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Evaluation of the benefits of design for deconstruction adoption for sustainable construction in the Nigerian construction industry

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Abstract

The predominance of a linear economic model and the limited integration of circular strategies in the design and execution of building projects—particularly in the construction sectors of developing countries—have resulted in ongoing pressure on natural resources, high levels of waste generation, reduced productivity, and frequent time and cost overruns. Collectively, these issues contribute to unsustainable development, adversely impacting the social, economic, and environmental dimensions of sustainability. This study explores the perceptions of design professionals regarding the benefits, awareness, and implementation of Design for Deconstruction (DfD) within the Nigerian construction industry (NCI). Data were collected through a structured questionnaire distributed electronically to design experts in Nigeria's South-South geopolitical zone using a snowball sampling technique. With a 40.10% response rate and a reliability index above 0.800, the data were analysed using Exploratory Factor Analysis (EFA) and Partial Least Squares Structural Equation Modelling (PLS-SEM). Findings reveal that awareness of DfD is moderate, but its adoption remains low. EFA identified five key categories of DfD benefits: (1) business benefits, (2) economic benefits, (3) environmental benefits, (4) green certification and technology integration, and (5) social benefits. PLS-SEM results show that all five categories have a positive and significant influence on the decision to adopt DfD within the NCI. This study contributes to the theoretical advancement and practical understanding of circular construction practices, particularly DfD, with implications for reducing construction waste, improving resource efficiency, and supporting the achievement of Sustainable Development Goals (SDGs) 3, 9, 11, 12, and 13.

Keywords: Deconstruction, circular design, benefits, sustainable construction, waste minimisation, construction industry, Nigeria

1. Introduction

The construction industry's response to the pressures of industrialisation, urbanisation, and globalisation has led to an increased extraction and consumption of natural resources. This is evident in the growing number of housing and infrastructure projects, which are accompanied by high levels of harmful gas emissions and significant volumes of construction waste−much of which ends up in landfills due to the dominance of the linear production model[1,2]. According to the literature, the global construction industry consumes approximately 40% of raw materials and contributes a similar share (40%) of global carbon emissions[3,4]. Additionally, it accounts for 45% of global energy consumption and 40% of waste generation[5,6]. Currently, the rate at which natural resources are being depleted far exceeds nature's ability to regenerate them[7,8]. If substantial changes are not made to reduce the environmental impact of construction activities, the situation is expected to worsen significantly by 2050, when the global population is projected to reach 9.7 billion[7].

One of the most effective approaches to reducing pressure on natural resources and minimising landfill waste is the adoption of circular economy (CE) strategies[9-11]. CE promotes the conservation of material value through the reuse, repurposing, refurbishment, repair, and remanufacturing of building components at the end of a building's life cycle (EoL)[9]. Key CE practices for reducing construction waste include deconstruction, prefabrication, and modular construction[12]. Among these, Design for Deconstruction (DfD) is a core CE principle and a modern construction method gaining growing attention[9,13], as resource efficiency and waste reduction must begin at the design and preconstruction stages[5,10,14,15]. The design phase is widely regarded as the most effective point for implementing CE strategies[16]. Suleman *et al.*[5] advocate for circular design (CD) at the design stage due to its advantages across the building life cycle. DfD specifically addresses the EoL stage by enabling buildings or their components to be deconstructed with minimal effort and material loss[17]. The DfD approach facilitates the efficient, economical disassembly of construction materials for reuse and recycling[18,19].

The adoption and implementation of CE and DfD practices are significantly more advanced in developed nations such as the USA, European countries, Japan, New Zealand, and Australia[20], compared to developing countries like Nigeria. This disparity is largely attributed to technological, economic, and geographical differences[5]. Nigeria, a leading developing nation in Africa, has relatively low uptake of DfD practices[5,10], compounded by persistent challenges such as time and cost overruns, declining productivity, high waste generation, and excessive landfill accumulation[15]. Economic constraints and a lack of knowledge further limit the diffusion of circular design in Nigeria[10]. Despite the significance of DfD principles, their practical application remains limited due to the absence of enabling tools and technical expertise[21]. Limited awareness and understanding of DfD are major barriers to its wider adoption and are key contributors to industry resistance[17]. Construction waste is a growing concern in Nigeria, where the population is expanding rapidly. Ibe[22] notes that with a population exceeding 200 million, the Nigerian construction industry (NCI) generates approximately 3 million tons of construction and demolition waste annually. Materials wasted in the construction of 100 housing units could be sufficient to build an additional 10 homes[23], highlighting not only environmental implications but also economic and social consequences. These issues are largely the result of linear (non-circular) practices, alongside poor recycling and inefficient waste management[15,24]. Furthermore, like many other developing nations, the NCI lags behind in adopting innovative and sustainability-driven approaches[25].

A review of the literature reveals limited research on DfD at the international level, with only a few studies from the UK[13,26,27], USA[28], Central Asia[9], and Ghana[19,29]. Within Nigeria, DfD remains an underexplored topic, with scant literature available. For example, Suleman *et al.*[10] examined challenges to circular design adoption among construction experts, while Akinwonmi and Ilesanmi[30] evaluated deconstruction techniques. These studies focused on professionals in Lagos State and employed descriptive statistics and principal component analysis for data evaluation. The limited research on DfD in Nigeria—particularly in the South-South region—underscores the need for region-specific investigations. While most existing studies are based on mature construction markets in the USA, Europe, and the UK, their findings have limited applicability in developing countries like Nigeria[19,29]. Therefore, a more context-specific study is essential to raise awareness and enhance understanding of DfD principles in regions where traditional construction methods still dominate. While previous studies offer valuable insights, they also serve as a foundation for this study, which aims to examine the potential benefits of DfD in Nigeria, with a particular focus on design experts in the South-South region. This study also assesses the awareness and implementation levels of DfD among Nigerian design professionals. In addition to descriptive and exploratory factor analysis, Partial Least Squares Structural Equation Modelling (PLS-SEM) is employed to evaluate the relationship between perceived DfD benefits and its adoption in construction. The use of PLS-SEM addresses a methodological gap in existing research. Akinwonmi and Ilesanmi[30] assert that inadequate awareness and adoption of deconstruction approaches are key contributors to high waste levels and resource inefficiencies in the NCI. Enhancing knowledge and awareness of DfD benefits is expected to drive broader adoption among Nigerian design professionals. Ultimately, this study aims to raise awareness among construction stakeholders—including clients, contractors, and professionals—regarding the advantages of this sustainable construction approach, thereby stimulating market demand, reducing waste generation, and improving resource efficiency.

2. Literature review

2.1 Awareness and practice level of design for deconstruction in construction

In Ghana, studies have shown that knowledge, awareness, and implementation of DfD among design professionals remain low, primarily due to limited training and the absence of formal education on the concept[19,29]. Although awareness of DfD has gradually increased, it continues to receive limited attention in practice, largely because of the lack of technical expertise and supporting tools necessary for its implementation[13,21]. In Central Asian countries, EoL considerations are often overlooked, contributing to the low level of DfD practice[9]. This can be attributed to the fact that DfD has not yet been embraced in local regulatory frameworks or construction codes, which currently do not mandate or provide guidelines for its application[9].

