Examining the barriers to implementing design for deconstruction in the construction industry of a developing country

Citation for published version:
Pittri, H, Godawatte, GAGR, Agyekum, K, Botchway, E, Dompey, A, Oduro, S & Asamoah, E 2024, 'Examining the barriers to implementing design for deconstruction in the construction industry of a developing country', *Construction Innovation: Information, Process, Management*. https://doi.org/10.1108/CI-09-2023-0239

Digital Object Identifier (DOI):
10.1108/CI-09-2023-0239

Document Version:
Peer reviewed version

Published In:
Construction Innovation: Information, Process, Management

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Construction Innovation: Information, Pr
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Journal:	*Construction Innovation: Information, Process, Management*
Manuscript ID	CI-09-2023-0239.R1
Manuscript Type:	Research Article
Keywords:	Design for deconstruction, construction and demolition waste, design professionals, Barriers, Wilcoxon Signed Rank Test, Ghana

EXAMINING THE BARRIERS TO IMPLEMENTING DESIGN FOR DECONSTRUCTION IN THE CONSTRUCTION INDUSTRY OF A DEVELOPING COUNTRY

ABSTRACT

Purpose- Despite endeavors to alleviate construction and demolition waste and the indications that the process of deconstruction has the potential to steer waste reduction initiatives, there has not been a progressive increase in the adoption of Design for Deconstruction (DfD) in the global south, especially Ghana. This paper aimed to identify and analyze the barriers to implementing DfD in developing countries.

Design/methodology/approach- A structured questionnaire survey was used to solicit the views of 240 design professionals in the Ghanaian construction industry (GCI). The questionnaire was developed by reviewing pertinent literature and complemented with a pilot review. Data were analyzed using descriptive and non-parametric statistics.

Findings- The findings revealed ten (10) significant impediments to implementing DfD within the construction industries in developing economies. These impediments revolve around cost, legal matters, storage, incentive, and design-related matters. Key among these barriers is "For recovered materials, there are little performance guarantees", "The absence of strict regulations regarding design for deconstruction", "Lack of a large market enough for components that have been recovered", "The need for building codes that address how to design with reused materials", and "Lack of effective design for deconstruction tools".

Originality/value- The results of this research shed light on a relatively unexplored area within the construction sector, particularly in a developing country like Ghana. Furthermore, the study contributes fresh and supplementary knowledge and perspectives regarding the challenges in implementing DfD practices.

Keywords: Design for deconstruction; construction and demolition waste; design professionals; Barriers; Wilcoxon Signed Rank Test; Ghana.

1. Introduction

The result of an innovative creation or manufacturing process is not only the perceived product, but with it comes the baggage of waste. In its production process, the construction industry does not fall far from this logic and produces waste in countless forms. The construction industry is a significant waste producer, contributing about 40% to total solid waste production (O'Grady *et al.*, 2021; Marzouk and Elmaraghy, 2021; Shooshtarian *et al.*, 2022). Construction and Demolition (C&D) waste arises from errors made during the design stage, mistakes made while working on site, the confusion arising from workflow, renovation, demolition, and equipment malfunction (Akbarieh *et al.*, 2020). With rapid urbanization and high population growth, the C&D waste produced by the construction industry is reaching an unprecedented peak. It is affecting the environment in diverse ways, including pollution of air and water, contribution to greenhouse gas emissions, and degradation of the forest (Tingley and Davison, 2012; Lissah *et al.*, 2021; Shooshtarian *et al.*, 2022). Several steps are being taken continually to manage the negative impacts of C&D waste; notable among them are the use of the concept of circular economy in waste management systems (Shooshtarian *et al*., 2022), the use of modern technology such as Building Information Modelling (BIM) and Lean approaches in management of waste (Akbarieh *et al*., 2020; Marzouk and Elmaraghy, 2021; Rosli *et al*., 2023) and the trend towards new strategies for waste minimization which includes DfD and reversible building design (Durmiševic, 2018; Akbarieh *et al*., 2020).

Deconstruction is an alternate demolition strategy that capitalizes on the reuse value of building materials and components (Tzourmakliotou, 2021). It involves careful thought during the design stage of the building to retrieve the desired material value at the end of life (EoL) of the structure (Couto and Couto, 2010; Zoghi *et al*., 2022). This careful thought of material recovery requires deconstruction to be incorporated at an early stage of the building to ensure its effectiveness and hence brings about the concept of DfD (Couto and Couto, 2010; Tzourmakliotou, 2021; Zoghi *et al*., 2022). DfD is about concentrating on the end-of-life of a product right from the thought of its inception at the design stage with the intent of achieving sustainability and circularity (Tzourmakliotou, 2021; Tleuken *et al*., 2022; Roxas *et al*., 2023). Existing buildings need help implementing deconstruction simply because they were not designed for disassembly or deconstruction (Balogun *et al*., 2023). This leads us to the fact that designing for deconstruction is crucial and highly dependent on the professionals engaged in the design phase.

Recent research indicates that design decisions significantly impact the generation of materials waste at construction sites (Botchway *et al*., 2023a). It has been emphasized by Xu and Lu (2019) that waste management should not be an afterthought once construction begins; instead, it is crucial to address construction waste right from the design stage. This viewpoint is supported by Osaily *et al*. (2019), who suggest collaboration between demolition contractors and designers should occur before construction commences. Modern construction practices can effectively incorporate waste management strategies by adopting this sustainable approach, known as design for deconstruction (DfD).

Despite the benefits of DfD in managing waste (Balogun *et al*., 2022; Zoghi *et al*., 2022), developing workforce (Balogun *et al*., 2022), achieving cost savings (Marzouk and Elmaraghy, 2021; Balogun *et al*., 2023) and saving energy (Tingley and Davison, 2012; Zoghi *et al*., 2022), the engagement level by design professionals is still low (Pittri *et al*., 2023a; Akbarieh *et al*., 2020). Pittri *et al*. (2023b), Akinade *et al*. (2017), and Densley Tingley and Davison (2012|) added that despite endeavors to alleviate C&D waste and the indications that the process of deconstruction has the potential to steer waste reduction initiatives, there has not been a progressive increase in the adoption of DfD within the construction industry. The issue is worse in the global south, especially Ghana (Pittri *et al*., 2023b). In Ghana, the overall awareness and engagement level of DfD practices is low (Pittri *et al*., 2023a). Also, most design professionals perceive buildings as static construction (Tzourmakliotou, 2021).

