International Journal of Sustainable Built Environment (2017) 6, 260–271

HOSTED BY ELSEVIER

Gulf Organisation for Research and Development

International Journal of Sustainable Built Environment

ScienceDirect
www.sciencedirect.com

Original Article/Research

BIM-based deconstruction tool: Towards essential functionalities

Olugbenga O. Akinade [a], Lukumon O. Oyedele [a,*], Kamil Omoteso [b], Saheed O. Ajayi [c], Muhammad Bilal [a], Hakeem A. Owolabi [d], Hafiz A. Alaka [e], Lara Ayris [f], John Henry Looney [g]

[a] *Bristol Enterprise, Research and Innovation Centre (BERIC), University of the West of England Bristol, United Kingdom*
[b] *School of Economics, Finance and Accounting, Coventry University, Coventry, United Kingdom*
[c] *School of the Built Environment and Engineering, Leeds Beckett University, UK*
[d] *Faculty of Business and Law, University of Northampton, UK*
[e] *Faculty of Computing, Engineering and The Built Environment, Birmingham City University, UK*
[f] *Waste Plan Solutions, Northampton, UK*
[g] *Sustainable Directions Ltd, Gloucestershire, UK*

Received 8 June 2016; received in revised form 30 November 2016; accepted 20 January 2017

Abstract

This study discusses the future directions of effective Design for Deconstruction (DfD) using BIM-based approach to design coordination. After a review of extant literatures on existing DfD practices and tools, it became evident that none of the tools is BIM compliant and that BIM implementation has been ignored for end-of-life activities. To understand how BIM could be employed for DfD and to identify essential functionalities for a BIM-based deconstruction tool, Focus Group Interviews (FGIs) were conducted with professionals who have utilised BIM on their projects. The interview transcripts of the FGIs were analysed using descriptive interpretive analysis to identify common themes based on the experiences of the participants. The themes highlight functionalities of BIM in driving effective DfD process, which include improved collaboration among stakeholders, visualisation of deconstruction process, identification of recoverable materials, deconstruction plan development, performance analysis and simulation of end-of-life alternatives, improved building lifecycle management, and interoperability with existing BIM software. The results provide the needed technological support for developing tools for BIM compliant DfD tools.

Keywords: Building deconstruction; Building Information Modelling (BIM); Functionality framework; Focus Group Interviews; Descriptive interpretive analysis

1. Introduction

The recent wide adoption of Building Information Modelling (BIM) has revolutionised the approach to timely project delivery across the world (Eastman et al., 2011). The benefits accruable from BIM have stimulated several nations to set a deadline for its adoption. For example,

* Corresponding author.
E-mail address: ayolook2001@yahoo.co.uk (L.O. Oyedele).
Peer review under responsibility of The Gulf Organisation for Research and Development.

http://dx.doi.org/10.1016/j.ijsbe.2017.01.002
2212-6090/

the UK government has stipulated that from April 2016, all procurement in public sector work must adopt BIM approach. This deadline has forced most companies in the UK to integrate BIM into their activities in order to sustain their competitive advantage. Due to the rise in BIM adoption, the implementation of BIM has experienced diverse innovation especially for building design, cost estimation, 3D coordination, facility maintenance, building performance analysis, etc. In addition, there is progressive improvement on the capabilities of BIM and its integration with technologies such as RFID, GIS, big data, Internet of Things (IoT), and others (Bilal et al., 2016a). Despite the benefits accruable from the use of BIM and the steep rise in the adoption of BIM, the use of BIM for end-of-life scenarios is often neglected (Akinade et al., 2015). This is because most BIM implementations focus on the planning to the maintenance stages of the building and only few works have been done on BIM for end-of-life scenarios.

It is important to give additional attention to the end-of-life of building, especially in terms of waste generation, because evidence shows that demolition activities account for over 50% of the total Construction and Demolition Waste (CDW) output of the construction industry (Kibert, 2003). Diverting this amount of waste could lead to a cost saving of over £1.3 billion on landfill tax and haulage. Therefore, ensuring adequate management of waste at the end-of-life of building is imperative since the current rate of construction suggests that building renovation and demolition activities would grow substantially. The need to reduce waste at the end-of-life therefore requires that demolition, as the traditional method of building disposal, be replaced with building deconstruction. Deconstruction is a building end-of-life scenario that favours the recovery of building components for the purpose of building relocation, component reuse, recycling or remanufacture (Kibert, 2008). Design for Deconstruction (DfD) is not just concerned with the recovery of building components at the end-of-life but processes that make building to be easily assembled and disassembled. Despite efforts in mitigating demolition waste through deconstruction (Akinade et al., 2015; Phillips et al., 2011), there has not been a progressive increase in the level of DfD. Evidence shows that DfD is still far from reaching its waste minimisation potentials since less than 1% of existing buildings are fully demountable (Dorsthorst and Kowalczyk, 2002).

Considering the foregoing, the use of BIM for building deconstruction management would be an effort channelled in the right direction. This is because literature reveals that design decisions have high impact on waste generation and end-of-life performances of buildings (Faniran and Caban, 1998; Osmani et al., 2008). Based on the identified gap in knowledge, this study seeks to identify key BIM functionalities that could provide effective decision-making mechanisms for DfD at the design stages. Therefore, the specific objectives of the study include:

(1) To assess the effectiveness and limitations of existing DfD tools.
(2) To understand opportunities accruable from the adoption of BIM for DfD.
(3) To identify essential functionalities of a BIM-based tool for DfD.

In order to identify inefficacies of current DfD practices and tools, this study starts with a review of existing works on DfD and the discussion of the role of BIM in DfD. Afterwards, a descriptive interpretive research was conducted using multiple Focus Group Interviews. This approach allows the investigator to set aside all presuppositions about the phenomenon in the search of true meanings and to have in-depth understanding of the phenomenon as experienced by experts. This is important to understand why the use of BIM for deconstruction is not common practice in the industry and to unravel the expectations of the participants on how BIM functionalities could be leveraged for DfD.

2. Building deconstruction and BIM

Deconstruction is a building end-of-life scenario that allows efficient recovery of building components (Kibert, 2008) for the purpose of reuse, recycling or remanufacturing. The recycling and remanufacturing of building components is now common practice; however, a more beneficial and challenging task is the ability to relocate a building or reuse its components without reprocessing. This is because building relocation and components reuse require minimal energy compared to recycling and remanufacturing (Jaillon and Poon, 2014). In addition, the reuse of building components guarantees a closed material loop condition where request for new resources and the generation of CDW is minimised. Fig. 1 shows how deconstruction enables a closed material loop condition at the end-of-life of buildings. The closed material loop eliminates the linear pattern of material movement in demolition to a circular economy model, which is more sustainable.