Although DfD principles have been recognised for decades, their potential to reduce construction and demolition waste has yet to be fully realised. Remarkably, fewer than 1% of existing building stocks are fully demountable[31]. In the context of the NCI, awareness-related issues continue to hinder the adoption of deconstruction techniques[30].

2.2 Benefits of DfD in construction

Deconstruction offers multifaceted benefits and is garnering increasing attention across various communities as a more sustainable alternative to conventional demolition practices[32]. It delivers advantages not only to individuals and communities but also to the natural environment and the broader economy[19,29,33]. As a logical substitute for demolition, deconstruction provides a range of benefits, including reduced replacement costs through material reuse and recycling, decreased energy demand for manufacturing new components, and the creation of new employment opportunities and market sectors[34].

Demountable building components (e.g., walls), can be reused to improve room and office privacy, enhance spatial flexibility, and support a productive working environment, while also facilitating technology integration into building projects. DfD serves as a cost-effective construction method; once demountable components are acquired, they can be reused multiple times and integrated with existing structures. This approach allows for rapid transportation, easy assembly, long-term use, business and environmental performance improvements, and scalable expansion when additional space is required[35-37].

Deconstruction also mitigates greenhouse gas (GHG) emissions by significantly reducing emissions generated during demolition activities. In the United States alone, over 500 million tons of construction debris are produced annually—enough to build a 30-foot-high, 30-foot-thick wall around the country's entire coastline[38]. Deconstruction reduces the environmental impact of resource extraction, supports the use of locally sourced materials, decreases landfill dependency, and promotes the sustainable repurposing of building materials[33]. According to Rios *et al.*[39], DfD benefits can be classified into environmental, economic, social, and other categories. Environmentally, DfD extends the life of raw material sources, reduces the cost of construction materials, and lowers carbon emissions and embodied energy in buildings. It is a proven method for minimising construction and demolition waste[13]. Minunni *et al.*[40] found that circular design strategies can facilitate disassembly, achieving up to an 88% reduction in GHG emissions and at least an 87% reduction in acidification potential. These environmental benefits are further supported by studies[41,42]. Additionally, DfD fosters the creation of markets for reusable components, reduces landfill pressure, frees up land for housing, and provides access to affordable building materials.

The circular design approach discourages waste generation from demolition activities and provides additional benefits, including reductions in GHG emissions and pollution, conservation of biodiversity, job creation, improved community health, and progress toward sustainability goals[43]. Some studies suggest that embodied carbon emissions could be reduced by as much as 90% by incorporating component reusability features into building design[44], underscoring the critical role of EoL planning in reducing both waste and carbon footprints[45].

Unlike demolition, deconstruction is labor-intensive and time-consuming, thereby generating more employment opportunities. According to the U.S. Environmental Protection Agency[38], recycling activities in 2012 accounted for 681,000 jobs, $37.8 billion in wages, and $5.5 billion in tax revenues. Deconstruction promotes vocational training and green-collar job creation—aligning with many nations' pursuit of green economies. It also facilitates the reuse of household items and building components, significantly lowering material costs. Communities and businesses can thus access affordable materials, contributing to cleaner, safer neighborhoods. Moreover, the careful dismantling of building components offers opportunities for architectural preservation and the conservation of natural resources[33,38].

Decision-makers increasingly prefer deconstruction over demolition due to its positive social impacts, such as improved safety, enhanced worksite conditions, and greater community engagement. Deconstruction reduces the risk of injuries and exposure to hazardous materials associated with traditional demolition, while simultaneously creating employment and training opportunities[46,47]. DfD also fosters community empowerment, as residents are reassured that buildings retain residual value even at their end of life. It alleviates storage issues for salvaged materials, supports the preservation of regional architectural heritage, and cultivates a mindset conducive to adopting other green building practices[48].

From an economic standpoint, deconstruction strengthens local economies by promoting material reuse and recycling[38]. It results in cost savings for contractors through reduced landfill fees and demolition time, thereby improving project cost and schedule performance. It also makes materials more accessible and affordable for the construction and repair of homes, particularly those intended for the elderly and vulnerable populations. Furthermore, it can reduce tax burdens for contractors, as surplus disassembled materials may be exempt from disposal taxes[33]. Overall, deconstruction improves cost-efficiency, enhances productivity, and elevates quality in construction[49]. Circular economy strategies such as DfD also promote innovation within the industry[45,50], optimise resource utilisation, and offer better returns on investment[51].

2.3 Conceptual framework

DfD refers to the process of designing buildings and other engineering structures in a manner that facilitates future modification (alteration) and systematic dismantling—either in whole or in part—for the purpose of salvaging materials, components, and systems[52,53]. It is a proactive design practice that integrates considerations of reusability and recyclability of building elements during the planning and design phases. The core objective is to simplify disassembly at the building's EoL stage[54].

DfD has been described as an innovative and adaptive design approach that enables the reuse of structural materials and components[19]. It involves the adoption of construction techniques and methods that are resilient to frequent maintenance requirements. For example, DfD often employs modular or prefabricated components that can be systematically assembled on-site using bolts, screws, and other flexible jointing methods, with design features that ensure ease of access and eventual removal[9].

Guy and Ciarimboli[53] outline several core principles of DfD, which serve as guidelines for creating buildings that are easier to dismantle and repurpose. These principles include:

i. Ensure detailed documentation of the system, materials, components, and deconstruction techniques to facilitate future disassembly.

ii. Design connections in a way that makes them easily accessible for dismantling and reassembly.

iii. Provide a clear distinction between components that are recyclable, reusable, and those that must be disposed of.

iv. Standardise the design of components and dimensions to promote compatibility, interchangeability, and ease of reuse.

v. Incorporate design practices that support efficient labour use, meet safety requirements, and enhance productivity during both construction and deconstruction processes.

The systematic and strategic integration of DfD principles into building and infrastructure projects aims to facilitate dismantling, reuse, repurposing, and recycling at the end of a project's life cycle. DfD is a sustainable construction approach that aligns closely with the principles of the circular economy and broader sustainability goals. According to Broniewicz and Dec[52], DfD is consistent with CE concepts and has far-reaching impacts across the social, environmental, and economic dimensions of sustainability. Therefore, implementing DfD in construction represents a practical application of circular economy principles, serving as a mechanism to promote social equity, environmental protection, and economic efficiency within the built environment.

The disassembly of buildings facilitates the recovery, reuse, and recycling of materials, thereby supporting a circular economy that encompasses social, environmental, and economic dimensions[21]. The adoption of DfD plays a critical role in accelerating the transition toward CE practices and enables sustainable development within the construction industry. It offers a practical means to advance circularity and enhance the efficiency of waste minimisation and management in construction activities[49]. Deconstruction serves as a viable solution to the numerous environmental and economic challenges posed by conventional demolition practices in the built environment. Demolition contributes to increased waste generation and escalates the demand for new materials and products, thereby intensifying the strain on the Earth's finite natural resources[12]. Moreover, the demolition approach is often associated with high costs, and the majority of resulting waste ends up in landfills, negatively affecting environmental aesthetics and ecosystem health. Therefore, enhancing knowledge and raising awareness of the benefits of DfD could significantly promote its broader adoption and implementation. This, in turn, would support the advancement of sustainable construction practices and reduce construction-related waste generation in Nigeria (Figure 1).

