Design for deconstruction using a circular economy approach: Barriers and strategies for improvement

Abstract

This study explores the current practices of Design for Deconstruction (DfD) as a strategy for achieving circular economy. Keeping in view the opportunities accruable from DfD, a review of the literature was carried out and six focus group interviews were conducted to identify key barriers to DfD practices. The results of phenomenology reveal 26 barriers under five key barrier categories. The barrier categories to DfD are "lack of stringent legislation and policies", "lack of adequate information at the design stage", "lack of large enough market for recovered components", "difficulty in developing a business case for DfD", and "lack of effective DfD tools". After this, the study identifies the strategies for overcoming these barriers. The paper, therefore, addresses the need for actions within the construction industry to bring DfD to the fore towards achieving the current global sustainability agenda.

***Keywords**: [Building deconstruction, sustainability, circular economy model; construction and demolition waste; barriers and strategies]*

1 Introduction

The literature reveals that the UK construction industry consumes vast amount of natural resources and it contributes the largest proportion of waste to landfills (DEFRA, 2012; Merino et al., 2015; Yılmaz and Bakış, 2015). According to Sharman (2017), the industry delivers over 400 million tonnes of materials to site out of which 15% of the materials arise as waste. This figure raises serious concerns among stakeholders about the environmental sustainability of the construction industry (Coelho and de Brito, 2012; Ortiz et al., 2009), particularly due to increased likelihood of greenhouse effect and CO_2 emission. It is important to address these concerns because material depletion is inevitable if the current rate of natural resources extraction and waste generation continues. Thurer et al. (2017) highlights that waste is any system is an input that does not translate into valuable output to the customer. As such, material arisings from demolition sites that are not transformed to valuable usage could be regarded as waste. An opportunity for dealing with waste concerns exists if building materials are eventually reused or recycled after the end-of-life of buildings. This opportunity, therefore, calls for a change in the construction industry towards the consideration of the end-of-life salvage of building right from the design stage.

Two disposal options that are possible after the end-of-life of a building are demolition and deconstruction. Demolition, which is the traditional method, is a rapid means of building removal that is aimed at disposal. On the other hand, deconstruction helps to recover building materials primarily for reuse, recycling, and remanufacturing. Evidence shows that demolition activities account for over 50% of the total Construction and Demolition Waste (CDW) (Kibert, 2003). Using a baseline CDW generation of 55 million tonnes in 2014, diverting 10%, 20% or 30% of this figure through effective deconstruction could lead to a cost saving of about £433 million, £866 million and £1.3 billion on landfill tax and haulage respectively. Despite efforts to mitigate CDW and the evidence that deconstruction could drive waste reduction initiatives (Ajayi et al., 2016; Akinade et al., 2017a, 2015; Phillips et al., 2011), there has not been a progressive increase in the level of Design for Deconstruction (DfD) in the industry. Although the principles of DfD have been in practice for decades, existing studies show that DfD is still far from reaching its CDW minimisation potentials (Crowther, 2005; Densley Tingley and Davison, 2012a; Guy, 2001; Kibert, 2003). According to Dorsthorst & Kowalczyk (2002), less than 1% of existing buildings are fully demountable.

This study, therefore, explores the current DfD practices to identify barriers to DfD and to determine the strategies for improving the adoption of DfD in the construction industry. Achieving this will assist the entire industry to overcome factors hampering the full adoption of DfD and to reposition DfD as a strategy for circular economy. The following specific objectives are fulfilled to achieve the overall goal of the study:

a) To appraise existing DfD practices within the UK construction industry.
b) To identify barriers to the adoption of DfD within the construction industry as experienced by practitioners.
c) To identify strategies that could improve the adoption of DfD as a circular economy practice.

This study employs a phenomenological research methodology using Focus Group Interviews (FGIs). This approach allows the investigator to have detailed knowledge of a phenomenon as experienced by the FGI participants. Using this approach enables an in-depth understanding of why DfD practice is not common in the industry and it will help to identify key enablers for DfD. Enablers of DfD are strategies that facilitates DfD practices in the construction industry. The results of the analyses reveal five key barriers to the adoption of DfD and their corresponding strategies for improvement. The key strategies for improvement are imperative to ensure that DfD is established as a means of minimising the end-of-life impacts of buildings on the environment. Accordingly, the full adoption of DfD will also help the construction industry to ensure that long-term sustainability of existing buildings is guaranteed.

The remainder of the paper is structured as follows: Following the introductory section is a literature review that provides a motivation for the concept of building deconstruction and barriers to DfD. Section 3 contains the research methodology, which outlines the research procedure and methods and Section 4 details the data analyses procedure and the results. Section 5 contains the discussion of the identified barriers to the use of DfD in the construction industry and key enablers of DfD to eliminate the barriers. The study ends with a conclusion section that contains the key contributions of the study and areas of further research.