The aim of building deconstruction is to eliminate demolition as an end-of-life building disposal option. Apart from favouring the recovery of building components and diversion of waste from landfills, deconstruction is more beneficial than demolition in other ways. First, deconstruction eliminates environmental pollution and CDW generation that is characteristics of demolition (Akbarnezhad et al., 2014). Other benefits include reduction in harmful emission (Chini and Acquaye, 2001), preservation of the embodied energy (Thormark, 2001), reduction in site disturbance (Lassandro, 2003), etc.

Kibert (2008) suggests that effective strategy for closed-loop building material usage and material recovery requires basic rules which are: (a) building must be fully deconstructible; (b) building must be disassemblable; (c) construction materials must be recyclable; (d) the production

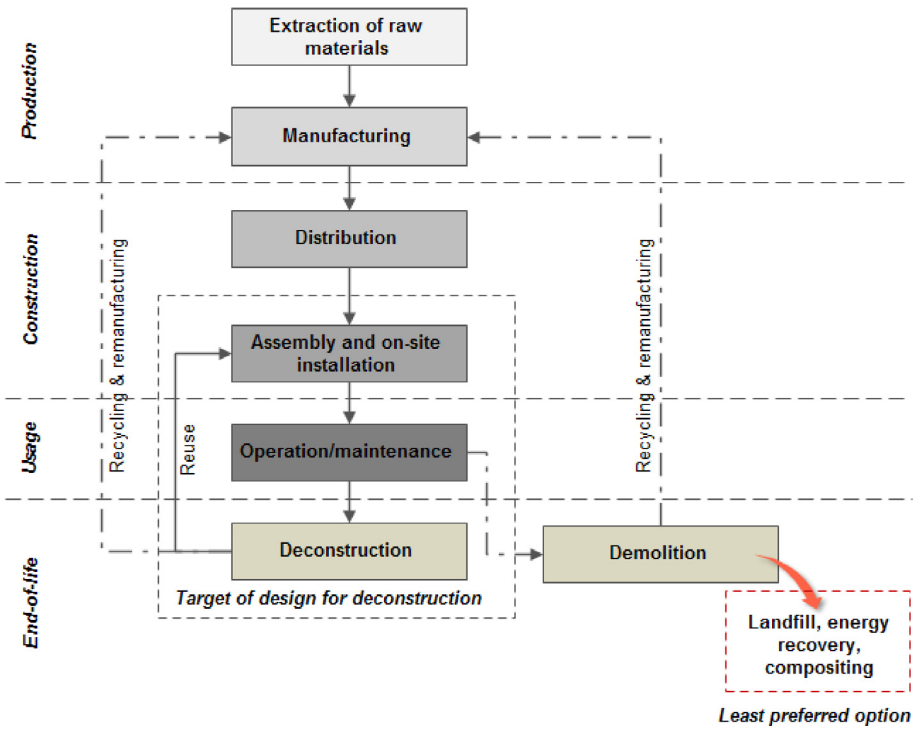

Fig. 1. End-of-life scenario in a closed material loop condition.

and use of materials must be harmless; (e) material generated as a result of the recycling process must be harmless. The main assertion from these rules is that construction materials must be recoverable and reuseable/recyclable to reduce waste generation at the end of the useful life of a facility. These rules uphold the reports by Egan (1998) and Latham (1994), which highlight the need to improve design and construction processes in order to improve efficiency and sustainability.

2.1. Existing Design for Deconstruction tools

Considering the impacts of design on how buildings are constructed, it is necessary to understand how design decisions affect how buildings are assembled and disassembled. Akinade et al. (2015) highlighted that tackling this challenge requires the knowledge of the intertwined relationships among design practice, DfD techniques and DfD tools. This therefore calls for a holistic approach to how the interplay among these key areas could ensure successful building deconstruction. Accordingly, the impact of computer tools for DfD and assessing the sustainability of building cannot be overemphasised in this regard. In order to access the effectiveness and limitations of existing DfD tools as presented in several studies, a thorough review of extant literature was carried out. The review reveals that DfD tools cover life cycle assessment tools, environmental sustainability tools and life cycle costing tools. The tools and how they match up with DfD related criteria are presented in Table 1.

Chief among the limitations of existing tools is that they are not BIM-compliant. Likewise, none of the existing BIM software offers DfD functionalities. This evidence shows that despite the steep rise in BIM implementation for several purposes, BIM implementation for end-of-life scenario of buildings is not common practice. Although several studies suggest that BIM has the potentials for end-of-life waste minimisation but no clear instructions has been provided on achieving this (Akinade et al., 2015).

Considering the recent trend of BIM implementation in the AEC industry, it is evident that BIM will continue to change ICT usage and the industry's cultural process (Arayici et al., 2011). This game changing endeavour as well as the numerous benefits and opportunities accruable from BIM adoption have prompted many countries, such as USA, UK, China, Finland, Qatar, Singapore, France, etc., to invest in BIM capability development. It is therefore envisaged that BIM will continue to play an important role in collaborative practices in the highly multidisciplinary AEC industry for several years. This clearly shows that a tight integration of BIM and DfD would therefore be an effort in the right direction since evidence suggests that planning for effective construction, operation and end-of-life management of buildings must start from the design stage (Faniran and Caban, 1998; Wang et al., 2014). This brings to the fore the need for the implementation of BIM-based DfD tools to ensure that participating teams can implement appropriate deconstruction principles right from the design stage. These tools will be in form of plugins to existing BIM software to extend their

Table 1
Existing DfD tools and their features.

