Drivers for Design for Deconstruction (DfD) Implementation Among Design Professionals

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ABSTRACT

Purpose- The Design for Deconstruction (DfD) technique, a contemporaneous solution to demolition by optimizing disassembly activities to enable reuse, has recently emerged with several promises to promote the circular economy. However, little attention has been given to its implementation among design professionals, especially in the Global South. Therefore, this study explores the drivers for DfD implementation among design professionals in the Ghanaian construction industry (GCI).

Design/methodology/approach- The study adopted a mixed research approach (explanatory sequential design) with an initial quantitative instrument phase, followed by a qualitative data collection phase. Data were analyzed using mean, standard deviation, One-Sample t-Test, and Normalization Value (NV) test after a review of pertinent literature. These data were then validated through semi-structured interviews with ten design professionals with in-depth knowledge of DfD.

Findings- The findings revealed that although all eleven drivers are important, the eight key drivers for the DfD implementation were identified as, in order of importance, "Availability of computer software applications regarding DfD", "Inclusion of DfD in the formal education of design professionals", "Increasing public awareness of the concept of DfD", "Organizing workshops/seminars for design professionals on the concept of DfD", "Availability of DfD training", "Regulation regarding DfD", "Industry guidance regarding DfD" and "Establishing a market for salvaged construction components".

Originality/value- This study's findings provide insights into an under-investigated topic in Ghana and offer new and additional information and insights into the current state-of-the-art on the factors that drive DfD implementation.

Keywords: Design for deconstruction; construction and demolition waste; design professionals; Ghana.

1. Introduction

Construction and demolition waste (CDW) has expanded dramatically with negative and catastrophic consequences for urban sustainability and survival regarding economic values and environmental safety (Aslam *et al*., 2020). CDW is viewed as the most urgent issue in the construction sector because of its devastating effects on the environment and economy (Botchway et al., 2023a). CDW impacts the environment, including the loss of land for new landfills, damage to the soil from removing raw materials for new construction items, and the depletion of natural resources (Aslam et al., 2020). Therefore, there is a need to develop measures to mitigate these effects (Devaki and Shanmugapriya, 2023).

Measures and materials that directly or indirectly impact a building's functionality, aesthetics, and upkeep are chosen during the early design and planning stages of new projects (Kanters, 2018). However, a problem seldom explored throughout the design and planning process is how the building and its components may be dismantled or disassembled at the End-of-Life (EoL) phase to design out waste or decrease the waste stream (Akbarieh *et al*., 2020). Densley-Tingley (2013) posited that with rising urbanization and resource consumption, a new approach to the built environment is required to assure sustainability, which may be accomplished by designing out waste at the design stage of the construction (Design for Deconstruction). Designing out waste reduces a building's overall environmental effect and provides social and economic advantages (Balogun, 2023; Kanters, 2018).

Design for deconstruction (DfD) is designing a structure to more effectively manage its end-of-life (Pittri et al., 2023). The procedure aims to make building disassembly as easy as possible to reduce waste and optimize the reuse and recycling of high-value secondary building components and materials. According to Pittri et al. (2023) and Tzourmaklioutou (2021), deconstruction is not only the dismantling and material recovery of buildings but the purposeful dismantling or removal of elements of structures or their contents to reuse them, as opposed to demolition when buildings are destroyed, and materials are landfilled.

The Design for Deconstruction (DfD) technique, a contemporaneous solution to demolition by optimizing disassembly activities to enable reuse, has recently emerged. It has much promise in promoting the circular economy. However, integrating DfD construction methods into the industry will require articulated design guides or principles. Despite initiatives to cut CDW and indicate that deconstruction may aid in waste reduction (Akinade *et al*., 2020), the extent of its implementation in the construction industry has been slow (Pittri et al., 2023). The difficulties of dismantling historic structures underscore the importance of including deconstruction solutions early in the planning phase (Gorgolewski, 2006).