2 Literature review: concept of deconstruction

Deconstruction is a building end-of-life scenario that allows the recovery of building components for building relocation, component reuse, recycling or remanufacture (Kibert, 2008). Although the recovered material may be utilised for reuse, recycling or remanufacturing, the focus of deconstruction is material reuse. One could argue that 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 (Akinade et al., 2015). This is because building relocation and components reuse require minimal energy compared to recycling and remanufacturing. Figure 1 shows how deconstruction enables a closed material loop and circular economy conditions at the end of life of buildings. Reuse is a process where salvaged building components are used “as-is” without any repair or upgrade (Nordby et al., 2009). Reuse is the most preferred end-of-life scenario because it requires no energy input compared to remanufacturing and reuse. Examples of building materials that could be reclaimed “as-is” and reused include brick, blocks, tiles and building components (doors, windows, radiators, etc.). Remanufacturing is the process of restoring salvaged materials to “like-new” condition. Remanufacturing sometimes require repair and replacement of damaged bit of the salvaged items to make them fit for usage. The process of remanufacturing usually requires intensive manual labour to isolate damages, repair and restore the item. Recycling is the process of converting salvaged materials into raw materials into the manufacturing of other building materials. Even so, recycling also includes the conversion of salvaged materials into aggregates and additives. Georgakellos (2006) argues that the process of transforming salvaged materials into raw materials could be criticised because its environmental impact could exceed the environmental benefits. However, a recycling process that requires less energy for processing and production will be more plausible to justify the adoption of recycling (Blengini, 2009). Example of recycling would be the use of rubbles as construction aggregate that is used as infilling materials and recycling reinforcement steel bars.