Several studies have evolved on DfD targeting its benefits (Tingley and Davison, 2012), the DfD process (Tzourmakliotou, 2021), barriers and opportunities (Tleuken *et al*., 2022; Tzourmakliotou, 2021), drivers influencing deconstruction implementation (Pittri *et al*., 2023b; Balogun *et al*., 2022) and DfD in relation to emerging technology and concepts like circularity (O'Grady *et al*., 2021; Marzouk and Elmaraghy, 2021). However, studies of a similar nature are scanty in developing countries like Ghana (Pittri *et al*., 2023a). A recent review of the current body of knowledge on DfD revealed that there are challenges to its adoption, especially in the Ghanaian construction sector (Roxas *et al*., 2023). Pittri *et al*. (2023b) added that the concept of DfD is new in the global south, and there is a need to identify the barriers to adopting this sustainability concept in the region. With these revelations, it is evident that to increase the participation level of design professionals in DfD practices and processes, more investigations need to be conducted, especially on the potential challenges and barriers to implementing DfD. Therefore, this sets the pace for this current study that examines the barriers to driving DfD implementation among design professionals focusing on the GCI.

The rest of this paper is structured as follows: Section 2 reviews pertinent literature on DfD. Section 3 discusses the methodology used to arrive at the results. Section 4 contains the results and a discussion of the findings and their implications. Section 5 is the conclusion, where the study's results are summarized in connection with the aim of the study, in addition to highlighting the originality, contributions, and future research suggestions.

2. Literature Review

2.1 Design for Deconstruction (DfD): Concept, Principles, and Guidelines

There is a rise in the demand for building materials, which causes natural resources to be depleted. This demonstrates the need for sustainability in C&D waste management (Jiang *et al*., 2023). To address this issue, a deliberate approach to planning for reusing or recycling building materials and components is required. This necessitates addressing the problem at its source, generally during the design stage, by designing for deconstruction to avoid demolition after a building's useful life has expired (Pittri *et al*., 2023a).

DfD is a design and planning approach that takes the idea of eventual demolition into account (Rios *et al*., 2015). It originated in the 1990s from the term deconstruction and was developed to resolve the issues with conventional demolition (Zoghi *et al*., 2022). Deconstruction is a different approach from demolition, and it includes dismantling, disassembling, recovering, and removing all or part of the building materials to maximize the possibilities for reuse (Tzourmakliotou, 2021). The view of deconstruction as an alternative to demolition is shared by Marzouk and Elmaraghy (2021), Balogun *et al*. (2022), and Zoghi *et al*. (2022) in their respective studies. Since its first establishment, numerous recommendations have been developed that clarify the fundamental concepts, practices, and methodologies of the separation process and reuse strategies. Currently, it goes by other names, such as "green demolition" and “construction in reverse” (Rios *et al*., 2015; Zahir *et al*., 2016; Zoghi *et al*., 2022).

Including deconstruction at the design stage of buildings is one step toward achieving radical change and transformative evolution (Roxas *et al*., 2023). According to Couto and Couto (2010), deconstruction is the deliberate and well-thought-out separation of components for material recovery and repurposing. Adopting this well-thought-out process at the design stage offers not only cost savings and resource preservations but also gives current buildings the potential to be adaptable for future expansions (Tzourmakliotou, 2021; Tleuken *et al*., 2022). Marzouk and Elmaraghy (2021) view DfD as the methodical removal of building components to maximize their possibility for recovery. The authors believe this method relies partly on reverse logistics, while others, like Roxas *et al*. (2023), believe the adoption of DfD is based on its connection with the circular economy.

To encourage the utilization of DfD in construction, it is imperative to have guidelines that construction practitioners can follow. According to Roxas *et al*. (2023), effective implementation of DfD involves simplifying the building system, employing appropriate materials, and ensuring the availability of pertinent deconstruction information. Adhering to these principles is crucial for promoting equitable DfD practices in construction. Akinade *et al*. (2017) propose integrating DfD into the planning stages of building construction to eliminate the uncontrolled generation of construction and demolition waste. Derived from these overarching deconstruction principles, specific DfD guidelines have been formulated. Lu (2016) offers DfD guidelines tailored for cold-formed steel structures. The guidelines encompass designing reversible connections, utilizing demountable fasteners while eliminating adhesives, ensuring easy connection access during disassembly using tools, simplifying and standardizing shapes and connection details, and reducing the number of connection elements and variety of member sizes.

Tleuken *et al*. (2022) emphasize that adherence to DfD principles involves minimizing the number of materials and components used, selecting materials suitable for reuse and recycling, employing visible and accessible connections for building elements, using simple yet robust connections that are easy to deconstruct (e.g., dry connections, dissolvable chemical or reversible welding connections), and adopting building modules that are sturdy, replaceable, and convenient for transportation.

2.2 DfD Implementation in the Construction Industry: The Context of Ghana

DfD is gradually gaining popularity within the construction industry, and several attempts are being made through research studies to fast-track its implementation and cushion its adoption (Balogun *et al*., 2022). Balogun *et al*. (2022) discovered that deconstruction implementation has been severely constrained by knowledge of a building or component's deconstruction viability. This confirms that simplifying the building system aids in the use of deconstruction. From their study, Balogun *et al*. (2022) proposed a deconstructability construct-based conceptual framework to aid in determining a building’s deconstruction viability. It was concluded that a total understanding of the DfD concept and the drivers influencing deconstruction is needed to make a building deconstructable adequately.

