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Computational Building Information Modelling for construction waste management: Moving from rhetoric to reality

Weisheng Lu[a,*], Chris Webster[b], Ke Chen[a], Xiaoling Zhang[c], Xi Chen[a]

[a] Department of Real Estate and Construction, The University of Hong Kong, Hong Kong
[b] Faculty of Architecture, The University of Hong Kong, Hong Kong
[c] Department of Public Policy, City University of Hong Kong, Hong Kong

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ABSTRACT

There is a lively debate on the application of Building Information Modelling (BIM) to construction waste management (CWM). BIM can be utilized as a less expensive, virtual, and computational environment to enable designers to ponder different design options, or contractors to evaluate different construction schemes, both with a view to minimizing construction waste generation. However, existing debate on this topic too frequently treats BIM as a cure-all silver bullet; without some major hurdles being adequately addressed, the applications of BIM will remain rhetorical. This paper aims to demystify BIM's computational application to CWM. Based on a critical literature review, a prototypical framework of a computational BIM for CWM is delineated, within which the two key prerequisites of 'information readiness' and 'computational algorithms' are highlighted. Then, the paper details the required information and how it can be organized in a standalone database or encapsulated in existing BIM for CWM. Learning from the historical development of data infrastructure in the field of BIM-based cost management, the process to develop the required information is likely to be tortuous but is unavoidable. The paper further explores computational BIM algorithms that can manipulate the information to facilitate decision-making for CWM. Finally, the operation of computational BIM is elaborated by relating it to various prevailing procurement models within which BIM applications are contextualized. Although the framework reported here has been substantially developed for experimental application, , it is not to be taken as an immediately applicable solution but rather as an illustration of the kind of platform on which future development of computational BIM for CWM can proceed in a more efficient and effective fashion.

1. Introduction

While construction is a noble industry essential for materializing the built environment, it also exerts grievous adverse impacts on the natural environment in the form of resource depletion, greenhouse gas emissions, noise, dust, and construction waste. Construction waste, sometimes called construction and demolition (C & D) waste, is defined as the surplus and damaged products and materials that arise from construction, renovation, and demolition activities [50]. It often constitutes a prodigious portion of total solid waste that contributes to degradation of the environment. For example, in the U.S., the estimated amount of building-related waste generated in 2003 was 170 million tons [60]. In China, it was estimated that approximately 1.13 billion tons of C & D materials were generated in 2014, a decline from peak C & D activity in the early 2010s [34]. The construction industry is responsible for about 32% of landfill waste and 25% of all used raw materials in the UK [48]. The EC (European Commission) [15] reported that construction waste is responsible for 25–30% of all waste generated in the European Union. In Hong Kong, solid waste ending up in landfills reached 14,311 t per day (tpd) in 2013, of which 25% was from construction activities [19]; whereas, in Japan, construction contributes 20% of the total solid waste generated by all industries [37]. It is a common practice for construction waste to be used for landfill, which leads to extensive amounts of air, water, and soil pollution due to production of CO_2 and methane from anaerobic degradation of the waste. It also brings tremendous pressure on valuable landfill space, particularly in compact urban spaces such as those in Hong Kong, Singapore, and Japan. Researchers and practitioners of the industry have thus endeavored to manage construction waste by devising policy, engineering, economical and managerial approaches.

In recent years, Building Information Modelling (BIM) has been

* Corresponding author.
E-mail addresses: wilsonlu@hku.hk (W. Lu), cwebster@hku.hk (C. Webster), leochen@connect.hku.hk (K. Chen), xiaoling.zhang@cityu.edu.hk (X. Zhang), chenx90@hku.hk (X. Chen).

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increasingly explored as one approach to managing construction waste. According to the U.S. National BIM Standard [38], BIM is “a digital representation of physical and functional characteristics of a facility and a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle” (p.149). Davies and Harty [10] define BIM as a term used to refer to a family of technologies and related practices used to represent and manage information used for, and created by, the process of designing, constructing and operating buildings. BIM is being adopted as a technological tool applied to improve the construction industry in a number of areas, including design quality enhancement, construction plan rehearsal and optimization, site management [23,28,6], communication amongst parties [16], retaining information and knowledge to reduce discontinuity [28], and encouraging integration and collaboration [56], particularly when used in collaboration with an integrated project delivery (IPD) model [2,53]. BIM has even been claimed as a paradigm shift in the architecture, engineering, and construction (AEC) industry [28]. Against this general backdrop, BIM has also been enthusiastically promoted as a solution to construction waste management (CWM). For example, the UK's Construction 2025 Strategy states that “BIM has the potential to reduce construction waste during design and construction stages” [20].

The rhetoric notwithstanding, many BIM-using professionals in architecture, engineering and surveying, tend to see BIM as a silver bullet in the battle against construction waste without giving due consideration to harnessing it effectively. The widely propagated potential benefits of BIM are assumed to automatically lead to improved performance in CWM. Without demystifying BIM, its application to CWM will remain a fad. Without giving attention to computational implementation, normative approaches to the use of BIM for CWM (e.g. [3,46,8,45,29]) are in danger of adding to the rhetoric rather than clarify a way forward.