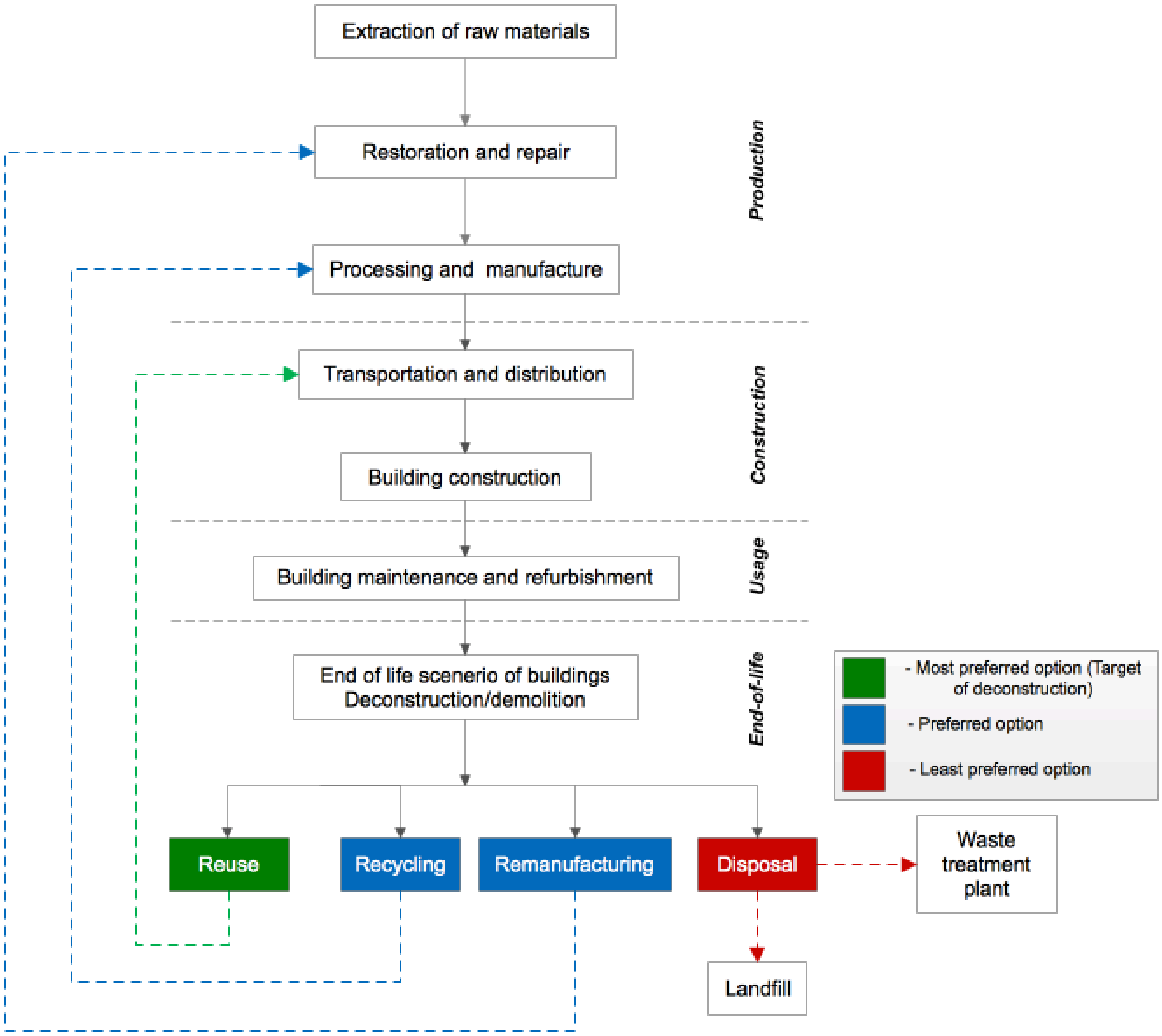

Figure 1: End-of-life scenario in a closed material loop condition

The ultimate focus of reuse is to ensure that a circular economy condition is maintained such that request for new resources and the generation of CDW is minimised. The closed material loop therefore eliminates the linear pattern of material movement in demolition to a circular economy model, which is more sustainable. The target of a closed material loop model is to avoid material disposal to landfills and to encourage reusing, recycling, and remanufacturing of building components at the end-of-life of the building. The resultant benefit of the “closed material loop” philosophy has resulted in the wide acceptance of the “Circular Economy” model in the production, manufacturing, and construction to address the limitations of linear models (Akanbi et al., 2018; De Angelis et al., 2018; Kumar et al., 2018; Lieder and Rashid, 2016; Prieto-Sandoval et al., 2018). The circular economy model is synonymous to the reverse logistic network which captured two directions of material lows: Beginning-of-life to End-of-life and End-of-life to Beginning-of-Life (Daaboul et al., 2016).

The aim of building deconstruction is to ensure efficient material flow from the end-of-life to the beginning-of-life. As such, building deconstruction eliminates demolition as an end-of-life building disposal option. The first activity that is usually carried out during deconstruction is a preventive site assessment of the building. The preventive site assessment includes checking for traces of hazardous materials (asbestos, refrigerants, lead-based paints, mercury in components, etc.) (Frost et al., 2008). Building assessment for salvageable materials with respect to type, material quality, and quantity, and storage opportunities is also carried out. Efforts are usually made at this stage to identify the local market for salvaged “as-is” materials. Thereafter, the needed scaffolding is put in place to provide appropriate level support for the weight of the site workers. The process of deconstruction then follows the theory of building layers, which structures building element with respect with their life expectancy (Brand, 1994; Habraken and Teicher, 2000). The theory of building layers contains six layers: (i) Layer 0: Site – The geographical settings of the building; (ii) Layer 1: Structure – load bearing elements (structural elements and foundation); (iii) Layer 2: Skin – external walls, claddings and roofs; (iv) Layer 3: Plumbing, electrical, mechanical and hydraulic services; (v) Layer 4: Space plan – internal walls, partitioning, finishes; (vi) Layer 5: Stuffs – movable items. The process of building deconstruction thus follows a top-down approach from Layer 5 down to Layer 1.

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 that is characteristics of demolition. This helps to divert

CDW from landfills (Akbarnezhad et al., 2014), reduce harmful emission (Chini and Acquaye, 2001), preserve embodied energy (Thormark, 2001), reduce site disturbance (Lassandro, 2003), etc. The UK construction industry is far shifting from the practice of total demolition and landfilling. It is worth noting that the Institute of Demolition Engineers (IDE) and National Federation of Demolition Contractors (NFDC) have made notable advancement on the recycling of buildings and the reuse of building components at the end-of-life. In addition, the production of Demolition and Refurbishment Information Datasheets (DRIDS) (NFDC, 2016) has improved the possibility of material reuse, recycling, reclamation and waste diversion from landfills. DRIDS provides a publicly accessible database that helps to identify building elements that could be reclaimed for reuse and recycling, and those that must be sent to landfills. However, the impact of design practices on the viability of end-of-life recovery of building element represents a huge gap in knowledge. Existing works on DfD (Akinade et al., 2017b, 2017a; Crowther, 2005; Tingley, 2012; Volk et al., 2014) only identified critical success factors and developed conceptual frameworks for DfD. The studies also emphasise that efficient building recovery at the end-of-life can only be made possible when the need for deconstruction has been considered from the design stage. Although bodies in the UK such as the Waste and Resource Action Programme (WRAP), Building Research Establishment (BRE), and Institute of Civil Engineers (ICE) have illustrated the benefits of DfD, the wide adoption of DfD is still not a common practice. A widely referenced example of DfD is the temporary accommodation for 17,000 athletes at eth London 2012 Olympics. The design has a CfSH (Code for Sustainable Homes) Level 4 and the accommodation was converted into new homes after the games.

Kibert (2008) suggests that effective strategy for closed-loop building material usage and material recovery requires basic assumptions, which are: (a) building must be fully deconstructable; (b) building must be disassemblable; (c) construction materials must be reusable; (d) the production 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 assumptions is that construction materials must be recoverable and reusable/recyclable to reduce waste generation at the end of the useful life of a facility. These assumptions aligns with the reports by Egan (1998) and Latham (1994), which highlight the need to improve the design and construction processes increase efficiency and reduce waste. Accordingly, Egan (1998) identified tight supply chains engagement and standardisation as potential drivers for the required sustainable construction processes.

3 Research methodology

A phenomenological research was adopted to achieve the aim of this study. This strategy involves a qualitative research using FGIs. Differences between Phenomenology, Grounded theory and Discourse Analysis. Starks (2007) notes that although the boundary between phenomenology and other qualitative research approach such as grounded theory is porous, they originate from diverse intellectual traditions. However, there are noticeable similarities at the analytical phase where they share data analyses methodologies. A phenomenological research methodology seeks to exhume common meaning from the lived experiences of several individuals (Creswell, 2014). Adopting phenomenology enables a close observation of experiences of stakeholders about a phenomenon. Glaser et al. (1968) highlight that grounded theory focuses on the development of an exploratory theory of the interaction among social processes that are studied in their natural environment. As such, grounded theory seeks to understand pattern and relationships among the six Cs of social processes, i.e., causes, contexts, contingencies, consequences, covariance, and conditions (Strauss and Corbin, 1998).