Through a review to identify the rate of applicability and benefits of DfD in the construction industry, Roxas *et al*. (2023) revealed that design professionals seldom use it despite compelling reasons for adopting DfD. This finding is supported by the study of Akbarieh *et al*. (2020) and Pittri *et al*. (2023a), who indicated that the general engagement of DfD practices in the construction industry is low especially in developing countries. In Ghana, Pittri *et al*. (2023a) found out that the low engagement of design professionals in DfD practices was a result of low awareness of the concept, while Roxas *et al*. (2023) attributed the low engagement to the lack of standard DfD guidelines. It was added that the concept is new in developing countries such as Ghana, and countries such as the UK, the US, and Australia have embraced it well. Tzourmakliotou (2021) also stated that the perception of design professionals concerning the nature of construction could have a hand in the low participation. However, design professionals in Ghana expressed interest in the concept and believed that through formal education, training, and advertisement, their engagement levels in DfD practices would increase (Pittri *et al*., 2023a). Pittri *et al.* (2023b) added that little attention has been given on the concept of DfD in the GCI in terms of research, policies and guidelines even though DfD presents several promises in promoting the circular economy.

The GCI must have some guidelines to reuse building components and train both design and construction professionals on these guidelines (Pittri *et al.,* 2023b).

The GCI is currently facing significant pressure to embrace sustainable practices. With the recognition of the circular economy concept as a potential solution to address sustainability challenges in the GCI (Agyekum et al., 2023), it becomes evident that DfD, a crucial strategy within the circular economy framework, could contribute to the ethical operation of the sector if put into practice (Pittri et al., 2023a).

2.3 Barriers to Driving DfD Implementation

While pushing the implementation of DfD among design professionals, reactions in the form of obstacles and challenges would undoubtedly be faced. Time restrictions are among the biggest obstacles to using less invasive deconstruction techniques (Kanters, 2018; Akinade *et al*., 2017). Traditional deconstruction methods, such as demolition with heavy machinery, are often faster and more straightforward in dismantling structures. However, deconstruction requires more time for planning and execution. In the early years of deconstruction, the challenges associated with its implementation were identified as the use of composite systems or irreversible connections/fasteners that require destructive demolition, lack of tools for demolishing buildings, low cost of disposing of demolition waste, the requirement for building codes that specify how to use recycled materials in designs, and the inadequacy (at the time) in calculating the environmental and financial benefits (Kibert, 2003). Buildings often use composite systems and irreversible connections/fasteners, making it challenging to deconstruct structures without resorting to destructive demolition. These elements were designed to withstand the forces associated with construction but posed challenges for disassembly (kanters, 2018). The absence of specialized tools for deconstruction contributed to the difficulties in efficiently dismantling structures. Unlike traditional demolition with well-established equipment, deconstruction requires innovative tools tailored for selective and careful disassembly (Akinade *et al*., 2020). The economic aspect played a crucial role. Disposing of demolition waste was often less expensive than investing time and resources in carefully deconstructing and salvaging materials (Kanters, 2018; Akinade *et al*., 2017). This economic imbalance discouraged the adoption of deconstruction practices. The absence of clear building codes specifying how to use recycled materials in designs presented a hurdle. Without established guidelines, architects and builders may have hesitated to incorporate recovered materials into new constructions, limiting the demand for deconstruction, and the early years of deconstruction lacked robust methodologies for accurately assessing the environmental and financial benefits of this approach. This made it challenging to convince people of the advantages of deconstruction over traditional demolition (Kanters, 2018; Kibert, 2003).

With time, some of these challenges have been mitigated. In contrast, others still present themselves in addition to new ones in the form of lack of certainty regarding the quality of the recycled materials, low demand brought on by users' negative perceptions, the financial profitability of demolition practices rather than disassembly, the risk of earthquakes when using bolted connections, and the high risk of corrosion in reinforced concrete (causing difficulty in reuse) (Salama, 2017). Tzourmakliotou (2021) confirmed uncertainty regarding the type and quality of materials used as a barrier and added that the lack of regulation and disconnection between decisions taken at the design stage of a building and those taken when the building is near its end life were additional obstacles faced when driving DfD implementation. Dodd *et al*. (2021) confirmed this in their DfD indicator manual.

A lack of strict legislation for DfD, a lack of adequate information during the structure's design phase, a lack of a sizable market for recovered components, difficulty in developing a business case for DfD, and a lack of practical DfD tools were some challenges identified by Akinade *et al*. (2020) in their study of barriers affecting DfD using a circular economy approach. Dodd *et al.* (2021) added that building designs, demolition processes, logistics systems, and markets were four significant obstacles that hindered material reuse and recycling in deconstruction practices. According to the study by Tleuken *et al*. (2022), which looked at DfD practices in Central Asia, economic factors such as cost significantly affect the uptake of DfD because using deconstruction may increase initial building costs. Policy development and factors relating to design requirements were crucial components as they substantially impacted the adoption of DfD in the United Kingdom (Akinade *et al*., 2017). Although Akinade *et al*. (2017) and Tleuken *et al*. (2022) investigations were conducted in distinct geographic contexts, they reached the same results about the necessity of treating the economic side of DfD, which may have worldwide ramifications. Pittri *et al.* (2023b) indicated that lack of digital tools and policy development are among the crucial reasons for the low engagement of DfD practices in the GCI. The barriers identified from the review of pertinent literature are summarized in Table 1:

(INSERT TABLE 1)

Source: Table created by authors

3. Research Methodology

This study adopted a quantitative approach. This methodology quantifies a wide range of opinions of respondents. Moreover, this approach presents a better generalizability of the findings and results of a study (Botchway *et al*., 2023b; Agyekum *et al*., 2022a). Based on the quantitative approach, a survey strategy in the form of questionnaires was used. This study used structured data collection and statistical analysis to minimize researcher bias. This objectivity makes it easier to replicate studies and verify results, contributing to the reliability and validity of research findings (Agyekum *et al*., 2022b). A summary of the methodology adopted for the study is presented in Figure 1.