Nos	Tools	BIM compliant	Embodied energy estimation	Carbon footprinting	End-of-life impact estimation	Estimation of building deconstructability	Deconstruction process simulation	Deconstruction plan generation	Material recovery assessment	Lifecycle costing	Whole-life environmental impact assessment	Optimisation of material selection
1	Building deconstruction assessment tool (Guy, 2001)	✗	✓	✓	✓	✗	✗	✗	✗	✗	✓	✗
2	Building end-of-life analysis tool (Dorsthorst and Kowalczyk, 2002)	✗	✓	✓	✓	✗	✗	✗	✗	✗	✓	✗
3	Construction Carbon Calculator (Buildcarbonneutral, 2007)	✗	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗
4	SMARTWaste (BRE, 2008)	✗	✓	✓	✓	✗	✗	✗	✓	✗	✓	✓
5	Building for Environmental and Economic Sustainability (BEES) (BEES, 2010)	✗	✓	✓	✓	✗	✗	✗	✗	✓	✓	✗
6	Design-out Waste Tool for Buildings (DoWT-B) (WRAP, 2011)	✗	✓	✓	✓	✗	✗	✗	✓	✗	✓	✓
7	IES IMPACT Compliant Suite (IES, 2012)	✓	✓	✓	✓	✗	✗	✗	✓	✓	✓	✗
8	Sakura (Tingley, 2012)	✗	✓	✓	✓	✗	✗	✗	✗	✗	✗	✓
9	eTool life cycle design (LCD) (ETools, 2013)	✓	✓	✓	✓	✗	✗	✗	✗	✗	✓	✓
10	Demolition and Renovation Waste Estimation (DRWE) (Cheng and Ma, 2013)	✓	✓	✓	✓	✗	✗	✗	✓	✓	✓	✗
11	Integrated Material Profile and Costing Tools (IMPACT, 2015)	✓	✓	✓	✓	✗	✗	✗	✗	✓	✓	✓
12	BIM-DAS (Akinade et al., 2015)	✓	✗	✗	✓	✓	✗	✗	✓	✗	✗	✓
13	Athena environmental impact estimator (Athena, 2015)	✗	✓	✓	✓	✗	✗	✗	✓	✗	✓	✓
14	SimaPro 8 (SimaPro, 2015)	✗	✓	✓	✓	✗	✗	✗	✗	✗	✓	✗
15	Umberto NXT LCA (Umberto, 2016)	✗	✓	✓	✓	✗	✗	✗	✗	✗	✓	✗
16	GaBi – Building lifecycle assessment software (Gabi, 2016)	✗	✓	✓	✓	✗	✗	✗	✗	✗	✓	✗

functionalities. Based on the foregoing, this paper therefore seeks to unravel how BIM could complement DfD processes and to identify the essential functionalities that a BIM-based tool for deconstruction must have.

3. Methodology

After identifying the limitations of existing DfD tools, a descriptive interpretive study was carried out to understand how effective deconstruction process could be achieved by employing current capabilities of BIM. According to Creswell (2014), descriptive interpretive methodology seeks to qualitatively exhume common meaning from the experiences of several individuals. In this way, it allows deep understanding of individuals' experience about a phenomenon. This is based on the belief that a poorly conceptualised phenomenon could only be addressed if the researcher is in active correspondence with the participants (Holloway and Wheeler, 1996). Van Manen (1990) also highlights that being interested in the story of others is the basic underlying assumption of descriptive interpretive study. The investigators therefore try to set aside their experience to have a fresh perspective in exploring a phenomenon. In this regard, this study seeks to explore the experiences of the participants in terms of the use of BIM for DfD. The methodological flowchart for the study is shown in Fig. 2.

According to Moustakas (1994), two data collection methods dominate descriptive interpretive studies, which are in-depth interviews and Focus Group Interviews (FGIs). In-depth interview is conducted with individuals to elicit their perspective of a phenomenon, while FGIs particularly involve discussion among selected group of participants regarding a common experience (Hancock et al., 1998). In this study, FGIs are employed over individual interviews because FGIs allow participants to build on responses of others while discussing their personal experience. This approach provides deeper insights into a wide range of perspectives within a short time and it also helps to confirm group thinking and shared beliefs.

Multiple FGIs were therefore conducted with participants selected from the UK construction companies who have partially or fully implemented BIM on their projects. The sampling was done in a way that individuals who are directly involved in building design and BIM were chosen. The FGIs provide a forum for practitioners within the AEC industry to share their views and expectations on BIM usage for DfD. Although the practitioners are not specialists in tool development, understanding their views and expectation could help to uncover and analyse the industry requirement of BIM in DfD across different disciplines. In addition, end users are key in the engineering of any useful innovation development and their views and expectations need to be taken into consideration (Oyedele, 2013). Accordingly, 20 professionals were selected based on suggestion of Polkinghorne (1989) who recommended that FGI participants should not exceed 25. The distribution and the range of years of experience of the participants of the focus groups are shown in Table 2. The distribution of year of experience of participants across all focus groups is as shown in Fig. 3.

Participants of the FGIs were encouraged to discuss openly on the limitations of existing DfD practices and their expectations of BIM concerning DfD. This was done with the aim of understanding the possibilities of addressing limitations of DfD tools with the current capabilities of BIM. Discussion and interactions among participants were recorded on a digital recorder and later compared with notes taken. This is to ensure that all important and valuable information to the study were captured. Afterward, the voice recordings were transcribed and segmented for thematic analysis. These tasks were conducted to develop clusters of meanings by themes identification.

4. Analyses and results

In a descriptive interpretive research, data analyses follow structured methods, which starts with the description of researchers' own experiences followed by the description of textual and structural discussions of participants' experiences (Creswell, 2013). This allows the researcher to move from a narrow unit of analysis to broader units. According to Moustakas (1994), descriptive interpretive research follows a concise analytical approach as summarised in Table 3.

Thematic analysis was carried out using appropriate coding scheme to identify units of meaning from significant statement and to classify them into recurring themes. The coding scheme employs four tags, which are discipline, context, keywords, and theme category. Discipline coding classification shows the job role of the participant that provided a transcript segment. Context coding depicts the circumstances informing a transcript segment. The context coding classification include: (i) *New* – marks the start of a new subject of discussion; (ii) *Response* – signifies a response to a question; (iii) *Build-up* – shows when a contribution to an ongoing discussion is made; and (iv) *Moderator* – marks a control segment provided by the moderator. Keyword coding classification depicts a summary of the main issue raised within a segment. This helps to identify prevalent issues and concerns across the transcript. The keywords are underlined within the quotation segments. The theme category shows the principal theme under which the issue discussed in the transcript segment falls. Example of quotation classification based on this coding scheme is shown in Table 4.

The results of the analyses suggest that it is important to adopt solutions available within tools used throughout the entire lifecycle of buildings in the implementation of a robust tool for DfD. This is to ensure effective management of end-of-life scenarios right from the planning stages, through subsequent stages, i.e., design, construction, commissioning, usage and maintenance stages. Arguably, the participants of FG1 pointed out directions for the adoption of BIM for DfD as follows:

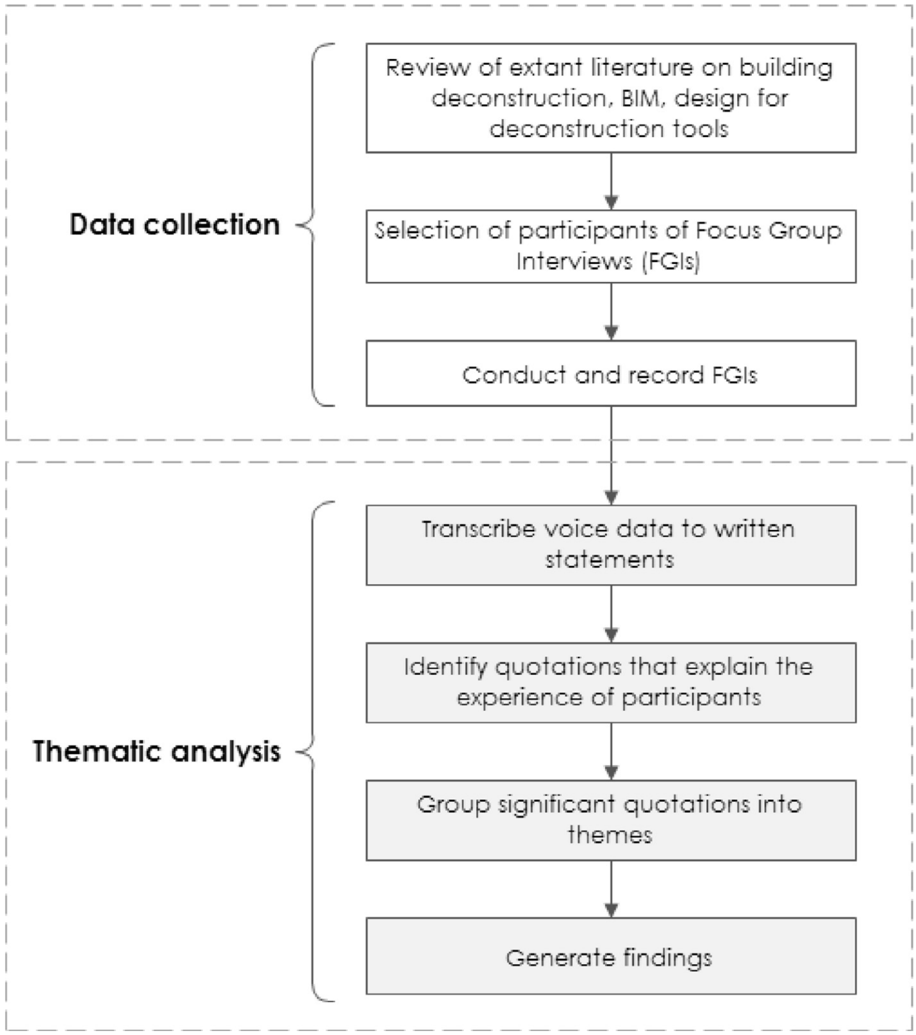

Fig. 2. Methodological flowchart for the study.

Table 2
Overview of the focus group discussions and the participants.

FG	Categories of participants	No of experts	Years of experience
FGI1	Architects and design managers • 3 design architects • 1 site architect • 2 design managers	5	12–20
FGI2	M&E engineers • 2 design engineers • 3 site engineers	5	9–22
FGI3	Construction project managers	5	12–22
FGI4	Civil and structural engineers • 1 design engineer • 3 site based engineers	5	8–18
Total		20	

A major breakthrough in the construction industry is the use of BIM packages to model, visualise and simulate building forms and performances. In fact, any useful innovation in the AEC industry must embrace BIM… the life of the building. In order to ensure that a building is fit for disassembly, it is important that tools [design for deconstruction tools] are accessible within current BIM design tools used throughout the lifecycle of buildings…"

"We all understand that the usability of building components is influenced by various decisions made throughout

"We know that end-of-life activities are influenced by decisions made at all building stages. As such, to ensure

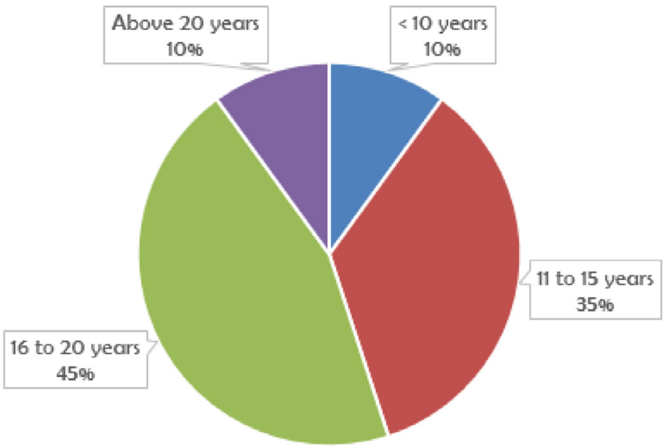

Fig. 3. Distribution of year of experience of participants across all focus groups.

that buildings are demountable at the end-of-life, project teams must use tools that are relevant from the design stage throughout the entire building cycle …"

These assertions imply that the future DfD tools must be BIM compliant considering the current rate of BIM adoption in the industry. The participants echoed that integrating DfD with BIM would offer greater flexibility to influence end-of-life performance of buildings at a stage where design change is cheaper.

Thematic data analysis reveals seven key BIM functionalities to be leveraged for DfD. These key functionalities include: (i) improved stakeholders' collaboration, (ii) visualisation of deconstruction process, (iii) identification of recoverable materials, (iv) deconstruction plan development, (v) performance analysis and simulation of end-of-life alternatives, (vi) improved building whole life management, (vii) interoperability with existing BIM software. Thereafter, these key functionalities are developed into a functionality framework for BIM-based DfD tools as shown in Fig. 4. The framework highlights the potentials of BIM in driving effective DfD and it provides a basis for the development of BIM-based DfD tools.

5. Functionality framework for BIM-based Design for Deconstruction tools

This section discusses the functionality framework for BIM-based DfD tools. The identified functionalities would exploit existing BIM key functionalities through BIM software Application Programming Interface (API) (Akinade et al., 2016; Bilal et al., 2016b). The key components of functionality framework are as follows.

5.1. Improved collaboration among stakeholders

The extent to which project teams collaborate and communicate is critical to the success of building construction projects (Oyedele and Tham, 2007). DfD takes no exception to this because it is important that continued justification should be provided for deconstruction at all life cycle stage and all stakeholders must be committed to it. In this regard, BIM can play a major role in ensuring that all stakeholders are actively involved in taking deconstruction related decisions right from planning through the entire building life cycle. In keeping with the foregoing fact, the participants of FGI3 suggest that adopting BIM on projects allows every member of the project teams to focus on the success of the project. It was stressed that:

Table 3
Descriptive interpretive analysis process.

Step	Analytical method	Activity
1.	Describe personal experience with phenomenon	This is important to set aside personal experiences and to focus on participants' experiences
2.	Develop a list of significant statements from interview transcripts	• Transcribe voice data to written statements. • Identify quotations that explain participants' experiences with phenomenon
3.	Develop coding scheme for thematic analysis	• Identify units of meaning using thematic analysis • Group significant statements into themes using coding scheme
4.	Describe "*what*" participants experience with phenomenon	Carry out a textual description of participants' experiences with verbatim quotations
5.	Describe "*how*" the experiences happened	Carry out a structural description of the setting and context in which phenomenon was experienced
6.	Synthesise "*what*" the participant experienced and "*how*" they experienced it	Carry out a composite description that contains the textual and structural descriptions

Table 4
Example of classification based on the coding scheme.