This paper aims to move BIM-enabled CWM from rhetoric towards reality. It does so by proposing a prototypical framework of a computational BIM for CWM, within which the prerequisites of ‘information readiness’ and ‘computational algorithms’ are highlighted and elaborated. The central argument is that with such a database of information in place, BIM can then be utilized as a less expensive, virtual, and computational environment within which designers and contractors can manipulate different design and construction options with a view to minimizing construction waste generation. The reminder of the paper is divided into four main sections. Section 2 is a critical assessment of the existing studies of the application of BIM to CWM. Section 3 delineates our prototypical framework for computational BIM for CWM and highlights two essential prerequisites and their relation to procurement models as the contexts wherein BIM operates. Section 4 details the required information by suggesting the development of two databases, namely, a ‘Design Options – Waste Generation’ database and a ‘Construction Schemes - Waste Generation’ database. Section 5 explores how BIM can be developed into a computational environment that will allow different design and construction options to have their waste generation levels calculated instantaneously. Section 6 explores the operation of computational BIM by relating it to different procurement models. In-depth discussion is provided in Section 7 and conclusions drawn in Section 8.

2. Literature review

There is a limited but growing body of literature exploring how BIM can be implemented for CWM. Porwal and Hewage [46] conducted a BIM-enabled analysis to minimize the waste rate of structural reinforcement. They used BIM as a hub for communicating project information among various design teams (architectural, structural, and mechanical, electrical, and plumbing) and then used an optimization algorithm to minimize reinforcement waste. Cheng and Ma [8] developed a BIM-based system for demolition and renovation waste estimation. While their research illustrated the importance of information to make BIM truly useful for CWM, it did not articulate the key information required to develop a convincing algorithm to perform the estimation based on the information specified. Research from Loughborough University advocated ‘designing out’ construction waste [3,41]. This work were espoused in a Generic Process Model for the detailed design process and a technique known as the Design Structure Matrix (DSM), which was developed in-house and promoted as a major decision-support system by the school. In their recent work, BIM was proposed as a potential design decision-making tool to support effective CWM [29].

Whilst the above studies are yet to convincingly link BIM and CWM, they have at least identified the sources of construction waste generation as a starting point. In CWM literature, many researchers have focused on on-site waste management by rightly viewing it as the stage where waste is generated. On-site practices such as construction methods, materials handling skills [52], housing keeping [59], on-site sorting [68], and off-site sorting [31], all have a significant impacts on waste generation, although a certain level of waste generation is perceived as unavoidable [57]. Since construction adopts a contracting/sub-contracting system, researchers have extended CWM downstream in the construction supply chain by managing sub-contractors, advocating green procurement [40] and extending producer responsibilities [1]. Those advocating ‘designing out’ construction waste ascertain that designers have a decisive role in helping waste reduction, although survey results show that this has only been sporadically practiced (e.g. [62,69]). Minimization of construction waste is still secondary to the traditional project objectives of time, cost, and quality. The UK-based WRAP (2007) (Waste & Resources Action Program) conducted a comprehensive study to identify five key principles that design teams can use to reduce construction waste, cited by Liu et al. [29] as: (a) Design for reuse and recovery; (b) Design for off-site construction; (c) Design for materials optimization; (d) Design for waste efficient procurement; and (e) Design for deconstruction and flexibility. The measures outlined in WRAP's [65] report are guided by the ‘3Rs’ principle of ‘reduce, reuse, and recycle’ and by classifying waste management strategies according to their desirability [42]. As a result of the foregoing research, it has become clear that decisions made at both design and construction stages can have an impact on construction waste minimization.

So what can BIM offer to construction waste minimization? In simple terms, BIM is a digital representation of physical and functional characteristics of a facility that aims to facilitate the exchange and interoperability of information [13]. BIM is a “richer repository” of information [14] than a set of drawings or static CAD files, since it has the ability to store different types of information and contains both geometric and non-geometric information about a project [47]. Geometric information includes size, volume, shape and spatial relationships, while non-geometric information includes the type of individual construction component, specifications of material, construction schedule, and cost. Schlueter and Thesseling [51] claimed that BIM information should include geometric, semantic and topological information. Geometric information directly relates to the building form in three dimensions; semantic information describes the properties of components, i.e., more advanced rule and function information; and topological information captures the dependencies of components. Without such information in place, BIM cannot do anything meaningful. The level of development (LOD) and specification defined by BIMForum [4] not only stresses the importance of information in BIM but also goes further to specify which development level of the information, ranging from 100 to 400, corresponds to BIM functionalities, e.g. for quick demonstration, fabrication, assembly, or installation. The momentum that BIM has gained can be understood by Flanagan and Lu's [17] contention that managing a construction project involves using available information and knowledge to make an array of decisions across processes including architecture, engineer-