(INSERT FIGURE 1)

Source: Figure created by authors

3.1 Questionnaire design

Utilizing quantitative methodology through a questionnaire survey enables extrapolating findings from a population subset to a significantly broader audience (Kumah *et al*., 2022). The questionnaire was designed after a detailed literature review to identify potential barriers to driving DfD implementation. In all, twelve (12) barriers were developed (*see Table 1*). The questionnaire was divided into two sections. Section one sought to gather demographic information from the respondents. In contrast, the second section required the respondents to rate their level of agreement with the proposed barriers using a five-point Likert scale where 1= strongly disagree, 2= disagree, 3= neutral, 4= agree, and 5= strongly agree. Before the questionnaire was administered, it was piloted among seven (7) design professionals, four (4) of whom were both practicing professionals and researchers in the field of DfD, and three (3) who were experts in the construction industry who have been involved in DfD practices over the past decade. This was a critical step in validating the questionnaire, as its effectiveness in measuring what it was designed to measure needed to be confirmed. Also, there was the need to assess the extent to which the questionnaire's items accurately represent the entire theoretical concept it aims to evaluate (Agyekum *et al*., 2023). Furthermore, the experts were tasked with determining if the questions were clear and straightforward, if the questionnaire could be used for future assessments in the same field of study, and if any questions raised privacy concerns, among other considerations. The experts revealed that some variables were impractical, and some had the same meaning and could be merged. The piloting study also helped to correct the grammatical errors in the questionnaire. The questions/variables in the questionnaire were corrected based on the feedback from the piloting study. The final set of questionnaires was then distributed online using Google Forms. This form of data collection was deemed sufficient since, unlike other methods like face-to-face, it is cost-efficient, offers convenience for both the researcher and the respondents, and guarantees respondents' anonymity.

3.2 Data collection

As Pittri *et al*. (2023a) indicated, the DfD concept has yet to be widely known among design professionals in Ghana. Consequently, the study recognized the necessity to enlist participants well-versed in the concept to ensure valid data acquisition. This led to the utilization of purposive and snowball sampling techniques. Initially, 68 design professionals possessing knowledge and experience in DfD were identified through purposive sampling. Questionnaires were distributed, accompanied by a cover letter specifying the study's focus on individuals familiar with DfD or involved in DfD practices. The snowball sampling technique was subsequently employed to identify additional respondents who were challenging for the researchers to locate, relying on recommendations from the initially identified participants. A total of 240 responses were received out of the 250 questionnaires distributed among architects and civil/structural engineers throughout Ghana, representing a 96% response rate. Similar studies on DfD in the region have used the same approach (Pittri *et al*., 2023b).

3.3 Data Analysis

Data was analyzed using the Statistical Package for Social Sciences (SPSS) version 26. Before the analysis was done, the Cronbach Alpha coefficient was derived to check the internal consistency and reliability of the data. The coefficient was recorded as 0.98, implying that the data was reliable and that analysis could proceed. This study adopted both descriptive and inferential statistics to analyze the data.

The normality of the data was tested using the Kolmogorov-Smirnov (K-S) test with Lilliefor's significance correction for normality. The results showed that the data were not normally distributed. Hence, the study resorted to non-parametric statistics using the Median, Quartile Deviation, and Wilcoxon Signed Rank tests (Woolson, 2007). To adequately rank the barriers to DfD implementation, the median of the various variables was considered in terms of the variable with the highest median value. When two or more variables had the same median, the variables were ranked based on their Quartile Deviation (QD), with the lowest QD implying the least deviation, hence the most preferred choice.

Furthermore, variables with the same QD were ranked according to their means and standard deviations (Lydersen, 2020). The Wilcoxon Signed Rank test was used to analyze the barriers to DfD implementation further to compare the sample's medians to the hypothetical median. A hypothetical median of 3.5 was used to aid in this test, and the null hypothesis (H_o) was used because the variables were not statistically significant. A hypothetical median of 3.5 was used to mean that for the scale adopted (1= strongly disagree, 3= neutral, and 5= strongly agree), a variable should have a median that is higher than the neutral point (3=neutral) to be considered a barrier to the implementation of DfD in the construction industry of a developing economy. Hence, a value greater than the neutral point was set between 3 and 4 (in this case, 3.5).

4. Results and Discussion

4.1 Demographic information of survey respondents

Table S1 displays the demographic characteristics of the survey's participants. Of the 240 completed questionnaires, 220 (91.7%) were filled out by architects, while 20 (8.3%) were completed by civil/structural engineers. When examining the respondents' professional experience in the construction industry, it was found that 28 (11.6%) had less than six years of experience, 48 (20%) had between 6 to 10 years of experience, 64 (26.7%) had between 11 to 15 years of experience, and 100 (41.7%) had more than 15 years of experience in their respective professions. This indicates that the respondents are well-experienced in the construction industry and can give valid responses for the study. Regarding educational background, the breakdown revealed that 12 (5%) held HND degrees, and 128 (53.3%) had BSc. Of the degrees, 80 (33.3%) possessed MSc./MArch degrees, 16 (6.7%) had MPhil degrees, and 4 (1.7%) held Ph.D. qualifications. Regarding professional affiliations, 91.7% (220) were members of the Ghana Institute of Architects (GIA), 4.2% (10) were affiliated with the Ghana Institute of Engineers (GhIE), 1.6% (4) were part of the Association of Building and Civil Engineering Contractors of Ghana (ABCECG), and 2.5% (6) were design professionals within the Institute of Engineering and Technology Ghana (IET Ghana).

(INSERT TABLE S1)

Source: Table created by authors

4.2 Tests of Normality of Barriers to Design for Deconstruction Implementation

The study assumed a null hypothesis that the data set follows a normal distribution. After analyzing data using the Kolmogorov-Smirnov (K-S) test with Lilliefor's significance correction for normality, the results showed that the data collected for each variable had a p-value less than 0.05. The p-value served as a measure of compatibility between the underlying assumptions of the statistical model and the data, implying 0 as total incompatibility and 1 as total compatibility. The Lilliefors significance correction was used to improve the test statistic values of the K-S test as the data set was not based on a specified population mean and standard deviation. The findings provide significant evidence to reject the null hypothesis, which is in line with the assertion of Adachi (2022) that p-values less than or equal to 5% lead to a rejection of the null hypothesis. The Shapiro-Wilk test was conducted to validate the p-values obtained further, revealing similar results. The results are displayed in Table 2. Following these results, the study resorted to non-parametric statistics using the Median, Quartile Deviation, and Wilcoxon Signed Rank Test.