Wimpenny and Gass (2000) argue that data collection in phenomenology and grounded theory differs and depends on the focus of the study. Phenomenology emphasises co-creation of knowledge between the researcher and the researched rather than seeing the participants as data repositories. As such, phenomenology exceeds the preconceived understanding of the researcher whose perspective may differ from the participants. However, grounded theory focuses on theory development about a phenomenon and making observation as a third person. In addition, sources of knowledge in phenomenology is largely dependent on the interaction with those that have experienced phenomenon directly through interviews and focus groups (Wimpenny and Gass, 2000). Sources of knowledge in grounded theory on the other hand exceeds interviews and focus groups, but it could include field works, observation (direct or participatory), and artefacts (e.g. archival records and other documents).

Phenomenological research is thus a more useful tool for addressing poorly conceptualised phenomena through active engagement with the stakeholders (Holloway and Wheeler, 1996) without interfering with the understanding of the phenomenon. Van Manen (1990) highlights that being interested in the story of others is the basic underlying assumption of phenomenological study. The investigators, therefore, set aside previous experience to have a fresh perspective about the phenomenon being studied. In this regard, this study seeks to explore the experiences of the participants on the impediments to the adoption of DfD as a circular economy strategy. The methodological process for this study is shown in Figure 2.

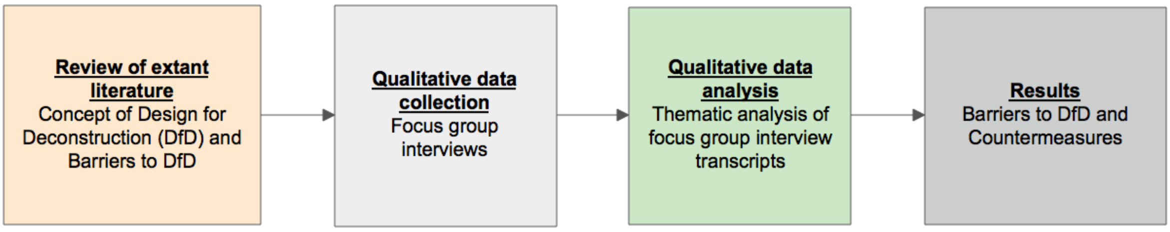

Figure 2: Methodology process of the study

The methodology process for the study is done in four stages. The study starts with a review of extant literature on design for buildings' end of life activities, DfD, and existing barriers to DfD. Thereafter, FGIs were carried out with major stakeholders in the construction industry to confirm factors identified from the literature and to uncover more factors on the barriers to DfD and strategies for improvement. Underpinned by a purposive sampling approach, the participants of the FGIs were selected based on their roles and year of experience. Using the research team’s network of practitioners within the UK construction industry, twenty-eight (28) industry professionals were selected for the FGIs. It was ensured that all the participants of the FGIs have a minimum of 8 years of experience. The description and description of the FGI participants are presented in Table 1 and sample questions from the FGI schedule are shown in Table 2. The FGI transcripts were then subjected to thematic analysis to isolate recurring patterns within the FGI transcripts. The results of the thematic analysis are then discussed vis-à-vis existing literature.

Table 1: Distribution of FGI participants

No.	**Code**	**Job title**	**No of participants**	**Average Year of experience**
1	FGI 1	Architects and design managers	6	15
3	FGI 2	Design structural and MEP engineers	6	14
4	FGI 3	Demolition operatives	5	16
5	FGI 4	BIM managers and specialists	5	10
6	FGI 5	Project managers	6	18

Table 2: Sample Questions from the focus group interview Schedule

No.	**Sample questions from focus group interviews**
1	Do you think deconstruction should be considered at the design or construction stage?
2	What do you think are the benefits of design for deconstruction?
3	Why are designers (architects and engineers) not so interested in design for deconstruction?
4	What are the main measures to encourage design for deconstruction in the industry?
5	What are some of the challenges faced by designing for deconstruction?
6	How can the challenges facing design for deconstruction be addressed?

According to Gray (2009), FGIs allow participants to discuss their personal opinions based on their experiences. This data collection method provides deeper insights into a broad range of perspectives within a short time. The participants were asked to discuss what could hinder the adoption of building deconstruction and factors that can encourage the acceptance of DfD as an approach to sustainable development. Discussion and interactions during the FGIs were recorded on a digital recorder and later transcribed for thematic analysis.

4 Data Analyses and Results

Data analyses in a structured qualitative approach as suggested by Moustakas (1994). The methods include (a) describe personal experience with phenomenon, (b) develop a list of significant statements from interview transcripts, (c) develop coding scheme for thematic analysis, (d) carry out a textual description of participants' experiences with verbatim quotations, (e) carry out a structural description of the setting and context in which phenomenon was experienced, and (f) carry out a composite description that contains the textual and structural descriptions. As such, thematic analysis, was carried out after the development of the appropriate coding scheme by using the description of textual and structural discussions of participants' experiences.

