Guruge, K., Waidyasekara, K.G.A.S., Jayasena, H.S. and Manewa, R.M.A.S., 2024. Unveiling the potential of design for deconstruction in the circular economy. In: Sandanayake, Y.G., Waidyasekara, K.G.A.S., Ranadewa, K.A.T.O. and Chandanie, H. (eds). *Proceedings of the 12th World Construction Symposium*, 9-10 August 2024, Sri Lanka. pp. 1101-1111. DOI: https://doi.org/10.31705/WCS.2024.87. Available from: https://ciobwcs.com/papers/

UNVEILING THE POTENTIAL OF DESIGN FOR DECONSTRUCTION IN THE CIRCULAR ECONOMY

Kavini Guruge[1], K.G.A.S. Waidyasekara[2], H.S. Jayasena[3], and R.M.A.S. Manewa[4]

ABSTRACT

The construction industry plays a vital role in fostering sustainability through various concepts and strategies being implemented globally. Among these, Circular Economy (CE) stands out as a prominent approach to enhancing sustainability. CE aims to move the industry away from the traditional linear model (i.e., build-use-demolish) towards a more sustainable circular approach. In the built environment, the 'Design for Deconstruction' (DfD) aims to integrate planning for a building's end-of-life disassembly and material/component salvaging into the design process, thereby promoting sustainability through waste minimisation. However, the relationship between DfD and circularity is less evident. For example, most of the literature about DfD explains the potentials of end-of-life disassembly is limited in terms of discussion on the second life (potential reuse) of those disassembled materials/components. This research aims to bridge this gap. A detailed literature review has been undertaken to establish the status of DfD within the construction industry, including principles, practices, advantages, and barriers of DfD and its contribution to CE. The findings confirm that the blurred link between DfD and CE, and the required improvements in standardisation, awareness, and deconstruction information model/databases are the key priorities to enhance the circularity through DfD.

Keywords: *Circular Economy; Construction Industry; Design-for-Deconstruction; Sustainability.*

1. INTRODUCTION

The construction industry plays a crucial role in the global economy. It is a major consumer of raw materials and contributes to generating significant amounts of waste, which led environmental degradation. This has led to a quest for a sustainable environment achieved through Sustainable Construction (SC) globally (Oke et al., 2019). Sustainability in construction has been enhanced through various concepts and innovative practices in the recent past (Lima et al., 2021).

[1] Student, Department of Building Economics, University of Moratuwa, Sri Lanka, kviniveenadhi1997@gmail.com
[2] Professor, Department of Building Economics, University of Moratuwa, Sri Lanka, anuradha@uom.lk
[3] Senior Lecturer, Department of Building Economics, University of Moratuwa, Sri Lanka, suranga@uom.lk
[4] Senior Lecturer, School of Civil Engineering and Built Environment, Liverpool John Moores University, UK, R.M.Manewa@ljmu.ac.uk

The circular economy offers a new way of thinking about construction that can help to reduce waste and conserve resources. It is an economic system that reconsiders the way resources are used, placing a major focus on waste reduction, resource efficiency, and the development of a resilient and regenerative economic system (Yu et al., 2021). CE conceptualises a closed-loop economy that minimises waste generation and treats any waste as a valuable resource. In this context, the concepts of DfD, aim at designing construction assets (buildings, infrastructure) that can be easily reused or repurposed, using recycled materials and elements, and minimising waste during construction and demolition. In foresight, this paper explains the potential of DfD in promoting circularity in the built environment.

2. RESEARCH METHOD

Sylvester et al., (2013) explain that a literature review is required to identify any gap in the knowledge and a successful researcher claims a gap in the existing knowledge with evidence. This paper is based on a detailed literature review part of an ongoing MPhil research, which is aimed at developing a Deconstruction Information Model for Design Decisions in Construction Assets. As the research is in its initial stages, the analysis is purely based on a review of current literature revealing the existing gap in the knowledge, principles and practices of DfD and its contribution to enhancing CE. Mainly, literature evidence was taken referring to journal articles, books, published and unpublished bibliographies, conference proceedings, and documents. During the literature review, key terms including; circular economy, design for deconstruction, design for disassembly, benefits, barriers, and construction were used (Sylvester et al., 2013).

