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A BIM-aided construction waste minimisation framework

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ABSTRACT

At present, there are insufficient design decision making tools to support effective construction waste minimisation evaluation and implementation throughout all design stages. A limited but growing body of recent literature suggests that building information modelling has the potential to assist architects to minimise design waste on their projects. The research reported in this paper is the first attempt to develop a design decision making framework for improving construction waste minimisation performance through building information modelling. The potential use of building information modelling to drive out construction waste in building design was investigated through a questionnaire survey and follow-up interview with the top 100 architectural practices in the United Kingdom. An industry-reviewed 'building information modelling-aided construction waste minimisation framework' was developed based on the results of the literature review, questionnaire data, and interview data. The Framework is intended to act as an integrated platform for designing out waste decision making, by providing informed building information modelling-driven guidance to address waste causes throughout design stages.

1. Introduction

Construction and demolition activities generate 32% [19] and 44% [22] of all waste generated within United Kingdom (UK) and England, respectively. As such, the construction industry has been targeted by the UK government as a priority sector for the reduction of carbon emissions, energy consumption, and material resources usage. The latter increased from 420 million tonnes in 2003 [26] to 470 million tonnes in 2013 [22]. Currently, the UK construction industry produces 120 million tonnes of waste [79], of which 13 million tonnes are materials that have been delivered to the site but are never used [20]. Owing to a continuous increase of construction waste, the Strategy for Sustainable Construction [33] set a target of halving construction, demolition, and excavation waste to landfill by 2012 compared to 2008. Defra [22] confirmed that the target has been achieved except for increased excavation waste and called for further waste prevention actions, including designing out waste. Moreover, reducing construction waste has been driven by economic and environmental considerations due to the cost of waste, which relates to landfill tax that increased from £32/tonne in 2008 to £80/tonne in 2014 [37], and it is considered around 15 times that of disposal [56].

At present, the construction industry is responsible for about 32% of landfill waste and 25% of all used raw materials in the UK [66]. Thus, the construction industry has been exploring and developing approaches to minimise waste generation throughout the project lifecycle stages by employing sustainable building design and reducing waste during the design process [41]. The Green Overlay to the Royal Institute of British Architects (RIBA) Outline Plan of Work, that organises the process of building design projects into a number of key stages, has been introduced to provide a process for helping architects and project stakeholders to embed sustainable design strategies (e.g. energy and water efficiency, and carbon and waste reduction) in their design projects [69]. However, construction waste minimisation (CWM) has been paid little attention in the Green Overlay. At present, there are insufficient design decision making tools to support effective CWM evaluation and implementation throughout building design stages [59]. Recently, the UK Government Construction Strategy mandated the use of fully collaborative building information modelling (BIM) on public sector projects by 2016 [34]. Furthermore, the UK Construction 2025 Strategy recognised that BIM has the potential to reduce construction waste during design and construction stages [36]. The RIBA recently issued a BIM Overlay to the RIBA Outline Plan of Work in conjunction with the Green Overlay [70], which provides stage-by-stage guidance to assist architects to design and manage construction projects through the use of BIM. However, no efforts have been made to date to develop BIM-aided CWM design decision making tools and methodologies, which is the aim of this paper. Within the context of this research, construction waste is defined as a material or product which needs "*to be transported elsewhere from the construction site or used on the site itself other than the intended specific purpose of the project due to damage, excess or non-use,*

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or which cannot be used due to non-compliance with the specifications, or which is a by-product of the construction process" [78].

2. Construction waste minimisation

Construction waste minimisation is a process which helps to prevent, eliminate, or reduce waste at its source during design [16,59,71]. Prevention includes all activities that can reduce the amount of construction waste, which involves minimising waste generation at source and reducing waste before it enters the waste stream [4,21,60]. A significant proportion of construction waste occurs during the early design stages [7,24,27,72]. Around 33% of waste may be directly influenced by design decisions [39]. WRAP [82] indicated that there is a greater opportunity for reducing waste at the design stage than later stages, because fundamental design decisions related to building material, sharpness of form, size, and complexity are more likely to have a significant impact on waste.

There is agreement in the literature that construction waste during design is mainly related to design changes [3,7,24,27], ineffective coordination and communication [28,43,58,59], material specification [24, 58,60,62], design and detailing complexity [43,58,60,63], and design and construction detail errors [27,28,60,61]. A number of studies indicated that design changes during the construction stage, known as re-work, are major waste generation causes. It has been reported that causes of re-work are mainly due to client changes during site operations and poor communication among project stakeholders [49]. Al-Hajj and Hamani [2] argued that poor design-related material off-cut waste is clearly outside the control of the contractors but is within the control of the designers. A study conducted by Sinclair [77] suggested that designers have a great deal of influence over construction waste generation during various project stages. However, there is a lack of understanding by designers on causes of design waste [59]. Effective coordination and communication is critical to minimising construction waste at the design stage [83]. Additionally, limited 'know-how' and incoherent coordination and communication between project members affect design waste [59]. Some studies suggested that coordination and communication of design decision making are partly influenced by the late involvement of the contractor to provide consultation on waste reduction during design stages [7,59,60]. Rounce [72] and Al-Hajj and Hamani [2] equally believed that construction waste causes should be taken into consideration through better management of the design process.