Furthermore, deconstruction design is not a mainstream concept partly due to construction experts using incorrect deconstruction procedures (due to a lack of suitable training) and/or structures created without considering the deconstruction process by design professionals (Pittri et al., 2023; Kanters, 2018). Designing for deconstruction needs design experts to examine jointing methods and the structure itself to be developed during the design stage of construction to simplify the dismantling process, in addition to a comprehensive deconstruction plan that helps this process (Webster and Costello, 2005). According to Akinade et al. (2020), less than 1% of buildings are demountable, which could be attributed to the inability of design professionals to embrace or implement the concept in their daily design practices. Construction and demolition waste is a global issue, and the Ghanaian construction industry is no exception. Agyekum *et al*. (2012) established that the construction industry in Ghana is reluctant to encourage the reuse of waste materials, using low-waste technologies, and recycling waste materials on site. To lessen the number of issues caused by building and demolition debris, the Ghanaian construction sector could shift towards the practice of DfD. Despite the rise in interest in DfD, little attention has been given to DfD implementation among design professionals, especially in Ghana (Pittri et al., 2023). Generally, knowledge of the deconstruction feasibility of a building or its component has greatly limited the implementation of deconstruction (Balogun et al., 2023). As a result, it is often hard to decide the candidacy of a building for deconstruction at its End-of-Lifecycle (EoL). However, the deconstructability assessment is possible only after understanding the concept of deconstruction and the drivers influencing its implementation. With little empirical evidence of the factors that drive DfD among design professionals, this study fills a necessary gap by exploring the key factors that drive DfD implementation among design professionals in Ghana.

2. Literature review

2.1 Concept of Design for Deconstruction (DfD) and its implementation in the Global South

According to Guy and Ciarimboli (2008), DfD refers to the design of structures to enable future alteration and eventual dismantling (in part or whole) to recover systems, components, and materials. To achieve this, the design process involves creating the assemblies, components, materials, building methods, and information and management systems. Buildings designed for deconstruction employ reused materials to reduce energy usage and waste. In DfD, salvaged materials from historic structures are used immediately in new projects, saving money on waste disposal, producing new materials, and recycling processes (Cai and Waldmann, 2019). In addition, DfD employs maintenance-friendly construction technologies, such as prefabricated pieces that are assembled using "dry" methods (e.g., bolting) and building elements that are easily accessible (Tleuken *et al*., 2022).

DfD practice uses planning and design to make deconstruction processes and procedures easier while preserving the demolished parts (Pittri et al., 2023; Zoghi et al., 2022). The deconstruction process significantly changes the typical waste management procedure. The DfD method is an important strategy for raw material conservation (Zoghi et al., 2022). According to Tzourmaklioutou (2021), DfD is desirable when the predicted lifespan of the building components exceeds the expected lifetime of the entire structure. Life Cycle Analysis (LCA), building materials reuse, energy use in structures, and building materials, amongst others, are all strongly tied to the concept of DfD. According to Kanters (2018), DfD is a technique where a design team develops a structure that permits adaptation, refurbishment, and the reuse of building materials and components.

According to Tleuken et al (2022), current practices in developing countries of Central Asia show that lifecycle analysis of buildings' end-of-life influence is not well-practiced, which has led to the low implementation of DfD practices in this region. Pittri et al. (2023) further explained that the low implementation of DfD practices in the global south could be attributed to various factors, such as limited awareness of the concept and a lack of training on DfD practices. It was added that design professionals in many developing countries such as Ghana do not learn about DfD in their formal education, making it challenging for them to understand the concept and its principles before entering the industry.

According to Tleuken et al (2022), the construction sector in Kazakhstan has not fully embraced the DfD concept. Local construction codes and regulations do not require DfD practices, and there are no specific guidelines for its implementation. However, some construction companies in the region have started taking initial steps towards incorporating DfD principles. According to Saghafi and Teshnizi (2011), buildings that are demolished in Iran are often made in 1960s or earlier. They are mainly made with masonry (clay brick) and often demolished manually. Only limited materials such as bricks, metal, doors and windows are recycled, and the rest are crushed with sledgehammers and sent to landfills without separating from each other.

2.2 Factors driving DfD implementation in the construction industry

According to Tzourmaklioutou (2021), traditional building design focuses on short-term performance, such as optimizing functionalities, costs, and construction deadlines. Buildings may accommodate the changing demands of their owners and users by having dynamic and flexible constructions and components that can be dismantled, changed out, recycled, or used again (Tzourmaklioutou, 2021). According to Hobbs and Hurley (2001), an array of legislative, fiscal, and policy frameworks affecting the demolition industry is needed to effectively implement DfD among designers in the construction industry. Policy and legislation should encourage the following developments: funding, tipping reduction, tax reduction, funding, and quicker construction license issuance (Saghafi and Teshnizi, 2011; Hobbs and Hurley, 2001). To begin a practical approach to deconstruction, guidelines are required. They should back up the choice to use appropriate demolition procedures. As a result, the benefits and drawbacks of various demolition procedures should be evaluated in terms of economic, environmental, and other factors. They should also include information regarding building elements that may contain toxic substances and advice on how to proceed before demolishing structures that have these elements (Marzouk and Elmaraghy, 2021; Saghafi and Teshnizi, 2011). According to Saghafi and Teshnizi (2011), one of the essential stakeholders in developing the secondary construction materials market for deconstruction is the government. The government should promote this national goal publicly by encouraging the use of secondary materials and prohibiting the use of primary materials for superfluous purposes. They can be essential in promoting deconstruction by providing financial assistance and effectively enforcing existing laws. The secondary construction materials market requires financial assistance, but public awareness must be developed.