The coding scheme helps to identify units of meaning from significant statements and to classify them into recurring themes. The coding scheme employs keywords and theme category tags. Keyword tag depicts a summary of the main issue raised within a segment. The keyword tag helps to identify prevalent issues and concerns across the transcript. The keywords are underlined within the quotation segments. The theme category tag shows the principal theme under which the issue discussed in the transcript segment falls. The results reveal five key barrier categories to DfD. Table 3 shows a summary of the identified 26 barriers to DfD.

Table 3: Main barriers to DfD and barrier groupings

No.	**Barriers**	**Reference**
A.	**Lack of stringent legislation for DfD**	
1	Lack of Government legislation for deconstructed facilities.	(Addis and Schouten, 2004; Guy and Ciarimboli, 2008)
2	Design codes generally favour specifying new materials	(Storey and Pedersen, 2014)
3	*Low Building Research Establishment Environmental Assessment Method (BREEAM) point for DfD	
B.	**Lack of adequate information in building design**	
4	*Lack of information about recoverable materials	
5	Lack of disassembly information	(Akinade et al., 2015; Storey and Pedersen, 2014; Tingley et al., 2017)
6	Inadequate information about cost-effective material separation methods	(Storey and Pedersen, 2014)
C.	**Lack of large enough market for recovered components**	
7	No standardisation and grading system for salvaged materials	(Kibert et al., 2000; Storey and Pedersen, 2014)
8	Perceived perception and risks associated with second-hand materials	(Hurley and Hobbs, 2004)
9	Low performance guarantees for recovered materials	(Kibert et al., 2000; Rios et al., 2015; Tingley et al., 2017)
10	Degraded aesthetics of salvaged materials	(Dunant et al., 2017; Rios et al., 2015)
11	Damaged or Contamination of materials during recovery	(Densley Tingley and Davison, 2012b; Rios et al., 2015)
12	Storage consideration for recovered materials	(Guy and Ciarimboli, 2008; Tingley et al., 2017)
13	Transportation considerations for recovered materials	(Rios et al., 2015; Storey and Pedersen, 2014; Tingley et al., 2017)
14	No information exchange system for salvaged materials	(Saghafi and Teshnizi, 2011)
15	Cost of product re-certification	(Couto and Couto, 2010; Tingley et al., 2017)
D.	**Difficulty in developing a business case for DfD**	
16	Additional cost of design that make the project more expensive	(Chini, 2005; Couto and Couto, 2010; Rios et al., 2015; Srour et al., 2012)
17	Insurance constraints and legal warranties of reclaimed materials	(Hurley and Hobbs, 2004; Tingley et al., 2017)
18	DfD will increase the design time	(Guy and Ciarimboli, 2008; Kibert et al., 2000)
19	Changing industry standards and construction methodology	(Akinade et al., 2015)
20	Believe that DfD could compromise building aesthetics and safety	(Rios et al., 2015; Storey and Pedersen, 2014)
21	Overall benefit of DfD may not happen after a long time	(Akinade et al., 2015; Storey and Pedersen, 2014)
E.	**Lack of effective DfD tools**	
22	Lack of DfD analysis methodologies	(Akinade et al., 2015; Densley Tingley and Davison, 2012b; Storey and Pedersen, 2014)
23	Existing DfD tools are not BIM compliant	(Akinade et al., 2015; Storey and Pedersen, 2014)
24	*No tools for identifying and classifying salvaged materials at the end-of-life	

25	*Performance analysis tools for end-of-life scenarios are lacking
26	*Limited visualisation capability for DfD

*Additional barriers identified from the focus groups

5 Barriers to effective design for deconstruction

The findings of the study reveal that despite the opportunities accruable from building deconstruction, there are impediments to the full exploitation of its potentials. This section discusses the five key barriers and their corresponding strategies for improvement as revealed from the data analyses.

5.1 Lack of stringent legislation for design for deconstruction

A common thread across the FGIs is that the major challenge confronting the adoption of DfD in the construction industry is the lack of stringent legislation and policies on DfD. It was highlighted that architects and design engineers have no moral or legislative obligation to ensure that the design is absolutely deconstructable at the end-of-life. In the same way, the participants of the FGIs agreed that although C&D waste is highly regulated in the UK and the benefits of building deconstruction is well known, there are no stringent legislation and policies that place obligation on clients and contractors to build deconstructable facilities. This assertion suggest that government legislative and fiscal policies are imperative towards achieving effectual DfD. This assertion aligns with existing studies (Ajayi et al., 2015; Lu and Yuan, 2010; Oyedele et al., 2013) that suggest that the government has a major role to play in the current national and global sustainability agenda.

