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Waste minimisation through deconstruction: A BIM based Deconstructability Assessment Score (BIM-DAS)

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ABSTRACT

The overall aim of this study is to develop a Building Information Modelling based Deconstructability Assessment Score (BIM-DAS) for determining the extent to which a building could be deconstructed right from the design stage. To achieve this, a review of extant literature was carried out to identify critical design principles influencing effectual building deconstruction and key features for assessing the performance of Design for Deconstruction (DfD). Thereafter, these key features were used to develop BIM-DAS using mathematical modelling approach based on efficient material requirement planning. BIM-DAS was later tested using case study design and the results show that the major contributing factors to DfD are use of prefabricated assemblies and demountable connections. The results of the evaluation demonstrate the practicality of BIM-DAS as an indicator to measure the deconstructability of building designs. This could provide a design requirement benchmark for effective building deconstruction. This research work will benefit all stakeholders in the construction industry especially those interested in designing for deconstruction. The eventual incorporation of BIM-DAS into existing BIM software will provide a basis for the comparison of deconstructability of building models during design.

1. Introduction

The increasing global urbanisation has resulted in high volume of Construction, Demolition and Excavation Waste (CDEW) from which demolition waste contributes up to 31.8 million metric tonnes yearly in the UK alone (WRAP, 2009). With so many demolitions taking place annually, its environmental and economic impacts cannot be ignored because building materials become unrecoverable and eventually sent to landfills. Tackling this problem calls for a strategic approach to planning for recovery of building materials and components for reuse or recycling. This requires dealing with the problem at source, which is usually at the design stage by designing for deconstruction (DfD) to avoid demolition after the end of life of buildings. Although literature abounds on causes and management of CDEW, only few studies have been conducted to mitigate the generation of end of life waste right from the early design stages. Even most of these few studies focus on disposal cost estimation (Chen et al., 2006; Cheng and Ma, 2011; Yuan et al., 2011) and waste quantification during demolition (Cochran et al., 2007; Masudi et al., 2012; Wu et al., 2014). Considering the fact that end-of-life activities generate the largest volume of waste (DEFRA, 2012), there is need to plan for the end of buildings right from the design stages.

Evidence shows that up to 50% of CDEW could be diverted from landfill through a well-planned deconstruction strategy (Kibert, 2008). This shows that in the UK alone, about 16 million tonnes of waste could be diverted from landfills (DEFRA, 2011), while saving over £1.3 billion in terms of landfill tax and waste transportation. Despite these opportunities accruable from deconstruction, research efforts on design performance assessment have been concentrated on buildability and construction waste assessment. Examples of such systems include Building Design Appraisal System—BDAS (CIDB, 1995a), Building Waste Assessment Score—BWAS (Ekanayake and Ofori, 2004), and Construction Quality Assessment System—CONQUAS (CIDB, 1995b). These performance assessment tools are concerned with the impact of design on construction stage but not with the end of life of buildings.

Blengini and Carlo (2010) highlighted that it is difficult to carry out life cycle analysis towards the end of life stage during design stage because information is still scanty. However, construction sustainability could be achieved if considerable effort is

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put in design with future benefits in mind (Ajayi et al., 2015). In this way, Design for Deconstruction (DfD) will increase the cost-effectiveness of material recovery and reuse from the early design stages (Davison and Tingley, 2011). Despite the general knowledge that design could initiate effective building deconstruction (Crowther, 2005; Guy et al., 2006) and the attempts to quantify the benefits of DfD, no practicable design tool has been provided to substantiate these claims. Existing design tools for deconstruction have been design guides, such as ICE deconstruction protocol, that provide no quantifiable measure similar to BDAS, BWAS, and CONQUAS. Other tools such as building end of life analysis tool (Dorsthorst and Kowalczyk, 2002), NetWaste tool (WRAP, 2011b), Design out waste for buildings tool (WRAP, 2011a), and Sakura (Tingley, 2012) focus more on material analysis for investigating end of life impact of buildings.

Apart from the above limitations, increasing adoption of Building Information Modelling (BIM) within Architecture, Engineering and Construction (AEC) industry (Arayici et al., 2011) requires a holistic rethink of entire construction activities. This means that any promising innovation within the AEC industry requires BIM compliance (Ajayi et al., 2014). Laying on this premise, the overall aim of this paper is to detail the development of BIM based Deconstructability Assessment System (BIM-DAS) to provide an objective and measurable system for building deconstructability during the design stage. This scoring system forms a basis for comparative analysis building models to choose the option with the least end of life impact on the environment. Accordingly, the specific objectives are:

(i) To identify critical design principles that ensures building deconstructability.
(ii) To develop an objective system, i.e. BIM-DAS, for scoring the degree of building deconstructability.
(iii) To test the performance and usability of BIM-DAS.