(INSERT TABLE 2)

Source: Table created by authors

4.3 Descriptive Statistics of Barriers to Design for Deconstruction Implementation

Table 3 presents the descriptive Statistics of Barriers to DfD Implementation. Following the rankings of the variables (barriers to the implementation of DfD) based on the Median, Quartile Deviation, mean score values, and standard deviations, "For recovered materials, there are little performance guarantees" came in first with a median of 5.00 and QD of 0.50. In contrast, "The absence of strict regulations regarding design for deconstruction" came in second with a median of 4.50 and QD of 0.50. The respondents perceive that recovered materials retrieved from deconstructions guarantee poor performance, discouraging most design professionals from designing for deconstruction. Also, there are no regulations modulating design for deconstruction, which does not encourage design experts to design structures for future recovery of materials that DfD offers. With the exact median of 4.0, "Lack of large market enough for components that have been recovered," "The need for building codes that address how to design with reused materials," "Lack of effective design for deconstruction tools," "Storage consideration for recovered materials," "Reliance on irreversible connections/fasteners or composite systems that necessitate destructive demolition," "Inadequate information available at the structure's design stage" "Inadequacy (at the time) in determining the environmental and economic benefits" and "Low disposal cost for demolition waste" came in third, fourth, fifth, sixth, seventh, eighth, ninth and tenth respectively. "Existing DfD tools do not adhere to BIM standards" took eleventh place with a median of 3.50 and QD of 0.50, while "A business case for DfD is difficult to create" took twelfth place with a median of 3.00 and QD of 0.50. From these results, a general conclusion can be made that respondents generally deem all variables as possible barriers to DfD implementation except for "A business case for DfD is difficult to create," with a median value less than the hypothesized median of 3.5. This further indicates that while business cases for DfD are challenging to create in other construction industries, especially in developed economies, the respondents in Ghana do not perceive it as a barrier. However, other pertinent barriers are crucial, as identified by the results. These results are in line with that of Akinade *et al*. (2020), Kanters (2018), and Kibert (2003), who revealed that the major obstacles to the implementation of DfD in the construction industry 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. Even though these studies were carried out in developed countries, the findings of this study reveal that the same barriers are paramount in developing countries such as Ghana. Further discussions of the results of this study have been elaborated in section 4.5 below.

(INSERT TABLE 3)

Source: Table created by authors

4.4. Significant Test of Barriers to Design for Deconstruction Implementation

After the Wilcoxon Signed Rank test was used to analyze the barriers to DfD implementation further to compare the medians of the sample to the hypothetical median as presented in Table 4, it was identified that out of the 12 variables, only 2 retained the null hypothesis. At the same time, the other 10 rejected the null hypothesis, indicating that the variables were statistically significant as barriers to the implementation of DfD in the GCI. This was based on the standard that H_o is rejected if the p-value is less than or equal to 0.05. This test confirms the descriptive test above, which showed that ten barriers had medians greater than the hypothetical median of 3.5.

(INSERT TABLE 4)

Source: Table created by authors

4.5 Discussion of Key Findings

The implementation of deconstruction in the early years of its origin was faced with challenges such as the use of composite systems or irreversible connections/fasteners that require destructive demolition, lack of tools for demolishing buildings, low cost of disposing off demolition waste, the requirement for building codes that specify how to use recycled materials in designs, and the inadequacy (at the time) in calculating the environmental and financial benefits (Kibert, 2003). The findings of this study have also revealed that these same challenges act as barriers to the implementation of DfD within the GCI. This discovery implies that the barriers that existed several years ago are still prevalent in this current era, and this displays how slow the construction industry is to accept change, especially in developing countries. Except for "a business case for DfD is difficult to create" and "existing DfD tools do not adhere to BIM standards" which were deemed insignificant by design professionals in Ghana, all other barriers to DfD implementation such as a lack of strict legislation for DfD, a lack of adequate information during the structure's design phase, a lack of a sizable market for recovered components, difficulty developing a business case for DfD, and a lack of effective design for deconstruction tools identified by Akinade *et al*. (2020) in their study were confirmed in this study.

In countries like Greece, Spain, and the UK, lack of information at the design stage was deemed a critical barrier to DfD implementation (Tzourmakliotou, 2021; Dodd *et al*., 2021; Akinade *et al*., 2017). However, the lack of performance guarantees on recovered materials was deemed the most critical barrier in Ghana. In Ghana, architects primarily represent the lead team player of the design team in most procurement systems (Pittri *et al*., 2023a). With this study having the majority of its respondents being architects and the results displaying little performance guarantee of recovered materials as the most critical barrier, it can be concluded that in Ghana, although inadequate information at the design stage can pose challenges to implementing DfD; it is not considered a critical barrier. The key barriers identified from the study are further elaborated below.

4.5.1 For recovered materials, there are few performance guarantees

According to the respondents, "*for recovered materials, there are few performance guarantees*" was ranked first as a barrier to implementing design for deconstruction in the GCI. Salama (2017) highlighted that the primary obstacle lies in the uncertainty surrounding the quality of reused materials. This means that construction stakeholders are concerned about the reliability and durability of materials salvaged from deconstructed buildings and reused in new construction projects. Therefore, it is critical to promote data collection on the performance of buildings and materials over time. This Long-term data can aid in understanding how various materials age and what factors influence their quality.

Designing for deconstruction, according to Hurley *et al*. (2002), entails creating flexible and adaptive structures made of deconstructible and reusable materials and components of sufficient quality for end-of-life disassembly, recovery, and reuse, which will be necessary to optimize the life of building materials and components through performance monitoring and feedback to design solutions that will permit this paradigm shift. However, the design professionals in the GCI perceive that there is no guarantee of the quality of the materials/components retrieved during deconstruction.