No.	Quotation	Source	Discipline	Context	Theme category
1	"…*We can then use the tools to determine the type and* volume of materials *that can be reused after* deconstruction"	FGD 2	Design engineer	New	Quantification of recoverable material
2	"…*BIM can allow the* visualisation of building demolition and deconstruction process *during the design*"	FGD 1	Design architect	Build-up	Visualisation of deconstruction process

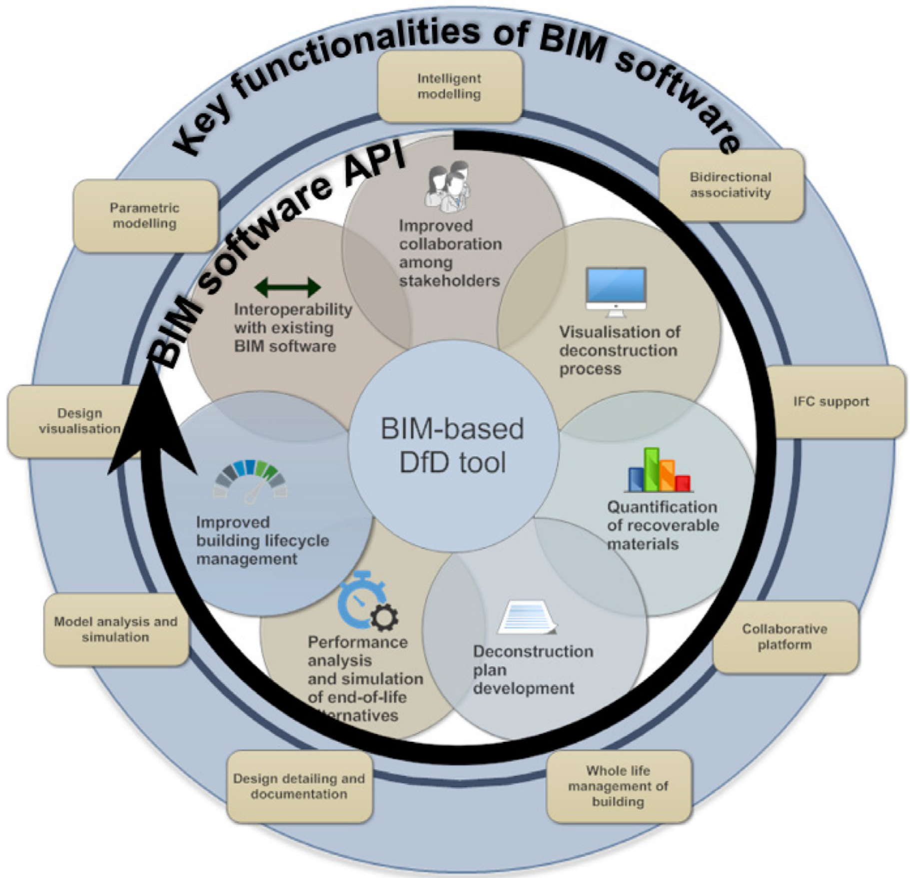

Fig. 4. Functionality framework for BIM-based Design for Deconstruction tools.

> *"Taking the right decisions for this [design for deconstruction] requires using appropriate tools from the design stages. Such tools will help all teams to contribute to project decisions and to the success of the project…"*

Collaborative stakeholders' relationship approach encourages 'shared risk and shared reward' philosophy, which engenders process efficiency, harmony among stakeholders and reduced litigation (Eadie et al., 2013). As such, BIM provides a robust platform for communication and information sharing amongst all stakeholders. BIM also engenders design coordination, task harmonisation, clash detection, and CDW management process monitoring. The participants of FGI3 echoed that incorporating DfD functionality into BIM would encourage effective participation of all projects teams. Adopting BIM would therefore facilitate transparent access to shared information, controlled coordination, and monitoring of processes (Eastman et al., 2011).

5.2. Visualisation of deconstruction process

A common thread runs through all BIM software and it is parametric modelling functionality that enables visualisation of the aesthetics and functions of buildings (Sacks et al., 2004). According to Tolman (1999). Parametric modelling employs an object-oriented approach that enables the reuse of object instances in building models, while sustaining object attributes, behaviour and constraints. This feature has aided the adoption of BIM across the AEC industry to improve project delivery and building performance. However, parametric modelling has not been leveraged for visualising building deconstruction process at the design stage and before the actual deconstruction takes place. This belief was shared by the participants of FGI1 who agreed that:

> *Visualising forms and performances of buildings has reduced the need for rework that serves as the major source of construction waste. Likewise, BIM can allow the visualisation of building demolition and deconstruction process during the design … However, no BIM tool currently offers this capability …*

This excerpt suggests that a BIM platform that allows deconstruction process visualisation would assist to optimise the DfD process in order to benchmark and minimise the impact of end-of-life alternatives. In addition, enabling this feature in BIM software will help to prepare adequately for the actual deconstruction at the end-of-life of buildings. This will help to develop appropriate pre-deconstruction audit report and to put in place strategies for site, transport, and waste management.

5.3. Quantification of recoverable materials

BIM implementation goes beyond 3D computer modelling and visualisation (Eastman et al., 2011). A key feature that make BIM stands out is Intelligent modelling that provides the ability to embed key asset and process information into building models right from the early planning stage and throughout the life of the building (Xu-dong and Jie, 2006). The information is preserved within a federated model to improve decision making during construction, maintenance of buildings and at the end-of-life of buildings. Accordingly, information about building materials could be enriched to support the whole life performance prediction of the materials. This will therefore empower BIM to be employed in the identification of recoverable material types and quantity throughout the entire life of buildings. Participants from FGI2 suggest that:

> *Design for Deconstruction practice will be taken seriously if it is possible to predict the amount of recoverable elements at the end-of-life of buildings…*

> *… This [design for deconstruction tool] will be usable if it is accessible within BIM platforms. We can then use the tools to determine the type and volume of materials that can be reused after deconstruction.*

The above assertions suggest that apart from the visualisation of deconstruction process, a key feature that BIM-based DfD tools must have is the ability to predict the amount of recoverable and non-recoverable materials at the end-of-life of buildings. This feature will allow stakeholder to be able to predict types and volume of materials that are reusable, those that could be recycled, and those that must be disposed. Achieving this will enable the provision of empirical evidence in support of DfD.