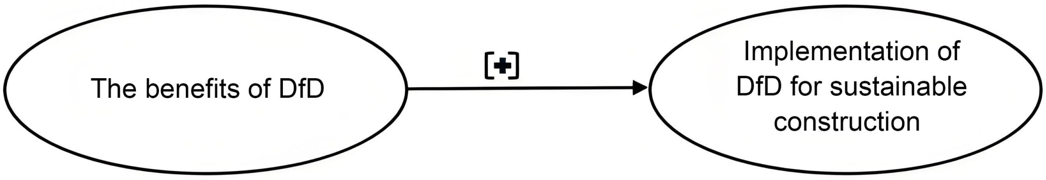

Figure 1. Impact of benefits of DfD in sustainable development. DfD: design of deconstruction.

3. Research Methodology

This study adopted a quantitative research approach underpinned by a post-positivist philosophical paradigm to achieve its objectives. This approach enabled the use of structured questionnaires to collect numerical and objective data from targeted participants, which were then subjected to appropriate statistical and mathematical analyses. The questionnaire method was chosen due to its cost-effectiveness and suitability for reaching respondents across a wide geographical area, allowing data collection to take place remotely[55]. This approach aligns with methodologies employed in similar studies[13,19,29].

The questionnaire was administered to design experts—specifically architects and engineers—in the South-South region of Nigeria, which comprises six states (Akwa Ibom, Bayelsa, Cross River, Delta, Edo, and Rivers) forming part of the Niger Delta. These professionals were selected due to their core responsibilities in building and engineering design, material selection, and construction technique specification[56]. The questionnaire was developed using variables identified through a comprehensive, random, and non-systematic literature review that was not restricted to a single database, thus enabling a broader synthesis of concepts[15,57]. This review yielded 31 variables related to the perceived benefits of DfD, which were incorporated into the questionnaire (Table 1).

The questionnaire consisted of two sections: the first collected information on respondents' profiles and their levels of awareness and adoption of DfD, while the second focused on participants' perceptions of the benefits of DfD in building and civil engineering construction. Respondents rated each item on a five-point Likert scale (1 = strongly disagree, 2 = disagree, 3 = moderately agree, 4 = agree, and 5 = strongly agree). A pilot survey was conducted to validate the questionnaire's clarity and relevance, involving six academics at the rank of Senior Lecturer and five senior design professionals. Feedback from the pilot survey led to refinements that enhanced the instrument's effectiveness in capturing the intended data.

Table 1. Benefits of design for deconstruction.

Item Code	Benefits	Literature source(s)
BDF1	Reduced greenhouse gas emissions from demolition works	[32,33,38,39,43]
BDF2	minimise energy requirement for new materials production	[30,34]
BDF3	Minimise the dangerous effects of Earth's resource extraction	[5,10,19,29,33]
BDF4	Improve the use of locally sourced materials	[5,10,19,29,33]
BDF5	Reduce the need for landfills	[5,10,19,29,33]
BDF6	Recycling helps to repurpose building materials.	[5,10,19,29,33]
BDF7	Lead to a more sustainable handling of materials	[5,10,19,29,33]
BDF8	Conservation of natural resources	[38]
BDF9	Improve quality, which minimises waste of products and materials	[49]
BDF10	Job creation	[5,10,33,34,38]
BDF11	It promotes career and vocational opportunities for the workforce.	[21,33]
BDF12	Allow communities to reuse building components and materials	[21,33]
BDF13	preservation of architectural history	[33,48]
BDF14	More materials and components can be purchased by communities and businesses.	[33,48]
BDF15	Cost savings due to reuse and repurposing	[5,10,33,34,39,40]
BDF16	Reduce dumping and demolition charges	[5,10,33,40]
BDF17	Support cheap repairs and new home provision for elderly and vulnerable people	[5,10,33]
BDF18	Excess materials can be disposed of with reduced tax	[5,10,33]
BDF19	Source of livelihood for designers and builders alike and artists	[5,10,33]
BDF20	Allow recycling of materials, which strengthens the economy	[38]
BDF21	Enhance productivity and performance	[36,49]
BDF22	creation of a new market for manufacturers	[52]
BDF23	influence products and materials design for the new market	[52]
BDF24	green rating and certification of buildings	[39-40]
BDF25	Increase space flexibility	[35-37]
BDF26	Enhance technology integration	[35-37]
BDF27	Integration with existing building	[35-37]
BDF28	Improve building aesthetics	[35-37]
BDF29	Demountable components allow for speedy building assemble	[35-37]
BDF30	Components can be transported quickly and easily	[35-37]
BDF31	Increase business performance	[35-37]

The selection of design experts for this study was guided by three key criteria: (1) familiarity with DfD practices, (2) a minimum of five years of professional experience, and (3) active involvement in building and construction projects within the study area. Due to the difficulty in establishing a comprehensive sampling frame of experts who met these conditions, a non-probabilistic snowball sampling technique was adopted. This approach was chosen based on the premise that it could yield a sufficiently representative sample, particularly in contexts where the target population is not clearly defined. Snowball sampling relies on referrals from one participant to another, which helps to expand the sample size[58], and has been effectively employed in previous construction management studies involving unknown populations[59,60]. Given the lack of a known sampling frame, Cochran's formula[61] was used to determine an appropriate sample size to guide data collection, consistent with its application in similar studies within the construction management domain[60,62].

$$n = \frac{p(1-p)Z^2}{e^2} \tag{1}$$

Where n represents the desired sample size, p is the estimated proportion of the population, Z is the Z-score corresponding to the desired confidence level (1.96 for 95% confidence), and e denotes the margin of error (set at 5%). Based on this formula, a sample size of 384 was calculated and adopted to guide the questionnaire survey. The questionnaire was designed using Google Forms and distributed to an initial group of design experts identified during a preliminary study. To ensure that only qualified individuals participated, the inclusion criteria were clearly stated at the beginning of the questionnaire. This measure was taken to enhance data quality and minimise response bias.

After a data collection period spanning 17 weeks, a total of 162 responses were received, out of which 154 were deemed valid for analysis. This corresponds to a response rate of 40.10%, which exceeds the 30% threshold commonly recommended for survey-based studies[63]. Descriptive statistics, including frequencies and percentages, were used to analyse the demographic profiles of the respondents. Exploratory Factor Analysis (EFA) was conducted to reduce the dimensionality of the dataset and group related variables into underlying constructs using Principal Component Analysis (PCA). In addition, PLS-SEM was employed to examine the relationships between the identified constructs and their associated variables.

PLS-SEM was selected over covariance-based SEM due to its greater robustness in handling small sample sizes, its relaxed assumptions regarding data normality, and its superior model prediction capabilities[64]. Therefore, the sample of 154 valid responses was considered adequate for the PLS-SEM analysis. Furthermore, the Cronbach's alpha value obtained from the reliability test was 0.843, indicating a high level of internal consistency and confirming the reliability of the research instrument and the quality of data collected from the design professionals. An overview of the research methodology is presented in Figure 2.