To begin with, people must understand that "secondary" does not always imply "inferior," and the environmental benefits of adopting secondary materials must be emphasized (Macozoma, 2001). Furthermore, public understanding of the importance and benefits of deconstruction will encourage people to participate and invest in this venture (Pittri et al., 2023). The importance of creating public knowledge of the necessity and benefits of deconstruction is demonstrated by the influential role of the public media in spreading public understanding of other experiences (e.g., lowering energy usage) (Pittri et al., 2023; Macozoma, 2001).

DfD assists in identifying markets for salvaged construction components, which enhances resale values (Marzouk and Elmaraghy, 2021; Akbarieh et al., 2020). According to Balogun et al. (2023), the key cost drivers for DfD implementation include market, labour cost, equipment and tool cost, and storage and logistic cost, among many others. In addition, the supply and demand for the recovered components play a crucial role in deconstruction. Also, many retailers have no precise value for the recovered components (Balogun et al., 2023; Gorgolewski et al., 2006). With no knowledge of the market and value for the recovered components, the appropriate deconstruction cost-benefit may never be achieved, hence influencing the deconstructability of the building.

One of the most challenging aspects of reusing deconstructed materials is the need for more demand for them (Tzourmaklioutou, 2021). Demand will naturally increase as more designers begin to employ DfD methods and specify the use of certain materials. It will rise even more if this protocol becomes generally embraced. This successful initiative will also inspire others and boosts the desire for reuse in general (Tzourmaklioutou, 2021). Stakeholder issues include a lack of experience with recycling processes, an inability to establish a market for garbage, opposition to change, contract structures, and a lack of communication among team members (Balogun et al., 2023; Liu, 2009). DfD would strengthen the ability to find markets for salvaged materials by requiring a deconstruction strategy and a thorough inventory of construction materials. In addition, the design process's extensive planning phase would make it easier to communicate about the reuse and recycling of recovered materials (Basta et al., 2020).

In the views of Pittri et al. (2023), the key drivers for DfD include creating awareness of the concept of DfD, DfD training, organizing seminars and workshops, and having the concept of DfD in the formal education curriculum of design professionals such as architects, civil/structural engineers, and services engineers. Akinade et al. (2020) also postulated that strict legislation for design for deconstruction, adequate information during the structure's design phase, a significant market for recovered components, creating a business case for DfD, efficient DfD tools, among others, are the key drivers to effective DfD implementation.
The drivers for the implementation of DfD identified in the reviewed literature are summarized in Table 1.

(INSERT TABLE 1)

3. Research Methodology

This study adopted the mixed research approach (explanatory sequential design) with an initial quantitative instrument phase, followed by a qualitative data collection phase to provide validating findings to the quantitative data. The paper settled on this design because, after the literature review, there was sufficient information concerning the drivers of DfD adoption. With this information, it became easier for the study to focus on the respondents' views concerning what is already available (quantitative survey) and follow up with their actual views concerning the subject under study (qualitative). This particular approach is preferred when the study aims to provide a more comprehensive understanding of the results obtained from the quantitative stage (in this case, the key drivers identified).

3.1 Survey Design, Administration, and Analysis

Following the review of pertinent literature, a questionnaire was prepared to collect data from design professionals in the GCI, including (Architects and structural/civil engineers). For this investigation, a two-part questionnaire was developed. Using a two-step piloting procedure, the questionnaire's applicability for the expected feedback was confirmed prior to data collection. The questionnaires were reviewed by an academic professor, an expert in DfD and sustainable construction, at the first stage. Based on his approval, the second phase of the piloting commenced, which required five industry practitioners (design professionals) who were knowledgeable of the concept of DfD to check the suitability of the questionnaire. After a few clarifications, both phases of piloting were approved. The final questionnaire was administered to the respondents through Google Forms via online. This form of data collection was deemed sufficient since, unlike other methods like face-to-face, it guarantees respondents' confidentiality.

Respondents were required to indicate their background information in the first section of the questionnaire. This included their profession, years of experience, and the highest level of education. Eleven (11) drivers for implementing DfD were revealed from the literature review and questionnaire piloting. In the second part of the survey, respondents were asked to rate their level of agreement on the identified drivers on a five-point Likert scale (where 1 = Strongly disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly agree).