5.4. Deconstruction plan development

In agreement with earlier studies, the participants of the FGIs agreed that another benefit of BIM is automatic capture of design parameters for report generation. It was highlighted during the FGIs that employing BIM during design would eliminate human error during data entry. For example, existing DfD require practitioners to manually transfer design parameters from the bill of quantity. This approach therefore makes these tools susceptible to errors in waste estimation. It was highlighted in FGI2 that this feature could be harness in the development of deconstruction plans and other documents such as pre-demolition audit reports and pre-refurbishment audit reports:

> *"One would appreciate the use of BIM when its potential is fully utilised especially when design documents are generated on the fly…"*

> *"… In terms of design for deconstruction, I believe BIM could be used to prepare the deconstruction plans and end-of-life audit reports at varying level of details"*

In support of the above excerpts, Davison and Tingley (2011) argue that the development of a deconstruction plan is an important requirement for a successful DfD. However, no tool exists with the capability of generating deconstruction plans from building models. The participants also argued that BIM features that enable on-demand generation of design documents (such as plan drawings, sections, schedules, etc.) from the model of the buildings could be leveraged for deconstruction plan development. This therefore will improve design coordination, time management, and engineering capabilities of DfD activities and documentation.

5.5. Performance analysis and simulation of end-of-life alternatives

Another functionality of BIM that aids its wide acceptability is the ability to analyse and simulate buildings' performance such as cost estimation, energy consumption, lighting analysis, etc. (Manning and Messner, 2008). According to Eastman et al. (2011), building performance analyses provide a platform for functional evaluation of building models before the commencement of construction. This allows comparison of alternative design options in selecting the most cost-effective and sustainable solution. The increasing popularity of BIM in the AEC industry has strengthened the development of various tools for design analyses and performance evaluation. Performance evaluation capability of BIM could be employed in DfD tools to identify possible design and operational errors that can hamper deconstruction. The participants of FGI1 highlighted that despite the availability of BIM based tools for the analyses of various building performances such as airflow, energy, seismic analyses, etc., no tool exists for DfD:

> *"A major breakthrough we have experienced in the construction industry is the ability to carry out performance analysis on building models. Numerous performance analyses are available to identify potential design errors and operational issues at a stage where design changes are cheaper…"*

> *"Despite the benefits of building performance analysis and the environmental/economic impacts of construction waste, none of the existing BIM software has capabilities for design for deconstruction. This gap calls for a rethink of BIM functionalities towards capacity for end-of-life simulation of building performance and disposal options right from early design stages."*

To support the above excerpts, the use of BIM for the analysis and simulation of deconstruction process will help to justify the environmental and economic benefits of deconstruction. This is because evidence shows that building deconstruction may be the most environmentally beneficial; however, it may not be the most economically viable option (Hamidi and Bulbul, 2012). As such, BIM can be used to simulate the cost benefit performance of deconstruction in order to decide on the appropriate design and end-of-life options.

5.6. Improved building lifecycle management

While discussing the role of BIM in whole-life performance of buildings, the participants agreed that the use of BIM encompasses all project work stages from the planning stage to the end-of-life of buildings. BIM allows information on building requirements, planning, design, construction, and operations can be amassed and used for making management related decisions on facilities. This feature allows all teams to embed relevant project information into a federated model. For instance, project information such as bill of quantity, project schedule, cost, facility management information, etc., is incorporated into a single building model. The information thus enables a powerful modelling, visualisation and simulation viewpoint that helps to identify design, construction and operation related problems before they occur. This distinguishing feature makes BIM applicable to all work stages by accumulating building lifecycle information (Eadie et al., 2013). The participants of FGI1 suggest that:

> *"Many practitioners in the AEC industry understand the benefits of adding more information into models, which could extend parametric BIM into 4D, 5D, 6D, etc. Preserving information throughout the lifecycle of buildings is important for effective facility management. In addition, the information could be accessed to make useful end-of-life decisions for buildings."*

In addition, improved lifecycle management of building offered by BIM encourages data transparency, concurrent viewing and editing of a single federated model, and controlled coordination of information access (Grilo and Jardim-Goncalves, 2010). In this way, BIM helps to address interdisciplinary inefficiency (Arayici et al., 2012) within the fragmented AEC industry. This will certainly improve team effectiveness while reducing project cost and duplication of effort. The participants agreed that although more time is required to create a federated model, its benefits surpass the cost. The participants highlighted that since waste is generated at all project work stages, adopting BIM for waste management will allow effective capturing of waste related data from design to the end-of-life of buildings.

5.7. Interoperability with existing BIM software

Although one could argue that the adoption of BIM is on the rise (Arayici et al., 2011), a major challenge confronted by construction companies is software interoperability (Steel et al., 2012). In view of this, project teams expend much effort in carefully selecting appropriate BIM software for effective collaboration and communication. This view was also shared among the participants of the FGIs. The participants highlighted that the use of IFC standard has improved model exchange among BIM software for design analyses. It was agreed among the participants of FGI1 that future DfD tools must embrace IFC open schema for model exchange with BIM software:

> *"While BIM software have diverse schema for model representation, the IFC open standard has allowed seamless exchange of models among them. One can now easily share building models with other project teams with different BIM software. Future DfD tools must therefore be BIM compliant and must support the use of IFC ..."*

It is worth noting that IFC schema allows the extension of its tags to capture various parameters for building objects. Despite this opportunity, IFC schema has not been equipped with adequate mechanism to streamline construction waste analysis and deconstruction process. This gap calls for a closer look into how IFC could be extended to support data exchange between DfD tools and BIM software. As such, information exchange requirement of DfD processes needs to be identified and captured within existing BIM and IFC models.

6. Conclusion

It is evident that despite the benefits accruable from the use of BIM, its use for end-of-life scenarios is often neglected. Giving more attention to the end-of-life of building is important because demolition activities accounts for over 50% of the total CDW output of the construction industry. This shows that a more sustainable approach to CDW would be demolition avoidance through efficient DfD. Although architects and design engineers are aware of DfD, existing DfD tools cannot support them effectively. Based on the foregoing, this study therefore seeks to identify essential functionalities of a BIM-based DfD tools. This is because evidence shows that design decisions have high impact on the entire life cycle of buildings (Faniran and Caban, 1998; Osmani et al., 2008) and that design based philosophy offers flexible and cost-effective approach to building life cycle management.

To achieve the objectives of this study, this paper assesses limitations of existing DfD tools and discusses the role of BIM in effective DfD. Thereafter, the study employs a descriptive interpretive methodological framework in order to enhance an in-depth exploration of how the experience of experts could help to address the phenomenon under study. After conducting a set of FGIs to discuss BIM functionalities for DfD with professional from the construction industry, the qualitative data analysis of the data reveals seven key functionalities of BIM-based

DfD tools. The key functionalities include (i) improved collaboration among stakeholders, (ii) visualisation of deconstruction process, (iii) identification of recoverable materials, (iv) deconstruction plan development, (v) performance analysis and simulation of end-of-life alternatives, (vi) improved building lifecycle management, and (vii) interoperability with existing BIM software. The key functionalities were then developed into a BIM functionality framework for integrating existing DfD tools with BIM platforms.