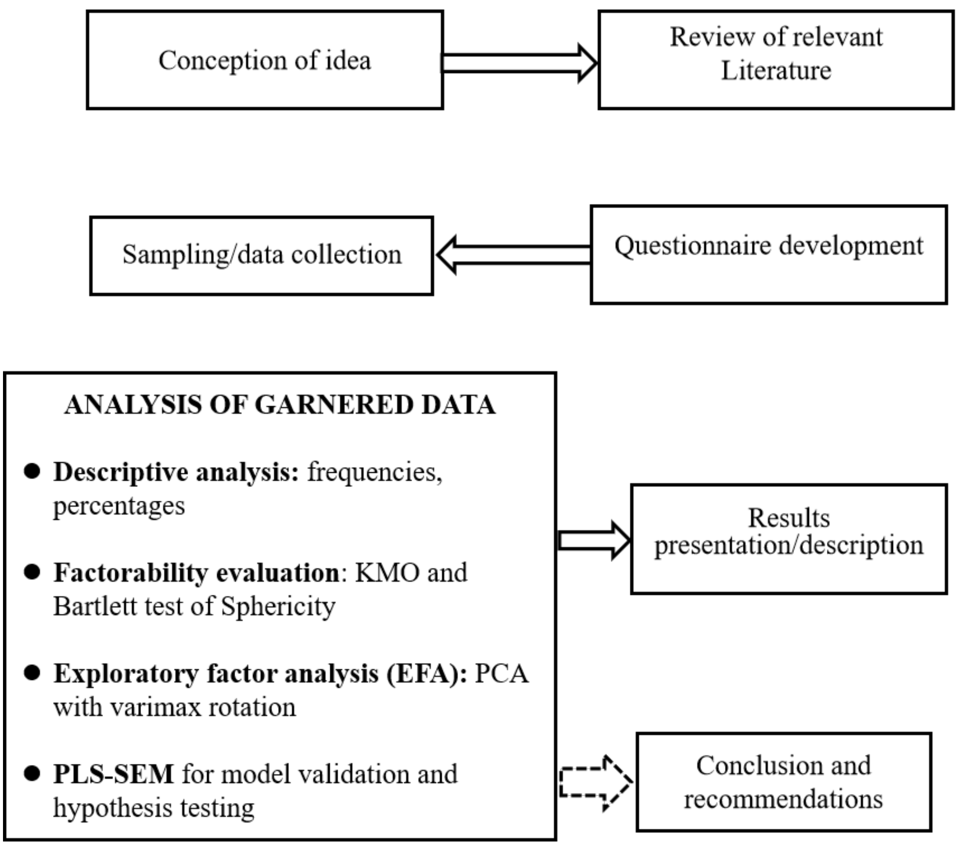

Figure 2. Flow chart of research approach. KMO: Kaiser-Meyer-Olkin; PCA: principal component analysis; EFA: exploratory factor analysis; PLS-SEM: partial least square-structural equation modelling.

4. Results and Discussion

4.1 Respondents' Background Information

The analysis of the respondents' background information, as illustrated in Figure 3, reveals that 52.60% of the design experts were architects, while 47.40% were engineers. In terms of organisational affiliation, 47.40% of the participants were employed by contracting firms, 31.82% by consulting firms, and 20.78% by client organisations. Regarding professional experience, 22.73% had 5-10 years of industry experience, 38.31% had 11-15 years, 25.32% had 16-20 years, and 13.64% had been in the industry for more than 21 years.

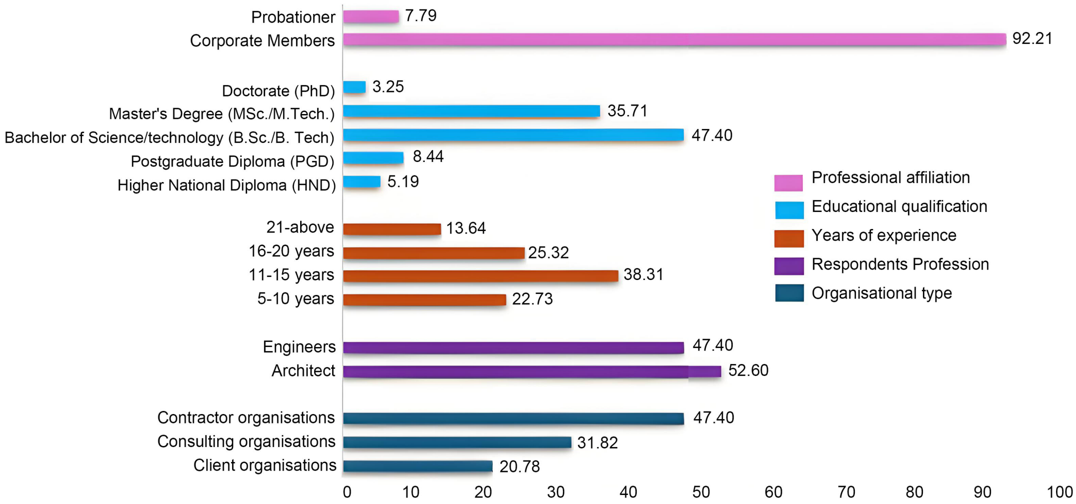

Figure 3. Respondents' demographic information.

In terms of educational qualifications, 5.19% of the respondents held a Higher National Diploma, 8.44% held a Postgraduate Diploma, 47.40% held a bachelor's degree, 35.71% held a master's degree, and 3.25% held a doctoral degree. Additionally, 92.21% of the participants were corporate members of professional bodies, while 7.79% were probationer members.

Overall, these findings indicate that the survey participants possess the requisite experience, qualifications, and professional affiliations to provide informed responses, thereby supporting the reliability and validity of the study's outcomes.

4.2 Level of awareness and adoption of DfD techniques in building construction

The results presented in Figure 4 reveal a noticeable disparity between the level of awareness and the level of adoption of DfD techniques among design professionals. The mean score for awareness was 3.097, representing 61.95%, indicating a moderate level of awareness. In contrast, the mean score for adoption was significantly lower at 1.78, equivalent to 35.58%. This suggests that while awareness of DfD techniques among professionals in the NCI is at an average level, actual implementation remains considerably low.

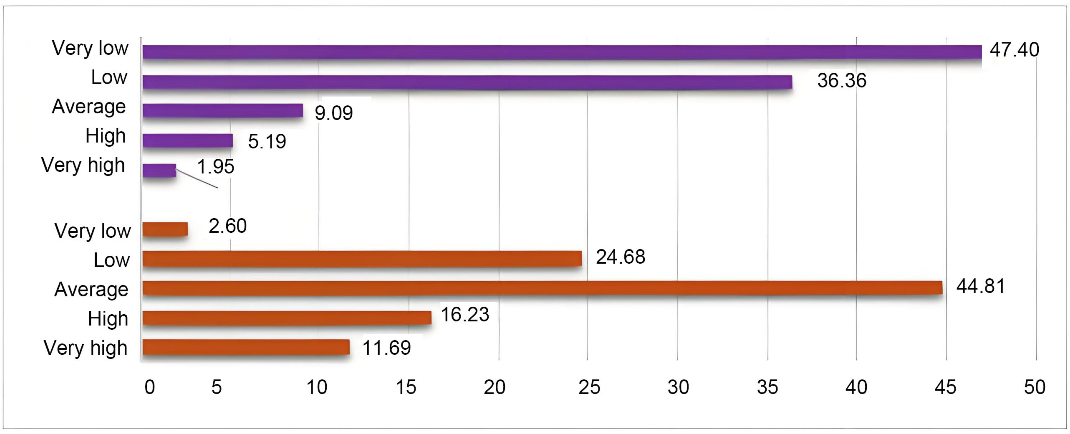

Figure 4. DfD awareness and adoption levels in NCI. DfD: design of deconstruction; NCI: Nigerian construction industry.