According to Pittri et al. (2023), not many design professionals know the DfD concept in Ghana. Therefore, there was the need to solicit participants who have in-depth knowledge of the concept to provide valid data for the study, which made provision for the deployment of purposive and snowball sampling techniques in this study. First, the design professionals with knowledge and experience in DfD were ascertained through the purposive sampling technique. The snowball sampling technique was employed to discover more respondents who were difficult for the researchers to locate through recommendations from the previously identified respondents. A total of two hundred and fifty (250) questionnaires were distributed to architects and structural engineers across Ghana. Two hundred and forty (240) responses were retrieved, representing a 96% response rate.

The survey data received were coded into the Statistical Packages for Social Sciences (SPSS) version 26 for analysis and interpretation after the questionnaire had been assessed and checked for completeness. Cronbach's alpha` was used to determine the reliability of the data collected from the respondents. The Alpha value for the drivers of DfD implementation in the GCI was 0.969, suggesting that the data were reliable for the analysis. The data was zanalyzed by simple frequencies, mean, standard deviation, Normalization Value (NV) technique, and One-sample t-test. The central tendency of the variables was assessed using descriptive-analytic procedures, such as the mean score ranking. The standard deviation was then used to measure the response variability and dispersion for the target population.

Mean Score Ranking (MSR) was used to rank the 11 drivers based on the means of each variable. Then, the various means were compared to a mean test value of 3.5. In this experiment, a predicted mean of 3.5 was used since, a 5-point Likert scale was used with 5 = Strongly agree, 4 = Agree, and 3 = Neutral. Thus, a factor's mean value must be higher than the neutral point, which is 3.0, in order for it to be taken into account. Since 3.5 is above the neutral threshold and roughly equals 4, it was decided that this value was appropriate for the test. This test result shows that the respondents agree on the variables with a mean score of 3.5 and above to be the drivers for adopting DfD in the GCI (Agyekum et al., 2022a; Kumah et al., 2022).

The One-sample t-test was used to test the significance of the mean values of the agreement or disagreement with the drivers to DfD implementation by the respondents. It was carried out with a 95% degree of confidence and a *p*-value of 0.05. When $p < 0.05$ at the 95% confidence level, the null hypothesis (H_o) was rejected. On the other hand, when $p > 0.05$ at the 95% confidence level, the alternative hypothesis (H_1) was held (Kumah et al., 2022). The null hypothesis in this study was defined as the absence of statistical significance in the mean scores of the drivers. The alternative hypothesis was defined to mean otherwise.

The MSR, standard deviation, and normalization technique were further used to rank the drivers for DfD implementation in the GCI. The NV indicates adjusting the survey items to standardized values between zero and one (Omer et al., 2023). In this manner, the variable that has the highest mean value converts to one, while the least mean value is converted to zero. Equation (1) is used to compute the NV of the various drivers. According to Omer et al. (2023), an NV of 0.60 was used to detect the crucial variables. In this regard, all the variables/drivers with NV of 0.60 and above were considered crucial to implementing DfD in the GCI.

$$NV = \frac{(Mean\ Value - Min\ Mean\ Value)}{(Max\ Mean\ Value - Min\ Mean\ Value)} \quad (1)$$

3.2 Design of interview guide, Conduct of interviews, and Analysis of the qualitative data

The qualitative phase of the study was initiated based on the results from the quantitative phase. The qualitative phase was necessary to obtain interviewees to give detail explaination on the results obtained from the quantitative phase. The interview guide was structured into two sections. The first section gathered some background information on the respondents. The second section sought the respondents' views on the drivers of DfD implementation in the GCI that were outlined using the results obtained from the quantitative phase. A two-step approach was followed to assess the appropriateness and rationality of the interview guide. A content validity test was first conducted by referring to 3 researchers with in-depth knowledge of DfD. The researchers' comments helped to revise the unclear and obscured questions by rewording them. Also, non-functioning and ineffective questions were discarded. The second step ensured the modification of the interview guide using the comments and suggestions from these researchers. Finally, the interview guide was given to the various interviewees, with an accompanying letter detailing the purpose of the study. The interview guide was distributed three weeks before the planned interview schedule to offer the interviewees quality time to prepare and provide salient responses. Agyekum et al. (2022b) posited that adopting a qualitative data collection method to augment the quantitative data is the most appropriate to capture relevant data and information to understand reality from the participants' perspective. The interview involved ten experts (design professionals) purposefully selected from the construction industry and academia based on their expertise in DfD and its principles.