Although DfD legislation does not exist anywhere, the FGI participants stressed that imbibing building deconstruction in the industry will be difficult unless it is driven by appropriate legislation. A demolition engineer from FGI-3 noted that: by the participants that: "*Except the government drives the idea [design for deconstruction], I believe it is not going to be widely adopted in the industry" [FGI 3].* The excerpts point out that it is not enough that the benefits of sustainable end-of-life strategies such as deconstruction is well known, targets of the stringency of building deconstruction legislation should include appropriate policies to ensure wide acceptance and compliance among practitioners. Achieving appropriate government legislation and DfD targets will also encourage clients and contractors to incorporate DfD within their core values that will be enforced by appropriate contractual agreements. A project manager from FGI-5 argues that: *"Why will I waste my time to design for deconstruction if it is not part of the contract" [FGI 5].* This excerpt shows that the requirements and terms for building deconstruction and material reuse must be clearly specified in the project contracts.

The stringency of such legislations and policies has been a proven way to ensure full compliance with government targets among the practitioners of the construction industry. An example is the UK government effort in diverting waste from landfills by imposing a landfill tax of £88.95/tonne for standard rated waste and £2.80/tonne for inert/inactive waste from 1 April 2018. In fact, there is a progressive increase in the landfill tax such that by 1 April 2020, £94.15/tonne will be charged as standard rate. In addition, the UK government made the provision of Code for Sustainable Homes (CfSH) compulsory for all residential building construction and the Building Research Establishment Environmental Assessment Method (BREEAM) is becoming a popular requirement for new and refurbishment projects. Without a doubt, achieving this level of compulsion will favour the development of standardised "best practice" and guidelines for DfD. A strategy in this direction would be attributing more points to DfD in the BREEAM environmental assessment method.

5.2 Lack of adequate information in building design

A major challenge identified in FGI-3 is that building designs of existing buildings (which are usually 2D drawings on papers due to the old age of the buildings) lack enough information on how they could be deconstructed. Evidence from the literature also suggests that deconstruction activities are impeded by lack of adequate information because building designs do not provide adequate information on how the buildings could be deconstructed (Aidonis et al. 2008; Akinade *et al.*, 2015). The fact is that most of the existing buildings were not built to be deconstructed and understanding the process of deconstructing them could be really difficult. A major concern to architects and design managers in FGI-1 is that understanding end-of-life performances of materials and accessing information about end-of-life recovery right from the design stage is challenging. Even so, Blengini and Carlo (2010) point out that building end-of-life information is still scanty at the design stage.

The way building information are used for various purposes across the lifecycle is transforming the construction industry and making access to more information possible at the early lifecycle stages. Besides, the need for more information for design, construction, building operation and maintenance has become vital due to the increasing sophistication of buildings (Jordani, 2010). Building information is now important for tracking building construction processes and performance, isolating inefficiencies in building operations, and responding to specific needs of clients (Bilal et al., 2016a). In line with the foregoing, a Demolition manager from FGI-3 argues that deconstruction could also benefit proactive information management by providing adequate information about the building's end-of-life options at the early design stage. As such, early involvement of demolition would be beneficial as follows: (1) to provide advice on specifying appropriate materials with high end-of-life value, (2) to suggest building methodologies that could improve building deconstruction, and (3) to provide information about the end-of-life performances of building materials.

It was emphasised during the FGIs that the current end-of-life disposal procedure is cumbersome because after a report of hazardous materials and historical features are obtained, the demolition contractor applies for demolition permit and proceeds with other activities such as waste management planning and meeting BREEAM requirements. A major challenge at this point is that it is difficult to know which of the components are reusable or recyclable. It was pointed out that "*The demolition of buildings is a complex process, which requires careful audit, execution, and review. Apart from obtaining the required permissions, a major challenge is understanding the nature and content of the building…*" [FGI 3]. The foregoing reveals that the inability to know the end-of-life performance and management routes of materials is impeding the diffusion of DfD as a sustainable process. It was argued that: "*… The process [deconstruction] could be easier if accurate building design could reveal the type of building component contained in the building. … achieving this would help contractors to know which of the components could be deconstructed for resuse …*" [FGI 3]. The except reveals that the process of identifying reusable components and hazardous materials could be easier if the materials are well documented in the building design, BIM models, and manuals. As such, effective building deconstruction could be achieved if considerable effort is put in DfD with future benefits in mind (Ajayi et al., 2015). It is also worth noting that the involvement of demolition and deconstruction contractors at the early design stages of buildings will also help to stimulate the consciousness for DfD across the industry rapidly.

5.3 Lack of large enough market for recovered components

Another impeding factor identified from the study is that the existing market for salvaged products (recycled and reusable) is not large enough. This finding confirms existing research works that existing market for salvaged products is marginal (Addis, 2008; Gorgolewski, 2008; Guy et al., 2006; Tatiya et al., 2017; Tingley and Davison, 2011). Evidence suggests that the success of building deconstruction and the reuse of components depend on the supply/demand dynamics of salvaged materials (Godichaud et al., 2012). The supply and demand dynamics include the source control, availability of distribution point for material sales, quality assurance, product standardisation and specification, product certification, ease of material transportation, availability of storage facilities, access to market, etc. This means that the provisioning of a sustainable route to market for salvaged material is important. In the same way, the opening of the market will require that salvaged components are also specified during design. However, enough attention is not given to the specification of salvaged components at the design because of the current negative perception about recovered materials. The participants in FGI-2 argued that: "*Do you think that people will design buildings that could be deconstructed when industry practitioners have huge concerns about the specifying recovered materials? [FGI 2]*". Another barrier to the adoption of DfD is the concerns about the aesthetic degradation of recovered products. It was highlighted that clients place emphasis on the forms and aesthetics of building and specifying recovered materials could compromise both.