4.3 Adequacy and factorability assessment of EFA

To determine the suitability of the collected data for factor analysis, the Kaiser-Meyer-Olkin (KMO) measure, Bartlett's test of sphericity, and communalities were assessed (Table 2). The KMO value was 0.806, which exceeds the recommended threshold of 0.60[65], indicating sampling adequacy. Bartlett's Test yielded a high chi-square value of 2,331.517 with a p-value of 0.000, confirming statistical significance at $p < 0.05$. The average communalities score was 0.693, which is well above the 0.50 minimum criterion, suggesting that the extracted factors are well represented within the dataset[66]. Additionally, with high communalities, the influence of sample size on factor analysis becomes less critical[67].

Table 2. KMO and Bartlett's test & communalities.

KMO and BTS		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.806
Bartlett's Test of Sphericity	Approx. Chi-Square	2,331.52
	df	465
	Sig.	0.000
Communalities		
Minimum value		0.519
Maximum value		0.832
Average value (for 31 variables)		0.693

KMO: Kaiser-Meyer-Olkin; BTS: Bartlett's test of sphericity.

Having confirmed the data's adequacy and factorability, PCA was conducted using varimax rotation. The PCA yielded a five-component solution with eigenvalues ≥ 1 and factor loadings ≥ 0.50, accounting for a cumulative variance of 57.105%, which exceeds the recommended 50% threshold for extracted factors[67]. As shown in Table 3, a total of 27 items met the minimum loading requirement (≥ 0.50) and were retained within the five-component structure. Each component was subsequently named based on a critical examination of the underlying characteristics of the loaded items.

Table 3. Rotated Component Matrix for the benefits of DfD.

Item code	Component name and Loaded items	Component					Total Eigenvalues	% of Variance	Cumulative %
		1	2	3	4	5			
A	**Environmental benefits**								
BDF1	Reduced greenhouse gas emissions from demolition works	0.843					7.778	25.089	25.089
BDF6	Recycling helps to repurpose building materials.	0.801							
BDF3	Minimise the dangerous effects of Earth's resource extraction	0.792							
BDF20	Allow recycling of materials, which strengthens the economy	0.742							
BDF7	Lead to a more sustainable handling of materials	0.688							
BDF8	Conservation of natural resources	0.629							
BDF4	Improve the use of locally sourced materials	0.550							
BDF9	Improve quality, which minimises waste	0.534							

	of products and materials								
BDF28	Improve building aesthetics	0.501							
B	**Social benefits**								
BDF19	Source of livelihood for designers and builders alike and artists		0.822				2.365	7.628	32.717
BDF10	Job creation		0.769						
BDF17	Support cheap repairs and new home provision for elderly and vulnerable people.		0.716						
BDF14	More materials and components can be purchased by communities and businesses.		0.694						
BDF13	preservation of architectural history		0.601						
BDF12	Allow communities to reuse building components and materials.		0.559						
BDF11	It promotes career and vocational opportunities for the workforce.		0.523						
C	**Business benefits**								
BDF21	Enhance productivity and performance.			0.856			2.169	6.997	39.714
BDF29	Demountable components allow for speedy building assembly.			0.783					
BDF30	Components can be transported quickly and easily.			0.564					
BDF31	Increase business performance			0.500					
D	**Economic benefits**								
BDF22	creation of a new market for manufacturers				0.716		1.952	6.298	46.012
BDF18	Excess materials can be disposed of with reduced tax.				0.623				
BDF25	Increase space flexibility				0.596				
BDF2	minimise energy requirement for new materials production				0.525				
E	**Green Certification and Technology Integration**								
BDF24	green rating and certification of buildings					0.736	1.646	5.308	57.105
BDF26	Enhance technology integration					0.549			
BDF27	Integration with existing building					0.507			

DfD: design of deconstruction.

4.4 Hypothesis and conceptual framework

The EFA was used to reduce the 31 variables on the benefits of DfD as perceived by the design experts, into 5 major constructs. Based on these constructs, five hypotheses were developed to guide the study. These hypotheses were incorporated into the study's conceptual framework (Figure 5) and subsequently tested using PLS-SEM.

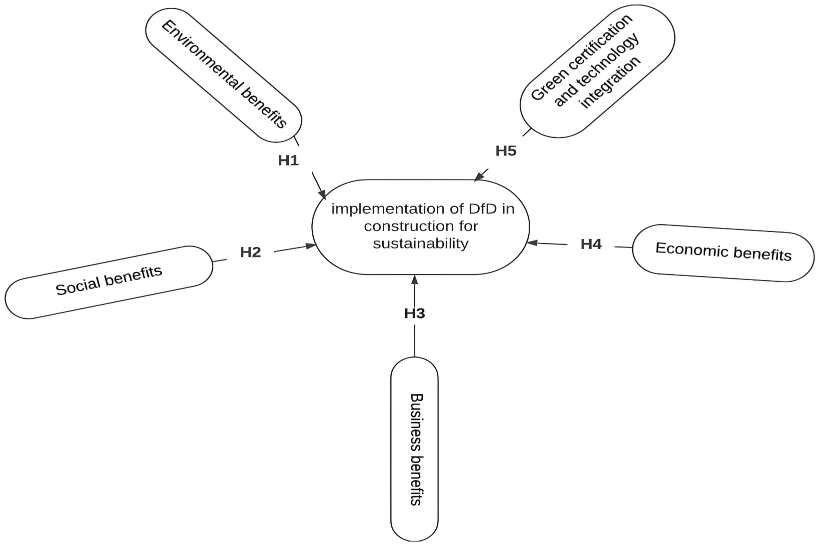

Figure 5. Hypothetical path and conceptual framework.

H1: *Environmental benefits can cause a positive and significant impact on the decision to adopt DfD in construction for sustainable development.* Circular design principles aid in building structure disassembling at end-of-life, which impacts the environment by reducing acidification and greenhouse gas emissions by 87% and 88%, respectively[40]. The environmental benefits of DfD that could enhance the decision to implement the circular design principles include resource conservation, reduction in waste generation and carbon footprint[41,42]. These studies support hypothesis H1.

H2: *Social benefits can have a positive and significant impact on the decision to adopt DfD in construction for sustainable development.* DfD has significant social impacts which enhance sustainable development. The social advantages include employment creation, better human and community health and well-being, and affordable housing development[46,47]. These social benefits can influence construction stakeholder decision to adopt DfD in the industry, thus, supporting H2.

H3: *Business benefits can have a positive and significant impact on the decision to adopt DfD in construction for sustainable development*. The business benefits of DfD abound and can influence construction organisations' decision to adopt DfD to enhance companies' efficiencies and competitiveness. Companies can also make meaningful profits from reusing construction materials in building development, which enhances competitive advantages[5,10,37].

H4: *Economic benefits can have a positive and significant impact on the decision to adopt DfD in construction for sustainable development.* In the construction industry, the adoption of DfD is influenced by economic reasons, including cost savings, which improve revenue generation. Reduction in waste to be transported away from the site and the reduction of energy associated with such disposal help reduce costs[37,52]. Thus, H4 is supported.