The majority of current CWM practices focus on the construction stage, such as on-site waste auditing [9] and construction supply chain management [17], with less effort being paid to reduce waste during design. Construction waste forecasting tools, such as design-based waste assessment [25] and online waste forecasting [84] have been used to assist construction waste reduction during design stages. These tools aimed to capture live data of waste and provide improvements to resource efficiency in terms of waste minimisation; however, they do not consider CWM decision making during design stages.

Emerging information management-related technologies, such as bar coding systems [13], Global Positioning System (GPS) [47], E-commerce system simulation [14], and Geographic Information Systems (GIS) [6] are being adopted for construction waste research. Most recently, Liu *et al.* [48] suggested that BIM techniques can be used by architects as a platform for minimising construction waste in their design projects.

3. Building information modelling (BIM)

There is still no single, widely accepted definition of BIM. BIM is currently being gradually used to achieve various design, construction, and facility management performance targets [40,46,67,76]. These include improving and enhancing simulation and analysis, coordination and communication for collaborative working, lifecycle information assessment and management, and sustainable design across project lifecycle stages, as shown in Fig. 1, which indicates that the current use of BIM appears to bring about benefits throughout a project lifecycle.

BIM is thought to provide significant enhancements in detailing [30], visualisation and simulation [23], clash detection [30], and improved project performance in terms of coordination and communication [45]. When generating layouts or designing details, BIM allows its users to annotate building components with data/parameters which can be used for analysis to meet sustainable design requirements [87]. Architects and engineers have used visualisation and simulation within BIM to improve their knowledge of design and increase their spatial cognition [42]. It is important for project team members to evaluate the design via visualisation and simulation in BIM during early design stages [88]. The enhanced coordination and communication for collaborative working processes within BIM can determine the success of the project; BIM is implemented to manage conflicts between project participants' models, known as clash detection [44].

BIM-enhanced coordination and communication for collaborative working are fundamental features offered by BIM [23]. They influence all aspects of construction projects across all lifecycle stages and have a significant impact on design and construction, where BIM helps to streamline processes that use 3D parametric models and facilitates communication among disparate project stakeholders such as client, design team, and contractor to achieve a better understanding and quicker decision making [29,75]. This decision making requires effective coordination and communication to be delivered without any interoperability problems at company level, design team level, and project level. Enhanced coordination and communication for collaborative working via BIM is achieved through enhanced human communication, innovative visualisation, a rich knowledge database, and parametric 3D interaction. The current use of BIM for coordination is not only to ensure design-phase coordinated 3D models, but also in monitoring the scale and speed of construction and in assigning responsibility for site management and work coordination [18]. This results in a 3D parametric BIM model as a common method to ensure enhanced coordination and communication for collaborative working by the various project team members on most relevant briefing, design and construction issues. Associating 3D parametric BIM models with online tools, such as a BIM model server and web-based forums, would improve interoperability performance [68].

BIM standards represent rules allowing users to develop and apply BIM efficiently and consistently [51], especially when communication encompasses different project teams, specialists, and suppliers during a project [38]. There are several BIM standards, including BS 1192:2007, which was recently developed as a Publicly Available Specification (PAS 1192-2:2013), and a Diagram of BIM Maturity Levels, which has been widely adopted by the UK's construction industry in recent years [35,55]. BS 1192:2007 was published by the British Standards Institution to provide guidelines to support collaboration by defining the rules for modelling, publishing, and sharing information [10]. These apply to all parties who are involved in the preparation and use of information throughout the construction project lifecycle. PAS 1192-2:2013 was developed in line with BS 1192:2007 to specify requirements in achieving BIM Level 2 by focusing on project delivery [11].The Diagram of BIM Maturity Levels, known as Bew and Richards's maturity diagram (Fig. 12), attempts to summarise the BIM evolutionary process originally presented by Mark Bew and Mervyn Richards in 2008 and updated in 2012 in line with the UK Construction Strategy 2012. The maturity levels (Levels 0, 1, 2, and 3) are widely referred to in the construction industry, as BIM implementation is phased in by the Government Construction Strategy 2011. This required large public projects to implement Level 2 BIM from summer 2012 and all public projects have to fully collaborate with BIM-associated asset information, documentation, and data being electronic by 2016. The latest UK Government Construction Strategy, Construction 2025 [36] calls for all central government departments' projects, irrespective of project size, to implement at least Level 2 BIM from 2016, and