The study suggests that the adoption of BIM could significantly increase the performance of DfD tools. To achieve this, the BIM functionality framework for DfD tools highlights the potentials of BIM in driving effective DfD and it provides a basis for the development of BIM-based DfD tools. The study therefore shows that BIM is key to improve the collaborative capabilities of DfD tools. This is especially required as the industry is far shifting towards a fully collaborative digital workflow and the building deconstruction industry can benefit from this. In addition, this study implies that visualisation capability of BIM could be employed to simulate and visualise building deconstruction process during the design stage. This will enable for the detection of possible site operational or management issues, such as transportation logistics, waste management, scaffolding requirements, health and safety considerations, that could hinder building deconstruction. Achieving this will help to identify recoverable materials during simulation of deconstruction process and to compare end-of-life alternatives.

Furthermore, BIM will empower DfD tools for improved document management and improved lifecycle management. Deconstruction plan could therefore be developed and embedded within a BIM federated model to support end-of-life deconstruction of the building. In addition, BIM will enable software interoperability between DfD tools and existing BIM platforms. This will enable DfD tools and BIM software to exchange data seamlessly without any loss of information. The study therefore reveals the need to explore how IFC could be extended to support data exchange between DfD tools and BIM software. This therefore necessitates the identification of information exchange requirements and format that capture DfD needs within existing BIM and IFC models.

In a summarised discussion, this study presents dual contributions: (i) the results of this study improves the understanding of BIM functionalities and how they could be employed to improve the effectiveness of existing DfD tools, and (ii) the BIM functionalities framework will support the implementation of BIM-based software prototypes for DfD management. These contributions have significant implications for DfD research and industrial practices. The BIM functionalities framework highlights the potentials of BIM in driving effective DfD process and providing a basis for the development of BIM-based DfD tools. BIM software and DfD tools developers would benefit from the results of this study by providing deeper understanding of what is required to enable a BIM-based DfD. The capabilities of BIM for visualisation and analysis could thus be leveraged to simulate deconstruction processes from the design stage.

Despite the contributions of this study, there are some limitations. First, the study was carried out using qualitative methods to explore depth rather than breadth obtainable with quantitative methods. As such, further studies could investigate the generalisation of the findings from this study using a quantitative approach such as questionnaire survey. This is necessary to understand whether the findings from the small sample FGIs could be generalised to a larger sample. Second, the participants of the FGIs were drawn from the UK only. The results should therefore be interpreted and used within this context. Other studies can explore transferability of findings from this study to other countries. In this way, the result of this study could provide a basis for comparative study with other countries.

Acknowledgement

The authors would like to express their sincere gratitude to Innovate UK (Grant application No. 54832 – 413479 and File No 102473) and EPSRC (Grant Ref: EP/N509012/1) for providing the financial support for this study.

References

Akbarnezhad, A., Ong, K.C.G., Chandra, L.R., 2014. Economic and environmental assessment of deconstruction strategies using building information modeling. Autom. Constr. 37, 131–144. http://dx.doi.org/10.1016/j.autcon.2013.10.017.

Akinade, O.O., Oyedele, L.O., Bilal, M., Ajayi, S.O., Owolabi, H.A., Alaka, H.A., Bello, S.A., 2015. Waste minimisation through deconstruction: a BIM based Deconstructability Assessment Score (BIM-DAS). Resour. Conserv. Recycl. 105, 167–176. http://dx.doi.org/10.1016/j.resconrec.2015.10.018.

Akinade, O.O., Oyedele, L.O., Munir, K., Bilal, M., Ajayi, S.O., Owolabi, H.A., Alaka, H.A., Bello, S.A., 2016. Evaluation criteria for construction waste management tools: towards a holistic BIM framework. Int. J. Sustain. Build. Technol. Urban Dev. 7, 3–21.

Arayici, Y., Coates, P., Koskela, L., Kagioglou, M., Usher, C., O'Reilly, K., 2011. BIM adoption and implementation for architectural practices. Struct. Surv. 29, 7–25.

Arayici, Y., Egbu, C., Coates, P., 2012. Building information modelling (Bim) implementation and remote construction projects: issues, challenges, and critiques. Electron. J. Inf. Technol. Constr., ISSN 1874-4753

Athena, 2015. Athena Sustainable Materials Institute Homepage [WWW Document]. URL http://www.athenasmi.org/ (accessed 10.28.15).

BEES, 2010. Building for Environmental and Economic Sustainability [WWW Document]. URL http://www.nist.gov/el/economics/BEESSoftware.cfm (accessed 4.25.16).

Bilal, M., Oyedele, L.O., Akinade, O.O., Ajayi, S.O., Alaka, H.A., Owolabi, H.A., Qadir, J., Pasha, M., Bello, S.A., 2016a. Big data architecture for construction waste analytics (CWA): A conceptual framework. J. Build. Eng. http://dx.doi.org/10.1016/j.jobe.2016.03.002.

Bilal, M., Oyedele, L.O., Qadir, J., Munir, K., Akinade, O.O., Ajayi, S.O., Alaka, H.A., Owolabi, H.A., 2016b. Analysis of critical features and evaluation of BIM software: towards a plug-in for construction waste minimization using big data. Int. J. Sustain. Build. Technol. Urban Dev., 1–18

BRE, 2008. SMARTWASTE [WWW Document]. URL http://www.smartwaste.co.uk/index.jsp (accessed 4.25.16).

Buildcarbonneutral, 2007. Construction Carbon Calculator [WWW Document]. URL http://buildcarbonneutral.org/ (accessed 4.24.16).

Cheng, J.C.P., Ma, L.Y.H., 2013. A BIM-based system for demolition and renovation waste estimation and planning. Waste Manage. 33, 1539–1551. http://dx.doi.org/10.1016/j.wasman.2013.01.001.

Chini, A.R., Acquaye, L., 2001. Grading and mechanical properties of salvaged lumber. In: Proceedings of the CIB Task Group 39-Deconstruction Meeting, pp. 138–162.

Creswell, J.W., 2013. Qualitative Inquiry and Research Design: Choosing Among Five Approaches, third ed. Sage Publications, London. http://dx.doi.org/10.1111/1467-9299.00177.

Creswell, J.W., 2014. Research Design: Qualitative, Quantitative, and Mixed Methods Approaches. Sage Publications, London.