Face-to-face and telephone interviews were organized around a semi-structured interview guide. The interview duration ranged from 20 to 30 minutes, allowing interviewees to express their thoughts and ideas freely. According to Botchway et al. (2023a), using 2 to 50 participants for a qualitative study is adequate. Hence, the ten respondents in this study phase adequately provided the information needed. The data collected from the interview were analyzed through content analysis and comparison of qualitative data with quantitative data under the relevant themes to obtain a better understanding.

4. Results

4.1 Demographic information of survey respondents

The demographic details of the survey's participants are shown in Table 2. It shows that out of the 240 questionnaires returned, 220 (91.7%) of the respondents were architects, and 20 (8.3) were civil/structural engineers. The working experiences of respondents in their current profession revealed that few of the respondents, 28 (11.6%), had less than 6 years of working experience in their relative professions in the construction industry, 48 (20%) had between 6 to 10 years of working experience, 64 (26.7%) had between 11 to 15 years of working experience, and 100 (41.7%) had more than 15 years working experience in their relative professions. Regarding the level of education of respondents, Table 2 again shows that 12 (5%) had HND, 128 (53.3%) had BSc., 80 (33.3%) had MSc./MArch, 16 (6.7%) had MPhil, and 4 (1.7%) were Ph.D. holders. With respect to the professional bodies of the respondents, 220 (91.7%) are part of the Ghana Institute of Architects (GIA), 10 (4.2%) belong to the Ghana Institute of Engineers (GhIE), 4 (1.6%) belong to the Association of Building and Civil Engineering Contractors of Ghana (ABCECG) and 6 (2.5%) are design professionals in the Institute of Engineering and Technology Ghana (IET Ghana).

(INSERT TABLE 2)

4.2 Profile of interviewees

The minimum number of working experiences of the interviewees was 4 years and the maximum was 26 years, indicating that the interviewees were in a good position to give adequate information on the subject matter. Eight (8) out of the ten (10) interviewees were interviewed on a face-to-face basis, whiles the remaining two (2) were interviewed on the telephone after the samples of the interview guides had been sent to them. The professional background revealed that 6 interviewees were industrial practitioners, while 3 were in academia. One of the interviewees doubled as a senior lecturer and an architect.

4.3 Key Drivers of DfD Implementation
4.3.1 One-sample T-test for DfD Drivers

The one-sample t-test was conducted on the 11 drivers of DfD implementation to examine the statistical significance of these drivers at a confidence level of 95%, a *p*-value of 0.05, and a test value of 3.5. Table 3 shows that all the drivers had positive t-values, indicating that their means exceeded the hypothesized mean of 3.5. The means for the 11 drivers ranged from 4.35 to 3.93, suggesting they can be classified as drivers to the adoption of DfD in the GCI. Also, all the drivers had a *p*-value of 0.000 which is less than 0.05, implying that respondents agreed to the 11 variables as drivers for implementing DfD in the GCI. Therefore, the null hypothesis (Ho) which was defined as the absence of statistical significance in the mean scores of the drivers was rejected.

(INSERT TABLE 3)

4.3.2 Normalized Value (NV) for critical drivers to DfD Implementation in Ghana
The NV computed revealed that 8 out of the 11 drivers identified were critical to DfD implementation in the GCI, even though all the drivers had mean values greater than the hypothesized mean of 3.5. Table 4 presents the findings from the NV computation. Table 4 shows that the variables/drivers considered to be critical were D1 (Availability of computer software applications regarding DfD) with NV of 1.0, D6 (Inclusion of DfD in the formal education of design professionals (e.g., a degree programme for engineers, building technologists, and architects)), D9 (Increasing public awareness of the concept of DfD), and D11 (Organizing workshops/seminars for design professionals on the concept of DfD) had NV of 0.881 each. The fifth to eighth-ranked drivers, according to the NV computations, are D2 (Availability of DfD training), D4 (Regulation regarding DfD), D3 (Industry guidance regarding DfD), and D10 (Establishing a market for salvaged construction components) with NVs of 0.833, 0.762, 0.762 and 0.642 respectively. The other three drivers had NVs less than 0.60 indicating that the design professionals considered them as drivers but not crucial/critical to the implementation of DfD in the GCI. In the construction context of Ghana, the results suggest that clients have a limited role in deconstruction implementation. The participants of the study believe that design professionals are the primary influencers in the implementation of DfD. Moreover, government legislation, policies, and strategies such as funding, reducing tipping fees, lowering taxes, and expediting construction license issuance for DfD are not

highly significant in the implementation of DfD in Ghana. Instead, factors directly linked to the engagement of design professionals, such as their level of awareness of the conecpt and principles of DfD, training, and education level, among others hold more importance.