4.5.2 The absence of strict regulations regarding design for deconstruction

The second most significant hindrance to implementing design for deconstruction within the GCI is the need for more rigorous regulations centered on this concept. This finding is consistent with the discoveries of Akinade *et al*. (2020), who suggested that the lack of strict laws and regulations poses a challenge to adopting DfD in construction. It was pointed out that architects and design engineers lack ethical and legal mandates to ensure their designs can be thoroughly deconstructed at the end of their lifecycle. Tleuken *et al*. (2020) stressed how the need for more pertinent policies and regulations impacts the progress of DfD. Survey results from Hradil (2014) affirm that, in Finland, barriers to structure reuse are mainly related to legislative factors. Akinade *et al*. (2020)

also highlighted in their study that respondents concurred on the well-regulated nature of construction and demolition waste management in the UK and the recognized advantages of building deconstruction. However, no stringent legal or policy framework exists obligating clients and contractors to erect easily deconstructible facilities. Correspondingly, Ghanaian design professionals are free of such strict legislation or policies mandating the creation of deconstructible structures. This assertion indicates that effective implementation of DfD relies on essential government legislative and fiscal measures. This viewpoint is consistent with prior research (Ajayi *et al*., 2015; Lu and Yuan, 2010; Oyedele *et al*., 2013) that underscores the government's significant role in advancing the current global and national sustainability objectives.

4.5.3 Lack of a large market enough for components that have been recovered

The third most notable barrier highlighted by the study is the need for a sufficiently large market for reclaimed components. This discovery validates earlier research conducted by Akinade *et al*. (2020), affirming that the scarcity of a substantial market for reclaimed components hinders the successful integration of design for deconstruction within Ghana's construction industry. Tatiya *et al*. (2017) and Tingley and Davison (2011) also confirmed in their study that the market for salvaged products is marginal. Research indicates that the effectiveness of building deconstruction and component reuse relies on how salvaged materials align with supply and demand dynamics (Godichaud *et al*., 2012). These dynamics encompass various factors, such as managing the source of materials, having distribution points for selling materials, ensuring quality, standardizing and specifying products, certifying products, facilitating material transportation, having storage facilities, and enabling market access. As a result, establishing a sustainable pathway for bringing salvaged materials to the market is crucial. Therefore, there is a need to address market constraints for reclaimed materials, implying that interventions are needed to stimulate the development of a more substantial and viable market for these components to improve the successful adoption of DfD practices in Ghana's construction industry. Salama (2017) emphasized that a critical prospect for advancing DfD within the industrial market lies in diminishing the duration needed for building demolition and the labor invested in demolition processes. Another potential solution is policy initiatives, public awareness campaigns, or incentives to encourage the use and trading of reclaimed materials.

4.5.4 The need for building codes that address how to design with reused materials

Another impeding factor identified in the study is the need for building codes that address how to design with reused materials. This aligns with research conducted by Tleuken *et al*. (2020), which stated that the lack of construction codes addressing design for disassembly concepts (such as guidelines for designing methods and construction procedures) poses a significant legal barrier that obstructs the effective integration of design for deconstruction within the construction sector. However, the researchers emphasized that compliance with design for deconstruction is not mandated according to the local construction codes and regulations, and specific guidelines for such practices are absent. This means that, while there may be a need for more guidance, there is also no legal requirement to implement DfD strategies in construction projects. This same assertion applies in the Ghanaian context. However, Cristescu *et al*. (2020) pointed out that utilizing reclaimed timber in the production of cross-laminated timber is prohibited by European standards and codes of practice. This suggests that even though sustainability is emphasized, standards impose limitations that might hinder the use of certain types of reused materials. Additional limitations could also exist on a countrywide scale. For instance, the options for incorporating waste materials into construction in the United Kingdom are considerably constrained. The National House Building Council (NHBC), the largest insurance provider for new homes in the UK, exclusively permits the use of materials for reuse after obtaining their pre-approval (Cristescu *et al*., 2020). As a result, studying other countries' approaches to incorporating reclaimed materials and sustainable design practices may provide insights into how construction codes and standards can be developed or modified to support more environmentally friendly construction methods in Ghana's construction industry.

4.5.5 Lack of effective design for deconstruction tools

The absence of efficient tools for designing for deconstruction is the fifth major hindrance to implementing design for deconstruction within the construction industry of Ghana. This finding conforms to Akinade *et al*.'s (2020) study, which revealed that the obstacle to implementing DfD arises from the limitations of current tools in effectively assisting architects and design engineers with creating designs for building deconstruction. As a result, it is essential to promote the development and use of efficient tools designed specifically to assist architects and design engineers in implementing DfD principles. These tools should make it easier to design with deconstruction in mind.

According to Tingley and Davidson (2012), computer-aided tools and software such as Sakura (an online tool available for designers to examine the advantages of implementing DfD principles in their work), Deconstruction Material Estimating Tool (DMET) developed by National Defense Centre for Environmental Excellence (NDCEE), SMARTWaste^{TM}, which is a waste analysis tool that may also be used to offer pre-demolition audits and thus determine whether it is worth deconstructing the building for maximum material recovery, among others are crucial for making DfD implementation more accessible and faster. However, most construction industries, especially in developing countries, need access to these tools and software, making it difficult to easily embrace DfD (Guy and Ohlsen, 2003; Hobbs and Hurley, 2001).

5. Conclusion

The influence of design on the construction process of buildings and the compelling evidence supporting the idea that buildings designed for deconstruction can reduce landfill waste emphasize the need to comprehend how design choices impact how buildings are put together and taken apart. This study explored the barriers to implementing DfD in a developing country context. Using the quantitative approach, data was collected from design professionals in the GCI, including architects and civil engineers. Design professionals' data were analyzed using descriptive and inferential statistics. Results from the descriptive statistics conclude that respondents deem all variables possible barriers to DfD implementation in developing countries. However, the Wilcoxon Signed Rank Test results indicated ten (10) significant impediments to implementing DfD within the GCI. These impediments revolve around cost, legal matters, storage, incentive, and design-related matters.