While adopting a positivist theoretical framework, this study uses experimental research and case study as research methodology to achieve its objectives. As such, an in-depth review of literature was carried out to identify key features that could be used for assessing the performance of DfD. Thereafter, the key features were used to develop BIM-DAS using mathematical modelling approach, which is based on efficient material requirement planning. At the end, BIM-DAS was tested using case study design.

The research paper starts with a discussion of the concept of design for deconstruction, key design principles influencing deconstruction, and the role of BIM in achieving effectual deconstruction. After this, a full discussion of the research methodology preceded discussion of how BIM-DAS was developed. A discussion on the evaluation of BIM-DAS through a case study design is then presented before culminating the paper ends with a conclusion and areas of further research.

2. Design for deconstruction as a means to an end

Deconstruction is “the whole or partial disassembly of buildings to facilitate component reuse and material recycling” (Kibert, 2008) to eliminate demolition through the recovery of reusable materials (Gorgolewski, 2006). This is with the aim of rapid relocation of building, reduced demolition waste, improved flexibility and retrofitting, etc. (Addis, 2008). Despite a growing discrepancy of opinion on whether CDEW could be completely eradicated (cf. Yuan and Shen, 2011; Zaman and Lehmann, 2013), existing studies shows that effective deconstruction could drive construction waste eradication initiatives (Guy et al., 2006; Densley Tingley and Davison, 2012; Akbarnezhad et al., 2014). Example of such initiative is the EU target of zero waste to landfill by 2020 (Phillips et al., 2011). Apart from helping to divert waste from landfills, deconstruction also enables other benefits, which include: (a) *environmental benefits*: by reducing site disturbance (Lassandro, 2003), harmful emission, health hazard (Chini and Acquaye, 2001) and preserving the embodied energy (Thormark, 2001) through material reuse; (b) *social and economic benefits*: by providing business opportunities through material recovery, reuse and recycling; and providing employment to support deconstruction infrastructure.

To enable a well-planned deconstruction, conscious efforts must be taken by architects and engineers right from the design stages. (Kibert, 2008). As such, the eventual purpose of deconstruction must be identified to guarantee the success of DfD. This will enhance the understanding of relevant design strategies and tools required for deconstruction. This section therefore contains a review of extant literature on types of deconstruction, DfD techniques, theory of building layers and BIM as a tool for DfD.

2.1. Types of deconstruction

Two activities are possible at the end of life of buildings, which include demolition and deconstruction as shown in Fig. 1. Demolition as a building removal strategy is primarily aimed at disposal to landfill with little consideration for material recovery. On the other hand, deconstruction is carried out to recover toxic materials from buildings for safe disposal or to divert waste from landfills through material recovery. For example, harmful substances such as asbestos needs to be safely removed through careful deconstruction from old buildings to avoid occupational exposure (Frost et al., 2008). According to Crowther (2005), deconstruction of buildings without toxic materials could be for four main purposes, which include (i) relocation of buildings, (ii) component reuse in other buildings, (iii) material reprocessing and (iv) material recycling. This is inline with the viewpoint of Kibert (2003) who suggests that realisation of effective DfD for multiple purposes will significantly reduce CDEW and helps to divert waste from landfills.

Deconstruction for building relocation involves the recovery of all the building materials and components without generation of waste. This is only possible if all the building materials and components are separable and reusable (Crowther, 2005). Although it is impractical to achieve 100% material recovery, McDonough and Braungart (2002) argued that recovery of building components for relocation and reuse remains the most preferred deconstruction purpose because it requires the least energy and new resources (Oyedele et al., 2014). This is because other purposes of deconstruction require additional energy and materials to reprocess or recycle recovered materials (Jaillon and Poon, 2014). The term DfD used in this study therefore encapsulates design for the purpose of recovery for building relocation and component reuse. This takes a cue from the fact that it is becoming a common practice to recycle an entire building and that a more significant challenge is designing a building that could be deconstructed for component reuse with minimal reprocessing. This task therefore necessitates the requirement to understand the complexity of intertwined processes of building design practice, DfD techniques and associated factors. As such, next section takes a holistic approach in discussing existing perspectives on DfD principles and how interplay among them could ensure successful building deconstruction.

2.2. Design for deconstruction techniques

According to Warszawski (1999), there are various design rules that should be followed in order to enhance deconstructability of buildings. These rules help to maximise the flexibility of designs, thereby enhancing building re-modification and disassembly. Guy et al. (2006) argues that designing for deconstruction requires an