(INSERT TABLE 4)

5 Discussion

This section discusses the results from the quantitative and qualitative data collected from design professionals regarding the drivers of DfD implementation in the GCI. The section first presents the responses from the quantitative analysis and uses the qualitative responses from the interviews to further elaborate on the survey responses. The MSR revealed that all 11 variables could be considered as drivers of DfD implementation in the GCI. The one-sample t-test also revealed that respondents agreed to the 11 variables as drivers to implement DfD in the GCI as the drivers had *p*-values of 0.00 and positive t-values ranging from 5.740 to 13.179. Following the NV computation shown in Table 4, 8 out of the 11 variables were considered crucial/critical. These drivers are in order of D1 (Availability of computer software applications regarding DfD), D6 (Inclusion of DfD in the formal education of design professionals), D9 (Increasing public awareness of the concept of DfD), D11 (Organizing workshops/seminars for design professionals on the concept of DfD), D2 (Availability of DfD training), D4 (Regulation regarding DfD), D3 (Industry guidance regarding DfD) and D10 (Establishing a market for salvaged construction components). The top five (5) key drivers have been further discussed below:

5.1. Availability of computer software applications regarding DfD

The use of computer software for DfD practices was the most critical driver ranked by the respondents (Mean score value (MSV) = 4.33, SD = 0.999, $p = 0.00$, and NV = 1.000) among the drivers for DfD implementation. This finding corroborates that of Tingley and Davidson (2012) who posited that computer software in DfD practices makes DfD implementation easier and faster. The software also helps keep records of materials and designs for future DfD analysis. Various research organizations have created tools to evaluate the advantages of deconstruction over demolition. Sakura is an online tool available for designers to utilize to examine the advantages of implementing DfD principles in their work (Tingley and Davison, 2012). The goal of this application is to encourage the creation of more buildings that are designed with the ability to be deconstructed, which in turn would lead to a greater supply of materials that can be reused. By having more of these materials available and specified for use, there would be a decrease in the demand for natural resources, a reduction in the amount of waste produced by demolition, and a lowering of the overall energy and carbon footprint associated with building construction. In line with this finding, Guy and Ohlsen (2003) provided a tool for estimating deconstruction's cost and revenue possibilities. This software was created to determine which existing structures were ideal for deconstruction and serve as a deconstruction educational tool. It is also envisaged that it will be used throughout the design phase of new constructions to maximize the usage of recoverable materials. Another software developed at the National Defense Centre for Environmental Excellence (NDCEE) is the deconstruction material estimating tool (DMET). The Building Research Establishment (BRE) has also created software to reduce demolition waste and promote deconstruction. SMARTWaste™ is a waste analysis tool that may also be used to offer pre-demolition audits, which evaluate the materials/components in a building to see if they are suitable for reuse or recycling, and thus determine whether it is worth deconstructing the building for maximum material recovery (Hobbs and Hurley, 2001). All these technologies help to make deconstruction easier, simple, and sequential. When the interviewees were further asked to elaborate on why they think this driver is the most critical when it comes to implementing DfD, some of their comments are indicated below:

"*Technologies such as Building Information Modelling (BIM) can facilitate communication between design professionals and other construction stakeholders to make deconstruction easier and faster. Hence, computerized tools for DfD practices cannot be underemphasized as long as DfD implementation is concerned"*- Architect and a senior lecturer.

"BIM-enabled collaborative planning at the design stage informed by the waste management consultant, builder, and BIM operator would result in a more accurate prediction of CDW in real time which could drive DfD adoption in the GCI"- Architect and a senior lecturer and Architect 3.

"*In-depth knowledge about implementing advanced technology to recycle waste material is essential for DfD adoption"* – Senior lecturer 1.

Another interviewee added:

"Using computerized software applications and tools to assess the environmental impact of design choices can help the design team contribute to project sustainability and improve compliance with sustainable rating system requirements. This, in turn, could promote the adoption of DfD practices in the GCI" – Civil Engineer 1.

Tzourmaklioutou (2021) indicated that specialized site workers or complex tools are not necessarily required for deconstruction. Instead, site workers with foundational skill sets, who have received professional training to ensure high-quality craftsmanship and work ethics, are well-equipped to undertake deconstruction tasks. However, the findings of this study present otherwise that design professionals with computerized skills mostly in DfD related tools such as BIM make the whole deconstruction process easier.