Davison, B., Tingley, D.D., 2011. Design for deconstruction and material reuse. Proc. ICE - Energy 164, 195–204. http://dx.doi.org/10.1680/ener.2011.164.4.195.

Dorsthorst, B., Kowalczyk, T., 2002. Design for recycling. Design for deconstruction and materials reuse. In: Proceedings of the International Council for Research and Innovation in Building Construction (CIB) Task Group 39 – Deconstruction Meeting, Karlsruhe, pp. 70–80.

Eadie, R., Browne, M., Odeyinka, H., McKeown, C., McNiff, S., 2013. BIM implementation throughout the UK construction project lifecycle: An analysis. Autom. Constr. 36, 145–151. http://dx.doi.org/10.1016/j.autcon.2013.09.001.

Eastman, C., Teicholz, P., Sacks, R., Liston, K., 2011. BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors. John Wiley & Sons.

Egan, J., 1998. Rethinking Construction. Department of the Environment, Transport and the Regions, London.

ETools, 2013. eToolLCD [WWW Document]. URL http://etool-global.com/about-etoollcd/ (accessed 4.25.16).

Faniran, O., Caban, G., 1998. Minimizing waste on construction project sites. Eng. Constr. Ellipsis 5, 182–188.

Gabi, 2016. GaBi – Building Life Cycle Assessment software [WWW Document]. URL http://www.gabi-software.com/international/solutions/building-lca/ (accessed 4.24.16).

Grilo, A., Jardim-Goncalves, R., 2010. Value proposition on interoperability of BIM and collaborative working environments. Autom. Constr. 19, 522–530. http://dx.doi.org/10.1016/j.autcon.2009.11.003.

Guy, B., 2001. Building deconstruction assessment tool. Deconstr. Mater. Reuse Technol. Econ. Policy, 125–136.

Hamidi, B., Bulbul, T., 2012. A comparative analysis of sustainable approaches to building end-of-lifecycle: underlying deconstruction principles in theory and practice. In: ICSDEC 2012. American Society of Civil Engineers, pp. 155–162. http://dx.doi.org/10.1061/9780784412688.018.

Hancock, B., Ockleford, E., Windridge, K., 1998. An Introduction to Qualitative Research. Trent Focus Group, Nottingham.

Holloway, I., Wheeler, S., 1996. Qualitative Research for Nurses. Blackwell Science, Oxford.

IES, 2012. IMPACT Compliant Suite [WWW Document]. URL http://www.iesve.com/software/ve-for-engineers/module/IMPACT-Compliant-Suite/3273 (accessed 4.25.16).

IMPACT, 2015. Integrated Material Profile and Costing Tools [WWW Document]. URL http://www.impactwba.com/index.jsp (accessed 4.25.16).

Jaillon, L., Poon, C.S., 2014. Life cycle design and prefabrication in buildings: a review and case studies in Hong Kong. Autom. Constr. 39, 195–202. http://dx.doi.org/10.1016/j.autcon.2013.09.006.

Kibert, C.J., 2003. Deconstruction: the start of a sustainable materials strategy for the built environment. Ind. Environ. 26, 84–88.

Kibert, C.J., 2008. Sustainable Construction: Green Building Design and Delivery: Green Building Design and Delivery. John Wiley & Sons.

Lassandro, P., 2003. Deconstruction Case Study in Southern Italy: Economic and Environmental Assessment. CIB Publication.

Latham, M., 1994. Constructing the team: joint review of procurement and contractual arrangements in the United Kingdom construction industry: final report. Available from http://www.cewales.org.uk/cew/wp-content/uploads/Constructing-the-team-The-Latham-Report.pdf.

Manning, R., Messner, J., 2008. Case studies in BIM implementation for programming of healthcare facilities 13 (Special Issue – Case Studies of BIM Use). In: ITcon – IT in Construction. ITcon.

Moustakas, C., 1994. Phenomenological Research Methods. Sage Publications.

Osmani, M., Glass, J., Price, A.D.F., 2008. Architects' perspectives on construction waste reduction by design. Waste Manage. 28, 1147–1158.

Oyedele, L.O., 2013. Analysis of architects' demotivating factors in design firms. Int. J. Proj. Manage. 31, 342–354. http://dx.doi.org/10.1016/j.ijproman.2012.11.009.

Oyedele, L.O., Tham, K.W., 2007. Clients' assessment of architects' performance in building delivery process: Evidence from Nigeria. Build. Environ. 42, 2090–2099. http://dx.doi.org/10.1016/j.buildenv.2005.06.030.

Phillips, P.S., Tudor, T., Bird, H., Bates, M., 2011. A critical review of a key waste strategy initiative in England: Zero waste places projects 2008–2009. Resour., Conserv. Recy. 55 (3), 335–343.

Polkinghorne, D.E., 1989. Phenomenological research methods. In: Existential-Phenomenological Perspectives in Psychology. Springer, pp. 41–60.

Sacks, R., Eastman, C.M., Lee, G., 2004. Parametric 3D modeling in building construction with examples from precast concrete. Autom. Constr. 13, 291–312.

SimaPro, 2015. SimaPro 8: Sustainability Life Cycle Assessment Carbon Footprinting [WWW Document]. URL http://www.simapro.co.uk/index.html (accessed 4.24.16).

Steel, J., Drogemuller, R., Toth, B., 2012. Model interoperability in building information modelling. Softw. Syst. Model. 11, 99–109. http://dx.doi.org/10.1007/s10270-010-0178-4.

Thormark, C., 2001. Assessing the recycling potential in buildings. In: CIB Task Group 39: Deconstruction and Materials Reuse: Technology, Economic, and Policy, University of Florida, pp. 78–86.

Tingley, D.D., 2012. Design for Deconstruction: An Appraisal. The University of Sheffield.

Tolman, F.P., 1999. Product modeling standards for the building and construction industry: past, present and future. Autom. Constr. 8, 227–235.

Umberto, 2016. Umberto NXT LCA [WWW Document]. URL http://www.umberto.de/en/versions/umberto-nxt-lca/ (accessed 4.25.16).

Van Manen, M., 1990. Researching Lived Experience: Human Science for an Action Sensitive Pedagogy. Suny Press.

Wang, J., Li, Z., Tam, V.W.Y., 2014. Critical factors in effective construction waste minimization at the design stage: A Shenzhen case study. China. Resour. Conserv. Recycl. 82, 1–7. http://dx.doi.org/10.1016/j.resconrec.2013.11.003.

WRAP, 2011. Designing-out Waste Tool for Buildings. Available from http://dowtb.wrap.org.uk/.

Xu-dong, Z., Jie, T., 2006. BIM based on intelligent parametric modeling technology. J. Chongqing Univ. (Nat. Sci. Ed.) 6, 27.