DfD. Thereafter, 43 factors were identified and put together in a questionnaire survey. Data analyses include Cronbach's alpha reliability analysis, mean testing using significance index, and exploratory factor analysis. The results of this study bring to the fore the conditions that enable successful DfD and key factors that must be considered when designing deconstructable facilities. Pointedly, these factors will assist industry practitioners, such as design managers, project managers, architects, and design engineers, to understand the requirement for designing and constructing deconstructable facilities. In addition, the identified factors will form the basis for the development of tools for achieving sustainable construction.

The remaining sections of this paper are structured as follows: Section 2 contains a discussion of the concept of design for deconstruction and a review of critical success factors for building deconstruction. Sections 3 and 4 present a full discussion of the research methodology and data analyses process respectively. Then, a discussion on the identified groups of critical success factors is then presented in Section 5. The final part of the paper identifies contributions of the study to DfD and areas prompting further research.

2. Literature review: critical success factors for DfD projects

The traditional methods of building disposal require the dismantling and knocking down of buildings using crushing force using bulldozers, wrecking ball, explosives, etc. Although demolition offers a fast way of building disposal, its environmental and economic impacts are overwhelming. However, a more sustainable approach to the end-of-life disposal of buildings is building deconstruction, which is the disassembly of buildings piece by piece to maximise material reuse (Kibert, 2008). Accordingly, an efficient deconstruction procedure upholds the waste hierarchy by giving top priority to waste prevention through material reuse and recycling. The goal of deconstruction is to eliminate demolition (Gorgolewski, 2006) and to ensure the recovery of components during usage or at the end-of-life of buildings (Kibert, 2008). Although there are concerns about the residual performances of building components after many decades of use, evidence shows that ensuring building deconstruction could result into beneficial results. For example, deconstruction efforts could stimulate rapid relocation of building, improved flexibility and retrofitting (Addis, 2008) while minimising the end of life impact of buildings (Kibert and Chini, 2000; Tinker and Burt, 2003). Apart from diverting demolition waste from landfills, deconstruction reduces site disturbance (Lassandro, 2003), health hazard (Chini and Acquaye, 2001) and preserves embodied energy (Thormark, 2001). Considering the potentials of deconstruction at diverting waste from landfills and the desire to achieve sustainable construction through design necessitates the understanding of how design could influence deconstruction.

Architects and design engineers must understand the purposes of DfD before its benefits can be maximised. According to Crowther (2005), the term DfD could serve multiple purposes, which include material recovery for building relocation, component reuse, material recycling and remanufacture. However, the tenets of DfD are more concerned with building relocation and component reuse rather than recycling or manufacturing. This viewpoint is because the recycling of building is now common practice in the construction industry. Understandably, a much more significant challenge is to design buildings that can be deconstructed and its components reused with minimal reprocessing.

With this view in mind, a review of extant literature in the area of modern methods of construction, design management, and project management, was carried out and three broad categories of DfD critical success factors were identified. These include: (i) material related factors, (ii) design related factors, and (iii) site workers related factors as shown in Fig. 1. This section therefore presents a discussion of these three broad categories along with their associated factors (see Table 1).

2.1. Design related factors

According to Warszawski (1999), design related factors cover commonly observed design principles and key performance indicators for DfD. Building design methodology encompasses approaches adopted by architects and engineers during building design to achieve desired forms and functions. Design methodologies thus help to understand design conceptual frameworks, which help to navigate the design process successfully. Meanwhile, the several criticism of conventional on-site construction methods shows that the use of Modern Methods of Construction – MMC (such as off-site construction, modular construction, and open building system) offers significant benefits (Egan, 1998; Latham, 1994). Also, Pan et al. (2007) highlighted that MMC ensures cost and time certainty while improving building performances. In addition, MMC reduces on-site waste (Jaillon et al., 2009) and drives building deconstruction (Guy and Ciarimboli, 2008). Prefabrication alone, as an MMC, could reduce on-site waste up to 65% (Jaillon et al., 2009). Furthermore, the use of layer design approach facilitates building layout flexibility and retrofitting (Webster and Costello, 2005) and enables the recovery of building components. Other design methods in favour of DfD include using standard structural grid, using steel construction, using retractable foundations such as H-pile.

2.2. Building materials related factors

Although DfD is not a new idea in the AEC industry, its planning is largely dependent on appropriate specification of building components to facilitate easy disassembly (Addis, 2008; Akbarnezhad et al., 2014). Accordingly, conscious effort should be made to specify durable materials (Tingley, 2012), use materials with no

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