5.2. Inclusion of DfD in the formal education of design professionals

The second crucial driver to DfD implementation ranked by the respondents was the 'inclusion of the concept of DfD in the formal education of design professionals (e.g., degree programmes for engineers, building technologists, and architects)' with MSV = 4.30, SD = 1.040, p = 0.00 and NV = 0.881. Including the DfD concept in the formal education or curriculums of design, professionals are paramount in developing the awareness levels of design professionals and the general public as postulated by Pittri et al. (2023). For proper DfD training to be carried out, design professionals need to be taught basic lessons. These lessons can be learned if the concept of DfD is incorporated into the formal education curriculum of design professionals. This will also go a long way to inform design professionals of the benefits of implementing DfD. According to Pittri et al. (2023)**,** education and raising awareness play a major role in encouraging individuals to design differently. This can be done if education on the concept of DfD is incorporated into the formal education system of design professionals. Based on the qualitative data collected, some of the interviewees had this to say:

"*Education will make a cultural shift towards sustainable construction involving innovative and modern design promoting recycled or second-hand construction materials. Also, the shortage of educated designers with sustainability concerns willing to apply reused elements* *increases the cost of reusing material. Hence, inculcating the concept of DfD in the curriculum of design professionals such as architects, structural engineers, civil engineers, and services engineers is paramount to DfD implementation*" – Architect 1, Architect 2, and Structural engineer 1.

One of the interviewees revealed that:

"I heard about DfD when I started practicing as an Engineer. However, the concept is scanty in the formal education curriculum in Ghana. I believe improvement needs to be done since adding it will make design professionals conversant with the concept before they come to the industry to practice" – Civil engineer 1.
The findings of this study fall in line with that od Akinade et al. (2017) and Pittri et al. (2023) who stated that the design team working on DfD projects requires the appropriate expertise, training, and motivation which need to be acquired during their education before moving to the industry.

5.3. Increasing public awareness of the concept of DfD
With an MSV = 4.30, SD = 1.072, $p = 0.00$, and NV = 0.881, this driver was ranked third in this study. The finding conforms to the outcomes of Pittri et al. (2023), which postulated that the general awareness of the concept of DfD in the GCI among design professionals is low, even though awareness is necessary for the implementation of DfD practices in the industry. Design professionals need to be aware of the concept and principles of DfD for proper its proper implementation in the GCI. This can also be fulfilled if design professionals are aware of the benefits of implementing the concept in their designs. Osmani (2013) in line with the findings of this study was of the view that some designers still need to be aware of their duties in preventing construction waste, resulting in low DfD implementation in the construction industry. This is where the problem begins. Designers must be more informed, committed, and dedicated because they are the ones that drive the deconstruction process.

According to Shooshtarian et al. (2021) and Macozoma (2001), the secondary construction materials market requires financial assistance, but more significantly, public awareness of the concept of DfD must be developed/improved. To begin with, people must understand that "secondary" does not always imply "inferior," and the environmental benefits of adopting secondary materials must be emphasized. Furthermore, public understanding of the importance of deconstruction will encourage people (clients) to participate and invest in this technique. The importance of creating public knowledge of the necessity and benefits of deconstruction is demonstrated by the influential role of the public media in spreading public understanding of other experiences (e.g., lowering energy usage) (Pittri et al., 2023). In seeking the views of the interviewees on this driver, the following were revealed:

"*The general awareness level of the concept of DfD is low in Ghana, and I believe this has been a greater hindrance to its implementation. I believe the awareness level should be increased in several media, such as universities and design professionals proposing the concepts to clients. This will go a long way in driving the implementation of the concept in the GCI*" – Lecturer 1.

"*The concept of DfD looked new on the faces of my current fourth-year architecture students when I first introduced it in class. However, I did not look surprised since the concept is new in the industry and will take time to implement fully. Nevertheless, all stakeholders have a role* *to play in raising the awareness level of the concept since doing this will drive or make the implementation process easier”* – Senior lecturer 2.

5.4. Organizing workshops/seminars for design professionals on the concept of DfD

According to the study's findings, DfD implementation will be driven if workshops and seminars are carried out on the concept. This variable was ranked fourth with MSR = 4.30, SD = 1.102, p = 0.00, and NV = 0.881. This vindicates the findings of Ametepey *et al*. (2015) that discussions, seminars, training, and workshops on sustainable construction, such as DfD and its importance, should be initiated by stakeholders in the industry. Online courses and study materials on the concept of DfD should also be made available or accessible to design professionals. This includes deconstruction guides, strategies, and principles, amongst others. Confirming from the findings of Pittri et al. (2023), design professionals in the GCI are willing to engage in seminars and workshops on DfD because they see the concept as promising and have the potential to combat the waste problems in the GCI. This indicates that workshops/seminars for design professionals on the concept of DfD drive the implementation of the concept in the industry. When the views of the interviewees were sought regarding this driver, some interviewees indicated that;

"In a world where many natural resources are becoming scarce, it is important to consider alternatives that aim to close the material loop. Design for deconstruction is the best way to go. However, it is unfortunate that the concept is not popular in the GCI. In order to promote the concept, workshops, seminars, and conferences, amongst others on DfD, need to be organized by stakeholders in the construction industry. This will also go a long way to improve training and awareness of the concept of DfD among construction professionals”- Architect 2, Civil engineer 1, and Senior lecturer 2.