Another major market challenge is that a lot of effort is required to re-certify salvaged products. This is because there are certain issues that bother on materials reuse and recyclability. In particular, there are concerns about the residual performance and legal warranties of recovered building elements after several years of usage (Kibert, 2003). In addition, it might be difficult to find a good fit for purpose among the salvaged materials. For example, evidence shows that recovered elements such as wood cannot be regraded and can only be used for low market applications and non-structural use (Falk, 2002). This therefore prevents materials such as wood to be reused in "as-is" condition. In the same way, it is difficult to find fit for purpose reuse for elements such as concrete. It was highlighted that: "*Everyone knows that material reuse is the best strategy for reducing waste to landfills but it is difficult to find fit for purpose reusable products… This is a major challenge*" [FGI 2].

As identified from the FGIs, a way of overcoming the market challenge is the development of an information exchange service for recovered products. The service will serve as a one-stop market place for deconstruction operators, contractors, clients and house owners to list and buy recovered products. However, a grading system for recovered materials must be developed to facilitate the standardisation of products according to their performance and the effective running of the market place. For example, a grading system such that Grade A represents the highest quality of material and Grade E represents the lowest quality could be adopted. It was also a common thread across the FGIs that the need for material storage and transportation is also contributing to why building deconstruction is not commonly considered. Storage and transportation considerations are at a cost, which will eventually increase the total project costs.

5.4 Difficulty in developing a Business case for DfD

The participants of FGIs highlight that a major barrier to the adoption of DfD in the industry is how to provide adequate economic justification for it. This is so because the eventual recovery or full deconstruction of buildings is preferable but it might not be the most economical (Hamidi and Bulbul, 2012).The participants of the FGIs maintained that the perception is due to the lack of quantitative case studies to show the economic benefits of DfD. It was also argued that selecting materials and components that facilitate deconstruction may increase the total project design time and cost. Considering the time and cost concerns, Billatos and Basaly (1997) advised that it must be ensured that the cost of DfD does not exceed the cost savings from reuse of recoverable materials and diversion of materials from landfills. While the FGI participants all agreed that design has huge influence on building deconstruction, the participants of FGI-1 stressed that their primary responsibility is to deliver the best value that matches the clients' requirements. One of the participants mentioned that: "*I understand what you are saying; however, we did not consider that [design for deconstruction] on this project. We are more concerned about providing the best value for our client over the lifespan of the facility*". It could also be inferred from FGI-1 that architects believe that they have the moral and professional responsibility to ensure the buildability of their designs and not for DfD. An architect from FGI-1 opined that: "*why will I concentrate on design for deconstruction when there is the moral and professional responsibility of designing for construction*".

It is also acknowledged across the FGIs that DfD is time consuming and labour intensive. This concern therefore inhibits the consideration of deconstruction as an alternative building removal option at the design stage (Chini and Bruening, 2003). The participant also mentioned that a barrier to developing a business case for DfD is that the end-of-life of buildings may not occur for a long period and that the value of the building and its components is not guaranteed after its end of life. The participants argued that current building methodology and material choice might 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 (Akinade et al., 2015; Oyedele et al., 2013).

5.5 Lack of effective design for deconstruction tools

Evidence shows that design decisions have high impact on the entire building lifecycle and that design based philosophy offers flexible and cost-effective approach to building lifecycle management (Faniran and Caban, 1998; Osmani et al., 2008). Based on the foregoing, designers (architects and design engineers) are familiar with how design could influence building performance throughout its life time and at the end of life. However, the participants mentioned that another impediment to the adoption of DfD is that existing tools are not robust enough to support the architects and design engineers to design for building deconstruction. It was stressed by the participants that a major limitation of existing end-of-life waste analytics and DfD tools is that they are not BIM compliant. This submission aligns with evidence from the literature that lack of BIM compliance is a major barrier to DfD (Akinade et al., 2017b, 2016; Bilal et al., 2015). The participants of the FGIs stressed that: "*… sure, designing building for material reuse will reduce waste to landfills … but existing software that we use for design cannot support it [design for deconstruction]*" [FGI 1]. It was also stressed by a participant from FGI-4 that: "*I am aware that BIM is useful for collaboration, building visualisation and simulation …, I don't think that BIM software has a plugin to support design for deconstruction*"

The excerpts suggest that BIM implementation for end-of-life scenario is not common place despite the steep rise in BIM implementation. According to Akinade *et al.*, (2017b), adopting BIM for DfD will provide seven key functionalities, which 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. As such, BIM adoption will enable DfD to move towards a fully collaborative digital workflow. It was also stressed that another barrier to the diffusion of DfD practices is the lack of digital methodologies to identify reusable elements at the end-of-life. It was agreed that the adoption of emerging technologies such as sensors (Ali Ilgin et al., 2014) could positively improve the identification and classification of building products at the end-of-life of buildings.