H5: '*Green certification and technology integration*' *can have a positive and significant impact on the decision to adopt DfD in construction for sustainable development*. DfD is being prioritised because of its sustainability impact, which is supported by green certification and emerging technology integration for sustainable construction. The need to accumulate materials reuse credits and minimise wastes, which align with the DfD principle, can lead to green certifications/awards such as leadership in energy and environmental design (LEED) and building research establishment environmental assessment methodology (BREEAM)[39,40]. Technology integration drives circular economy practices as it improves deconstruction planning, execution and materials tracking[36,37]. These supports H5.

4.5 PLS-SEM of the benefits of DfD in the built environment

PLS-SEM was employed to validate the proposed model and test the formulated hypotheses. This involved assessing the validity of both the measurement model and the structural model. The PLS-SEM approach was utilised to examine the relationships between the identified constructs representing the benefits of DfD and their potential influence on the implementation of DfD principles within the NCI. This analytical strategy is consistent with similar studies in the construction management field[60,68-70].

4.5.1 Measurement model evaluation

The measurement model is a critical component of SEM, as it defines the relationship between observed indicators and their underlying latent constructs. A measurement model is considered satisfactory when it demonstrates adequate convergent and discriminant validity[71]. Convergent validity assesses whether the items associated with a construct are truly related and should therefore converge on that construct[72]. It is evaluated using several criteria, including factor loadings (FL), Cronbach's alpha (α), true reliability (rho_A), composite reliability (rho_C), and average variance extracted (AVE)[73,74]. According to established guidelines, the FL of items in reflective constructs should be at least 0.50[75].

Based on this standard, an initial analysis was conducted using all 27 items. Variables with FLs below 0.50 were systematically removed through an iterative process, resulting in a final set of 16 measurement items. Each deletion was carefully assessed to ensure that it improved the model's reliability and validity. Low-loading items were only removed if their exclusion increased the AVE and other key validity measures[72]. Accepted thresholds from the literature include 0.70 for α, rho_A, and rho_C, and 0.50 for AVE[72,73]. As shown in Table 4, the measurement model met all these thresholds, supporting the model's convergent validity and allowing for further evaluation of discriminant validity.

Table 4. Measurement model validity and reliability outputs.

Construct	Item code	Initial evaluation					Final Iteration					VIF
		Outer loading	α	CR (rho_a)	CR (rho_c)	AVE	Outer loading	α	CR (rho_a)	CR (rho_c)	AVE	
Environmental benefits	BDF1	0.196	0.670	0.774	0.777	0.329	-	0.772	0.784	0.846	0.525	-
	BDF6	0.814					0.827					2.552
	BDF3	0.704					0.706					1.769
	BDF20	0.368					-					-
	BDF7	0.605					0.668					1.778
	BDF8	0.640					0.652					1.625
	BDF4	0.723					0.757					2.472
	BDF9	0.576					-					-
	BDF28	-0.043					-					-
Social benefits	BDF19	0.519	0.685	0.697	0.787	0.349	-	0.701	0.702	0.834	0.626	-
	BDF10	0.706					0.804					1.898
	BDF17	0.507					-					-
	BDF14	0.495					-					-
	BDF13	0.654					0.796					1.413
	BDF12	0.648					0.772					2.126
	BDF11	0.570					-					-
Business benefits	BDF21	0.519	0.461	0.415	0.702	0.374	-	0.602	0.643	0.778	0.541	-
	BDF29	0.663					0.714					1.894
	BDF30	0.539					0.669					1.279
	BDF31	0.705					0.815					1.736
Economic benefits	BDF22	0.643	0.364	0.380	0.674	0.346	0.781	0.407	0.408	0.771	0.628	1.623
	BDF18	0.429					-					-
	BDF25	0.658					0.804					1.698
	BDF2	0.594					-					-

Green Certification and Technology Integration	BDF24	0.655	0.555	0.545	0.771	0.531	0.620	0.555	0.554	0.773	0.535	1.991
	BDF26	0.752					0.780					1.783
	BDF27	0.773					0.782					1.423

AVE: average variance extracted; VIF: variance inflation factor.

Discriminant validity assesses the degree to which constructs are distinct from one another, confirming that unrelated indicators do not exhibit high correlation[76]. This study employed both the Fornell-Larcker criterion and the Heterotrait-Monotrait (HTMT) ratio to assess discriminant validity. According to the Fornell-Larcker criterion, discriminant validity is achieved when the square root of each construct's AVE (represented on the diagonal in bold) is greater than its correlation with other constructs[74]. For HTMT, a threshold of 0.85 (or 0.90) is recommended, below which discriminant validity is considered acceptable[77]. As shown in Table 5, both criteria were satisfied, confirming strong discriminant validity for the model.

Table 5. Discriminant validity results of the constructs.

	Business Benefits	**Economic Benefits**	**Environmental Benefits**	**Green Certification & Technology Integration**	**Social benefits**
Heterotrait-Monotrait ratio (HTMT) Matrix					
Business Benefits					
Economic Benefits	0.221				
Environmental Benefits	0.358	0.682			
Green Certification & Technology Integration	0.720	0.640	0.305		
Social benefits	0.237	0.516	0.615	0.100	
Fornell-Larcker Criterion					
Business Benefits	**0.736**				
Economic Benefits	0.049	**0.792**			
Environmental Benefits	0.275	0.378	**0.725**		
Green Certification & Technology Integration	0.413	0.306	0.202	**0.731**	
Social benefits	0.166	0.274	0.464	-0.01	**0.791**
VIF	1.326	1.329	1.482	1.391	1.348

HTMT: Heterotrait-Monotrait; VIF: variance inflation factor.

Additionally, the Variance Inflation Factor (VIF) was used to assess multicollinearity among the indicators. A VIF value below 3.3 indicates the absence of multicollinearity and common method bias[78]. Based on the VIF values for both the retained items (column 13 of Table 4) and the overall constructs (last column of Table 4), no multicollinearity issues were detected.

With the measurement model meeting the required standards for validity, reliability, and multicollinearity, the analysis proceeded to the assessment of the structural model.

4.5.2 Structural model-path coefficient by bootstrapping

The bootstrapping technique is widely recognised as a robust method for testing the significance of path coefficients in SEM[79]. As a resampling method, bootstrapping enhances the reliability of parameter estimates. In this study, 5,000 subsamples were used to validate the proposed hypotheses based on standardised path coefficients (β), *p*-values, confidence intervals (CI), and t-statistics (*T*). Figure 6 presents the structural model with corresponding β-values and *p*-values, while Table 6 provides a comprehensive summary including β, *p*-values, CI, t-statistics, and the decisions regarding hypothesis testing.