5.5 Availability of DfD training

Availability of DfD training was ranked fifth by the respondents with MSV = 4.28, SD = 0.970, p = 0.00, and NV = 0.833. This finding corroborates that reported by Liu (2009) that stakeholder issues which include a lack of experience with recycling processes by design professionals, lack of technical know-how and training, opposition to change, contract structures, and a lack of communication among design team members could hinder the implementation of DfD. Training design professionals will enable them to gather the requisite skills and knowledge for easy DfD implementation. According to Densley Tingley (2013), providing training prospects to professionals in the construction industry is a crucial measure for driving the implementation of DfD. Akinade *et al*. (2017) and Densley Tingley (2013) added that the design team needs the right competence, training, and will to work with DfD. According to some of the interviewees;

“*Design for deconstruction and design for reuse need to be incorporated in the design stage of every structure; hence designers and architects have a pivotal role. Therefore, they need to be given the requisite training to develop their expertise and knowledge*” – Civil engineer 2

Senior lecturer 1 and Civil engineer 1 added, *"The GCI must have some guidelines to reuse building components and train both design and construction professionals on these guidelines."*

6 Conclusion

This study aimed to identify the critical drivers of DfD implementation in the GCI. A mixed-research approach (both quantitative and qualitative) was used in this study. The design was explanatory sequential, using qualitative data to augment the study's quantitative outcome. First, a quantitative survey was conducted among professionals in both industry and academia using a prepared questionnaire. The data collected from the survey were analyzed using descriptive and inferential statistics. In the second stage, 10 semi-structured interviews were conducted with DfD experts to validate the data obtained from the questionnaire survey. The review of literature, Mean score descriptive statistics, and the one sample t-test revealed 11 drivers for the implementation of DfD in the GCI. However, further analysis using NV computation revealed that eight (8) out of the eleven (11) are critical to implementing DfD in the GCI. The eight key drivers for DfD implementation were identified as, in order of importance, "Availability of computer software applications regarding DfD", "Inclusion of DfD in the formal education of design professional", "Increasing public awareness of the concept of DfD", "Organizing workshops/seminars for design professionals on the concept of DfD", "Availability of DfD training", "Regulation regarding DfD", "Industry guidance regarding DfD" and "Establishing a market for salvaged construction components". The interviewees agreed to and confirmed the importance of these identified drivers for implementing DfD in the GCI to validate the survey's key findings.

The primary goal of constructing buildings for deconstruction is to make it easier to disassemble them at the end of their useful life, minimize waste generation, and maximize the recovery of salvageable materials. Neglecting to adopt the practice of DfD could harm efforts to reduce construction waste in Ghana. Thus, this study has identified the factors that drive the implementation of DfD in Ghana. The study emphasizes the importance of considering DfD principles during the design phase since design decisions can affect a building's deconstructability at the end of its life. The results of this study could inform the design professionals, stakeholders and policymakers on what drives the implementation of DfD in order to achieve its overall objective of attaining sustainable construction and circularity. Employers can use the findings to ensure that they provide a robust training regime that empowers their design professionals to successfully deliver DfD projects in line with their expectations. Also, the research findings can inform design education programs and professional development initiatives. Design schools and training programs can incorporate DfD concepts and principles into their curriculum, ensuring that future designers have the necessary skills and knowledge for DfD implementation.

Theoretically, this study has established key drivers necessary for DfD implementation in a typical developing country setting (in this case, Ghana), currently under-reported in the literature. The identification of these drivers advances knowledge within the subject area.

In this study, only design professionals such as civil/structural engineers and architects in the GCI were included in the target audience of this study. Other design engineers, like service engineers, were not considered due to the sampling techniques used in this study. This is a key limitation. Future research could be broadened to include the opinions of other design professionals not involved in this study. Also, the views of other key stakeholders like the government and other construction professionals were not sought. Future studies should involve other key stakeholders to provide additional empirical realities to broaden the understanding of the views of these stakeholders on the factors that drive DfD.

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