6 Implications of the study

The impacts of design on how buildings are constructed and the evidence that deconstructable buildings could help to divert waste from landfills necessitates an understanding of how design decisions affect how buildings are assembled and disassembled. The understanding of the impact of design decision on building deconstruction reveals that a full consideration must be given to the make-up of the building, stages of deconstruction and how design decisions enhance building retrofitting and disassembly (Guy et al., 2006; Warszawski (1999). Accordingly, Akinade et al. (2015) highlighted that tackling this challenge requires the knowledge of the intertwined relationships among design practice, DfD techniques and DfD factors. DfD strategies include design-related factors, material-related factors and human-related factors (Akinade et al., 2017a). DfD design principles include building design methodology, dimensional coordination, and design documentation, (Akinade et al., 2015; Crowther, 2005). Evidence suggest that key considerations for effective deconstruction during building and structural design include design for material recovery, design for material reuse, and design for building flexibility (Akinade et al., 2017). The foregoing, therefore, calls for a holistic approach to how the interplay among these key areas and individual design elements could ensure successful building deconstruction.

While research efforts have been made towards achieving building deconstruction, certain barriers are affecting the diffusion of DfD within the construction industry. A key barrier is that the end-of-life of buildings may not occur for a long time (Anggadjaja, 2014; Guy et al., 2006). This means that the value of the building and its components after a long time is not guaranteed. Even so, building material choice would have changed due to changing regulations and performance requirements. Other barriers identified from this study are (a) lack of stringent legislations and policies, (b) lack of adequate information at the design stage, (c) lack of large enough market for recovered components, (d) difficulty in developing a business case for DfD, and (e) lack of effective DfD tools. Addressing these barriers is imperative to stakeholders and policy makers to understand how to reposition DfD within the building sustainability ecosystem.

Apart from creating an awareness on the roles of DfD in the current sustainability agenda, the findings of this study have other implications for construction stakeholders and policy makers. The findings of the study reveal that there is a need for legislation stringency with regards to DfD to ensure compliance with government targets. Evidence shows that government legislation is a proven way to ensure full compliance of policies and targets. The government, therefore, needs to achieve a level of compulsion for DfD just like the case of CfSH and BREAAM to favour the development of standardised DfD “best practice” and guidelines. Another implication that this study offers to project is the early involvement of demolition managers and specialists at the early design stage to influence the end-of-life alternatives. Ensuring that demolition specialists are involved at an early stage of design would be beneficial to help in specifying materials with high end-of-life value and to provide information about the end-of-life performances of materials. The demolition specialists will also help to suggest building methodologies that could improve building deconstruction at the end of life of buildings. Another implication that this study offers to key stakeholders (particularly the government and professional bodies) is the creation of large enough market and information exchange service for recovered products. In the same way, a robust grading system is required to facilitate the standardisation of recovered products according to their performance.

7 Conclusions

This study examines impediments to DfD from the perspective of industry experts. The focus of the study is to examine and articulate why DfD has not been widely adopted within the construction industry and to understand strategies for improvement. As such, FGIs were conducted with industry professionals to elicit their views. The qualitative analyses of the transcripts of the FGIs reveal 26 barriers to DfD under five categories, which are: (a) lack of stringent legislations and policies, (b) lack of adequate information at the design stage, (c) lack of large enough market for recovered components, (d) difficulty in developing a business case for DfD, and (e) lack of effective DfD tools. Overcoming these impediments is important to stakeholders and policy makers to know the practices that they must imbibe to reposition DfD within the building sustainability ecosystem.

The contribution of this study is therefore three-fold: (i) the study creates awareness on the roles building deconstruction in the current sustainability agenda; (ii) it broadens the understanding of key impediments to the adoption of DfD in the construction industry, and (iii) it aids the understanding of key drivers for the adoption of DfD as a circular economy strategy. At this stage of understanding the linkage DfD and sustainability, an urgent action is the development of best practices for achieving cradle-to-cradle design and construction through DfD and it must be driven by appropriate legislations to ensure compliance Just like CfSH and BREAAM. Stringent legislation and policy will also stimulate the development of standardised DfD practices and guidelines. The study also reveals that early involvement of demolition managers and specialists is required to ensure that appropriate end-of-life alternatives are adopted and that high-performance materials with respect with end-of-life are specified. The study also suggests the widening of the market for recovered products, development of a national grading system and the establishment of an information exchange service for recovered products to ease the diffusion of deconstruction design and end-of-life practices.

A major limitation of this study is that qualitative research methods were used. Considering that it has been argued that results of FGIs could be influenced by participants' subjective opinion (Lee 1991) and that it may be difficult to generalise findings to a wider population (Creswell 2014) due to the limit on the number of participants in FGIs, there is the need for empirical studies to determine the relative merits of each factor across a larger population sample. Thus, through continued iteration between empirical investigation and descriptive approaches, researchers will gain an understanding of the complex forces that influence the success of DfD and the eventual building deconstruction. It is therefore important that further studies are required to explore the linkages among the barriers to DfD. The use of Interpretative Structural Modelling (ISM) is recommended to take this research forward. The use of ISM in Production, Manufacturing and Construction studies is rife in the literature and it allows an order or direction to be imposed on a set of factors.

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