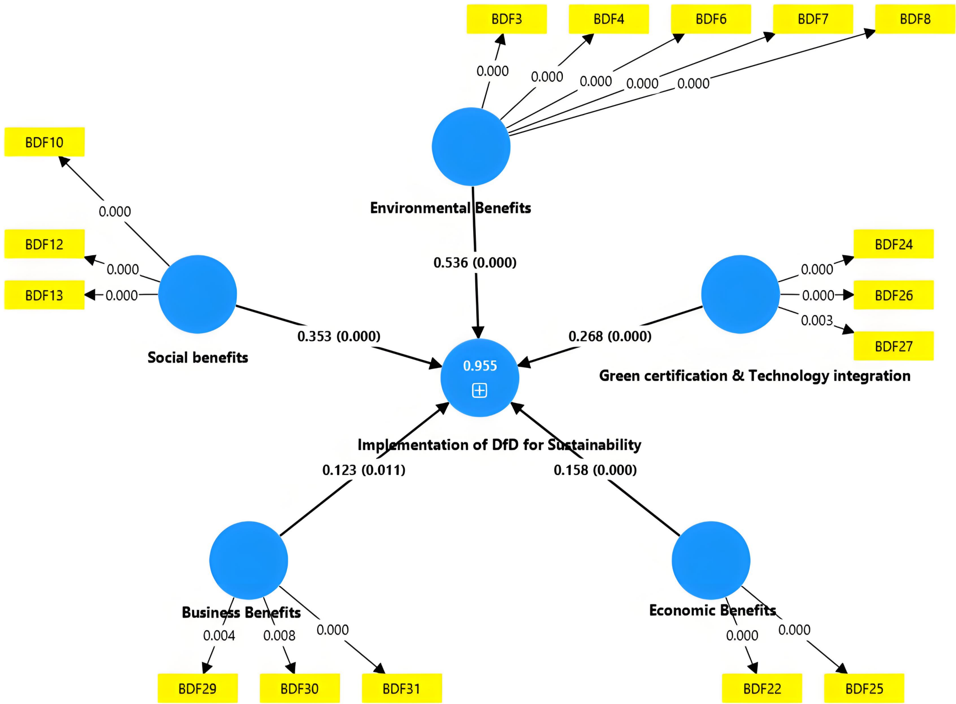

Figure 6. Structural model-Path analysis.

Table 6. Path analysis (Bootstrapping) results.

Hypothetical model path	*β*	SD	*T*	LCI 2.5%	UCI 97.5%	*P* values	Decision on Hypothesis
Business Benefits -> Implementation of DfD for Sustainability	0.123	0.049	2.53	0.027	0.214	0.011*	Supported
Economic Benefits -> Implementation of DfD for Sustainability	0.158	0.032	4.962	0.092	0.217	0.000*	Supported
Environmental Benefits -> Implementation of DfD for Sustainability	0.536	0.066	8.108	0.419	0.675	0.000*	Supported
Green Certification & Technology integration -> Implementation of DfD for Sustainability	0.268	0.072	3.716	0.073	0.363	0.000*	Supported
Social benefits -> Implementation of DfD for Sustainability	0.353	0.05	7.104	0.257	0.452	0.000*	Supported

β: Original sample; SD: standard deviation; *T*: *t*-statistics; LCI: lower confidence interval; UCI: upper confidence interval; **p*-value: significant; DfD: design of deconstruction.

The results presented in Figure 6 and Table 6 indicate that all five hypotheses were supported, signifying that each construct has a significant and positive influence on the decision to adopt DfD techniques in building construction. This finding suggests that enhanced knowledge and awareness of DfD benefits can stimulate greater interest and uptake of DfD adoption and implementation, contributing to a more sustainable built environment.

Among the five constructs, environmental benefits exerted the strongest influence on DfD adoption (β = 0.536; t = 8.108; p = 0.000), followed by social benefits (β = 0.353; t = 7.104; p = 0.000) and green certification and technology integration benefits (β = 0.268; t = 3.716; p = 0.000).

In terms of model explanatory power, the coefficient of determination (R^2) was 0.955, and the predictive relevance (Q^2) was 0.947. According to Hair *et al.*[64], R^2 values of 0.75, 0.50, and 0.25 represent substantial, moderate, and weak levels of explanatory power, respectively. Therefore, the R^2 of 0.955 indicates a substantial impact, suggesting that the five constructs collectively explain 95.5% of the variance in DfD adoption in construction. Similarly, the Q^2 value exceeds the recommended threshold of 0.35 for high predictive relevance[80], further confirming the model's strong predictive capability.

Moreover, the model's overall fit was assessed using the SRMR. The SRMR value obtained was 0.16, which falls within the acceptable range of 0 to 1 as recommended by[81], indicating an acceptable model fit.

4.5.3 Cross-validated predictive ability test (CVPAT) analysis

As shown in Table 7, CVPAT was conducted to determine whether the developed model outperforms a naïve baseline model[82]. The naïve baseline represents a fundamental reference point for evaluating predictive model validity[83]. According to established guidelines, a proposed model should be rejected if its average loss is not significantly lower than that of the naïve model[84]. The CVPAT results from this study (average loss = -0.184, t = 4.9, p = 0.000) indicate that the predictive ability of the model is very strong. These findings are consistent with the previously reported high values of Q^2 and SRMR, which collectively confirm the model's excellent predictive performance and validity.

Table 7. CVPAT LV summary.

	PLS loss	IA loss	Average loss difference	*t* value	*p*-value
Implementation of DfD for Sustainability	0.955	1.139	-0.184	4.9	0.000
Overall	0.955	1.139	-0.184	4.9	0.000

CVPAT: cross-validated predictive ability test; PLS: partial least square-structural; DfD: design of deconstruction; LV: latent variable; IA: indicator average.

4.6 Discussion of results

This study revealed a notable gap between the awareness and adoption of DfD principles among design professionals in the Nigerian construction industry. While the level of awareness is moderate, the actual adoption of DfD practices remains low, potentially contributing to the industry's persistent issues of high waste generation and resource inefficiency[30]. This finding supports earlier research by[19,29], which also attributed low awareness and adoption to inadequate training and limited education on DfD concepts.

Deconstruction represents a key strategy for environmental sustainability, as it reduces harmful emissions, facilitates material recovery and recycling, conserves natural resources, and significantly lowers waste production. Through material recovery, it contributes to the reduction of landfill dependency and enhances environmental aesthetics[33,37-39,49]. Deconstruction also reduces the need for raw material extraction and minimises on-site energy use, thereby limiting the emission of hazardous gases and reinforcing its role as an environmentally friendly approach.

Moreover, integrating deconstruction principles at the design stage can enhance organisational productivity and efficiency, enabling faster assembly of building components compared to traditional construction methods[35,37]. The incorporation of DfD into business strategies may help firms enhance their competitive advantage in a highly dynamic construction sector. As a result, organisations may increasingly advocate DfD to their clients as a viable and sustainable construction approach. The ease of component transportation and reusability at the EoL stage fosters a circular material flow, boosting business performance and revenue generation[35,37]. These findings affirm the positive influence of business-related benefits on the decision to adopt DfD, as demonstrated in this study.

From an economic perspective, deconstruction requires skilled labour and offers opportunities for job creation[34]. The reuse of deconstructed materials fosters the development of new markets and can lead to tax incentives for contractors, especially where disposal of salvaged materials is taxed at a lower rate (e.g., Second Chance, 2024). Additionally, since deconstructed materials can bypass energy-intensive manufacturing processes, overall energy costs are reduced[39]. These economic efficiencies make DfD an attractive option for reducing costs and improving resource productivity[49].

DfD also offers benefits in the context of green building certification. By avoiding traditional demolition and promoting sustainable material recovery, organisations may earn points toward systems such as LEED or BREEAM[39]. DfD supports both environmental and social sustainability by creating employment, preserving cultural heritage, limiting resource depletion, and minimising landfill waste. Furthermore, it facilitates the integration of Building Information Modelling and other digital technologies that enhance innovation and sustainability throughout the building lifecycle[35,37].