5.1 Key Contributions of the Study

In terms of practice, this study indicates that manufacturers and policymakers can work together to establish standards for recovered materials, providing guarantees that enhance trust in the quality and durability of reused components. The study also emphasizes the importance of collaboration between the government, businesses, and NGOs to create platforms or marketplaces for buying and selling recovered construction materials. Furthermore, the study suggests expanding the market for reclaimed products, creating a national grading system, and establishing an information exchange service for recovered products. These measures are intended to facilitate disseminating deconstruction design and end-of-life practices. The study also highlights collaborative efforts involving academia, industry experts, and technology developers to create and promote user-friendly tools for designing with deconstruction in mind. Given the current level of understanding regarding the connection between DfD and sustainability in this study, there is an urgent need to take action. This involves developing best practices for achieving cradle-to-cradle design and construction through DfD, emphasizing ensuring compliance through appropriate legislation. Implementing stringent legislation and policies will also serve as a catalyst for establishing standardized DfD practices and guidelines.

In terms of theory, this research has identified obstacles to implementing DfD in a typical developing country context, specifically in Ghana, a facet that is currently underemphasized in existing literature. Recognizing these hindrances contributes to advancing knowledge in this field by contributing to the theoretical understanding of sustainable construction practices in developing countries, mainly focusing on the role of DfD.

5.2 Limitations of the Study

The study acknowledges certain limitations it encountered. To begin with, it concentrated solely on architects and civil/structural engineers within the GCI. This was due to the specific sampling technique employed, which excluded other design professionals like building services engineers and landscape architects. Future research endeavors could be undertaken to incorporate the perspectives of these omitted design professionals. Moreover, it may be beneficial to solicit input from demolition contractors in subsequent studies to comprehensively assess the value of DfD within the construction industry. Another limitation of this study is that most respondents were architects, meaning the findings can only be broadly applied to some design professionals.

5.3 Recommendations for Future Research

To address the gaps and limitations highlighted in the study, future research could include a more significant proportion of other design professionals to obtain a more universally applicable viewpoint. Also, in-depth case studies that focus on specific construction projects in developing countries to gain a deep understanding of the barriers faced during the DfD implementation are recommended for future studies. This could involve analyzing successful DfD projects and those that faced challenges. Furthermore, future studies are recommended to use advanced data analysis techniques such as machine learning, cluster analysis, retention analysis, predictive analysis, and multivariate analysis, among others, to expand the discussions on this study.

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Table 1: Summary of barriers to the implementation of DfD in the construction industry

Barriers to DfD Implementation in the construction industry	Source (s)
The absence of strict regulations regarding design for deconstruction	(Roxas *et al*. 2023; Tzourmakliotou, 2021; Dood *et al*., 2021; Akinade *et al*., 2020; Akinade *et al*., 2017)
Inadequate information available at the structure's design stage	(Tzourmakliotou, 2021; Dood *et al*., 2021; Akinade *et al*., 2020)
Lack of a large market enough for components that have been recovered	(Akinade *et al*., 2020)
A business case for DfD is difficult to create	(Akinade *et al*., 2020)
Lack of effective design for deconstruction tools	(Akinade *et al*., 2020; Kibert, 2003)
Reliance on irreversible connections/fasteners or composite systems that necessitate destructive demolition	(Salma, 2017; Kibert, 2003)
Storage consideration for recovered materials	(Akinade *et al*., 2020)
Low disposal cost for demolition waste	(Tleuken *et al*., 2022; Salma, 2017; Kibert, 2003)
The need for building codes that address how to design with reused materials	(Kibert, 2003)
Inadequacy (at the time) in determining the environmental and economic benefits	(Kanters, 2018; Akinade *et al*., 2017; Kibert, 2003)
Existing DfD tools do not adhere to BIM standards	(Marzouk and Elmaraghy, 2021; Akbarieh *et al*., 2020)
For recovered materials, there are little performance guarantees.	(Tzourmakliotou, 2021; Dood *et al*., 2021; Salma, 2017)

Source: Table created by authors

Table 2. Tests of Normality of Barriers to Design for Deconstruction Implementation

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	p-value	Statistic	df	p-value
The absence of strict regulations regarding design for deconstruction	0.276	240	0.000	0.685	240	0.000
Inadequate information available at the structure's design stage	0.200	240	0.000	0.852	240	0.000
Lack of a large market enough for components that have been recovered	0.257	240	0.000	0.772	240	0.000
A business case for DfD is difficult to create	0.212	240	0.000	0.880	240	0.000
Lack of effective design for deconstruction tools	0.259	240	0.000	0.797	240	0.000
Reliance on irreversible connections/fasteners or composite systems that necessitate destructive demolition	0.249	240	0.000	0.819	240	0.000
Storage consideration for recovered materials	0.265	240	0.000	0.808	240	0.000
Low disposal cost for demolition waste	0.256	240	0.000	0.830	240	0.000
The need for building codes that address how to design with reused materials	0.262	240	0.000	0.733	240	0.000
Inadequacy (at the time) in determining the environmental and economic benefits	0.256	240	0.000	0.837	240	0.000
Existing DfD tools do not adhere to BIM standards	0.203	240	0.000	0.885	240	0.000
For recovered materials, there are little performance guarantees.	0.334	240	0.000	0.737	240	0.000

a. Lilliefors Significance Correction

Source: Source: Table created by authors

Table 3. Descriptive Statistics of Barriers to Design for Deconstruction Implementation

	Mean	Median	Std. Deviation	QD	Rank
The absence of strict regulations regarding design for deconstruction	4.29	4.5	0.959	0.50	2nd
Inadequate information available at the structure's design stage	3.91	4.0	0.981	1.00	8th
Lack of a large market enough for components that have been recovered	4.15	4.0	1.023	0.50	3rd
A business case for DfD is difficult to create	3.43	3.0	1.020	0.50	12th
Lack of effective design for deconstruction tools	4.08	4.0	1.019	0.50	5th
Reliance on irreversible connections/fasteners or composite systems that necessitate destructive demolition	4.02	4.0	0.983	1.00	7th
Storage consideration for recovered materials	3.96	4.0	1.138	0.88	6th
Low disposal cost for demolition waste	3.79	4.0	1.209	1.00	10th
The need for building codes that address how to design with reused materials	4.15	4.0	1.100	0.50	4th
Inadequacy (at the time) in determining the environmental and economic benefits	3.90	4.0	1.022	1.00	9th
Existing DfD tools do not adhere to BIM standards	3.57	3.5	1.068	0.50	11th
For recovered materials, there are little performance guarantees.	4.26	5.0	0.998	0.50	1st