Socially, DfD contributes to community development by generating local employment and reducing exposure to hazardous materials typically associated with demolition[46,47]. It also provides affordable materials for constructing or repairing homes for elderly and vulnerable populations[33]. By preserving architectural elements and cultural identity, DfD empowers communities to derive value from structures that would otherwise be lost[48]. Moreover, it fosters training and vocational development, enabling designers and builders to earn livelihoods through sustainable practices[33,38].

5. Implications of the Study

This study presents both practical and theoretical implications for the construction industry, particularly within the Nigerian context. Construction waste poses a significant threat not only to the health and well-being of society but also to the successful execution of construction projects and the broader goal of achieving the SDGs within the Nigerian construction sector. DfD facilitates the recovery of construction materials at the EoL of buildings, enabling these materials to be reused or repurposed for other valuable economic applications. By diverting materials from landfills, DfD helps reduce construction waste and preserve the aesthetic integrity of the built environment.

The practice of DfD promotes the continuous reuse of recovered materials in other projects, fostering a circular flow of materials and reducing the pressure on natural resource extraction. Consequently, the reuse and recycling of construction materials become more feasible, contributing to resource conservation. This study offers valuable insights for design professionals, who are encouraged to integrate DfD principles during the early stages of the building design process. By doing so, project decisions can be aligned with strategies that support deconstruction rather than demolition at the end of a building's useful life.

Furthermore, this study serves as a call to action for construction professionals who are unfamiliar with DfD principles and their contribution to sustainability objectives. Government bodies and regulatory agencies can also leverage the findings to inform and enhance policies that support sustainable construction practices. Notably, DfD aligns with SDGs 3 (Good Health and Well-being), 9 (Industry, Innovation and Infrastructure), 11 (Sustainable Cities and Communities), 12 (Responsible Consumption and Production), and 13 (Climate Action).

From a theoretical standpoint, this study contributes to the limited body of literature on DfD in developing countries, with particular focus on design experts, whose core responsibility lies in the planning of buildings and engineering structures. The proposed model offers a useful foundation for future research, including the application of technology adoption and innovation diffusion frameworks to assess stakeholders' intentions to implement DfD in their projects.

6. Recommendation for Implementation of DfD Principles

To promote the effective implementation of DfD in the Nigerian construction industry, the following actions are recommended:

i) The government should enact laws and regulations mandating the integration of DfD principles in construction practices. Such regulations should encourage the use of green and sustainable building materials, and require design adaptation that enables reuse, recycling, and EoL recovery. Additionally, construction firms should be compelled to incorporate deconstruction planning into their project designs from the outset.

ii) Tax incentives, grants, or other financial support should be offered to housing developers and construction stakeholders who adopt DfD-aligned innovations. These incentives would serve as motivation for the private sector to embrace sustainable design and construction practices.

iii) The government should collaborate with organizations possessing expertise in deconstruction through Public-Private Partnerships to drive circular economy initiatives in urban planning and building design. Such partnerships could also foster knowledge exchange and build national capacity in sustainable construction strategies.

iv) Government, development agencies, and private investors should support the adoption of modular construction systems and transformative technologies that promote low-carbon material usage. Emphasis should be placed on locally sourced, sustainable materials such as recycled bricks and concrete, compressed earth, wood, and bamboo, to enhance circular construction practices.

v) Dedicated funding should be allocated to support research and development in bio-based, recyclable, and net-zero construction materials. Universities and research institutions can leverage these resources to improve existing local materials or develop innovative alternatives. Furthermore, DfD principles should be integrated into the curricula of architecture, engineering, and construction-related programs in tertiary institutions to increase awareness and facilitate wider diffusion.

vi) Local marketplaces for buying and selling salvaged construction materials should be developed to support micro-businesses, encourage reuse, and promote circularity. Financial support through grants or soft loans should be made available to entrepreneurs engaged in this sector to ensure market sustainability and scalability.

vii) Targeted training programs for tradespeople and construction professionals should be implemented to enhance their understanding of DfD practices and material recovery techniques. Artisans and operatives should be equipped with the skills to safely and systematically dismantle buildings at their EoL. In addition, workshops and seminars should be organized to educate policymakers, local communities, and built environment experts on the value of DfD and its role in sustainable development, thereby encouraging wider acceptance and implementation across the industry.

7. Conclusion and Recommendation

This study employed a quantitative survey questionnaire to collect data from design experts in Nigeria's South-South geopolitical zone using a snowball sampling technique. The data were analysed using EFA and PLS-SEM, which yielded critical insights that informed the study's conclusions. The findings revealed that although design experts in Nigeria possess a moderate level of awareness and knowledge of DfD, the actual adoption and implementation of DfD practices in the industry remain notably low. This mismatch highlights a significant gap in the application of modern, sustainable construction methods within the Nigerian construction industry.

Through EFA, the perceived benefits of DfD were categorised into five key dimensions: business benefits, economic benefits, environmental benefits, green certification and technology integration, and social benefits. The PLS-SEM results confirmed that all five dimensions exert a positive and significant influence on the decision to adopt DfD in the NCI, thereby supporting hypotheses H1 through H5. Among these, environmental, social, and green certification and technology integration benefits emerged as the most influential drivers of adoption.

Furthermore, the developed structural model demonstrated very strong predictive power, reinforcing the conclusion that these benefit dimensions can effectively stimulate interest and motivate the adoption of DfD practices. Ultimately, embracing DfD principles offers a viable pathway toward achieving sustainability in the built environment, particularly in the context of developing countries like Nigeria.

8. Limitations of the Study and Future Research Suggestions

As with all scholarly investigations, this study has certain limitations that should be considered when interpreting its findings. First, the study was conducted within a specific geopolitical region of Nigeria, which introduces a geographical limitation that may constrain the generalizability of the results. Future research could replicate this study in other regions of Nigeria or in other African countries with similar construction market dynamics, to allow for broader comparative insights.

Second, the study relied solely on a quantitative research design, utilizing questionnaires, EFA, and PLS-SEM. Future studies could adopt a mixed-methods approach, incorporating qualitative techniques or fuzzy set logic to triangulate the findings and strengthen their validity. This may also enable the inclusion of a larger and more diverse sample, enhancing the robustness of future results.

Third, the study focused exclusively on design experts, thereby excluding other relevant built environment professionals such as project managers, quantity surveyors, or contractors, who may offer additional or differing perspectives. Future research could expand the sample pool to include a broader range of construction professionals, potentially leading to more comprehensive insights or validation of the present study's findings.

Lastly, the study revealed a mismatch between awareness and adoption levels of DfD among design professionals. This observed gap warrants further investigation into its underlying causes, which may include institutional, educational, economic, or policy-related barriers. Understanding these root causes could inform the development of more effective strategies to promote DfD adoption in the construction industry.

Declarations

Authors contribution

Nwaki1 W, Elemokwu JC: Conceptualisation of ideas, investigation, data curation, writing-original draft, writing-review & editing.
Eze E: Draft methodology, data analysis, validation, review & editing, writing-review & editing.
All authors approved the final version of the manuscript.

Conflicts of interest

The study was conducted using an anonymous questionnaire survey. No personal identifiable or sensitive information was collected. According to the institutional guidelines, ethical approval was not required and the study was exempt from ethical review.

Ethical approval

Not applicable.

Consent to participate

Informed consent statement was provided at the beginning of the questionnaire.

Consent for publication

Not applicable.

Availability of data and materials

Not applicable.

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