QD: Quartile Deviation

Source: Table created by authors

Table 4. Significant Test of Barriers to Design for Deconstruction Implementation using Wilcoxon Signed Rank Test

	Test Statistic	Std. Error	Std. Test Statistic	P-value	Decision
The absence of strict regulations regarding design for deconstruction	25195	1046.129	10.262	0.000	Reject H_o
Inadequate information available at the structure's design stage	20934	1039.477	6.228	0.000	Reject H_o
Lack of a large market enough for components that have been recovered	23260	1043.707	8.431	0.000	Reject H_o
A business case for DfD is difficult to create	13881.5	1022.197	-0.566	0.571	Retain H_o
Lack of effective design for deconstruction tools	22770	1044.762	7.954	0.000	Reject H_o
Reliance on irreversible connections/fasteners or composite systems that necessitate destructive demolition	22288	1043.327	7.503	0.000	Reject H_o
Storage consideration for recovered materials	20.915	1046.645	6.167	0.000	Reject H_o
Low disposal cost for demolition waste	19195	1049.045	4.514	0.000	Reject H_o
The need for building codes that address how to design with reused materials	23340	1048.238	8.471	0.000	Reject H_o
Inadequacy (at the time) in determining the environmental and economic benefits	21152	1040.197	6.433	0.000	Reject H_o
Existing DfD tools do not adhere to BIM standards	15.795	1036.854	1.288	0.198	Retain H_o
For recovered materials, there is little performance guaranteed.	24,535	1041.509	9.673	0.000	Reject H_o

Hypothetical Median = 3.5

Source: Source: Table created by authors

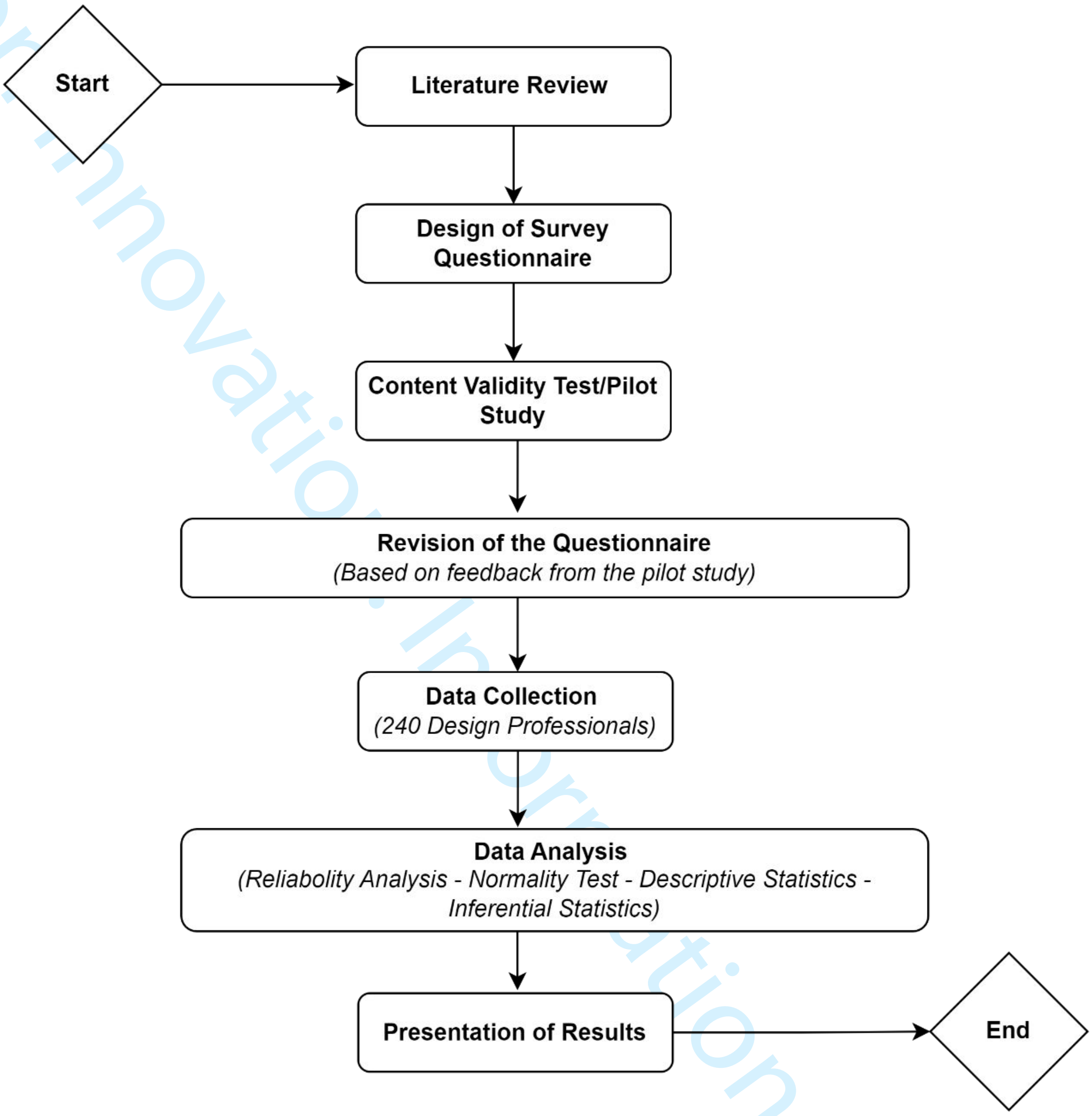

Figure 1. Flow chart of adopted methodology

Source: Figure created by authors