3. DESIGN FOR DECONSTRUCTION (DfD)

Rios, et al. (2015) stated that DfD, is a well-known practice within the construction industry to make the deconstruction process much easier through the procedure of planning and designing (Cruz et al., 2015). DfD has its own set of key principles which can be aligned with the process of Reduce, Reuse and Recycle as the functions; 3R processes as mentioned by various authors. According to Akanbi et al., (2019), to promote the practice of design for deconstruction, corresponding techniques to overcome obstacles to design for deconstruction and materials reuse were established.

Tleuken et al. (2022) stated that Design for Deconstruction (DfD) is the concept that considers the final demolition stage during initial design and planning. DfD focuses on saving the value that has been put into the building material or structural elements even after the buildings end-of-use. As mentioned previously, the deconstruction process can be predicted at the planning stage of a construction process (Akanbi et al., 2019). Therefore, this concept can result in several advantages economically, environmentally and socially (Akinade et al., 2020). For example, if the buildings are initially designed for deconstruction, it will significantly improve the environmental effect due to the possibility recover almost 95% savings of the embodied energy of the construction materials and up to 50% of the total building's life cycle energy (Tleuken et al., 2022). Moreover, it would also decrease waste management issues.

DfD has its own set of principles that are supposed to follow when its practices it is implemented. Literature promotes reducing the number of materials and components used; choosing materials that are possible for reusing and recycling; using visible and reachable building elements connections; using simple (yet strong) and connections that are easy to deconstruct, e.g., dry connections, dissolvable chemical or reversible welding connections; and practising utilisation of building modules that are robust, substitutable and convenient for transportation (Akinade et al., 2020).

3.1 DECONSTRUCTION OF COMPONENTS/ MATERIALS

As stated by Thomsen et al., (2011), 'Deconstruction' is generally a positive notion, an opposite practice of demolition, which is based on the process of taking apart and compressing a building and disposing the waste as landfill. In addition, past studies identified that deconstruction can explained under two different phases; firstly the careful planning and highly controlled deconstruction process producing a differentiated assortment of components and materials, and secondly, continued use of the deconstructed components and materials in other buildings or other functions at the highest possible level, to avoid down cycling, energy transformation and deposit into landfill as much as possible (Davila et al., 2019). Deconstruction is a present practice with various implications in the construction industry adopting the above-mentioned two phases. Some similar practices would include the planning stage associated with the selective deconstruction of the existing building asset, followed by the planning of the construction works for the redevelopment, adaptation, and in some cases the expansion of the building asset (Sanchez et al., 2019). When a building reaches the end of its useful life (economic or physical), deconstruction enables the recovery of building components for building relocation, component reuse, recycling, or remanufacturing (Akinade et al., 2020). The consideration of DfD practices within the early stages of construction (planning, design, procurement etc.) will promote efficient building recovery as opposed to the deconstruction processes of conventional buildings. However, the reusability of the deconstructed materials at their end of life is less evident.

3.2 APPLICATIONS OF DESIGN FOR DECONSTRUCTION

DfD is one of the most popular concepts in the global construction industry (Bertino et al., 2021) and there is less evidence of absorption of such practices within the Asian construction sector (Tleuken et al., 2022). Nevertheless, there are no standard practices or any certain regulatory concepts or frameworks to enhance DfD practices within the construction industry, efficient building recovery at the end-of-life can only be made possible when the need for deconstruction has been considered from the design stage (Ganiyu et al., 2020). Moreover, in the perspective of reusing Construction and Demolition Waste (C&DW), as an example, there are practices in maximisation of high-quality recycled aggregate, and further, according to the researchers, 'Reuse'; the third 'R' principle is still in its earliest stage of implementation (Tleuken et al., 2022).

In support of DfD, the production of Demolition and Refurbishment Information Datasheets (DRIDS) has improved the possibility of material reuse, recycling, reclamation and waste diversion from landfills (Akanbi et al., 2019). DRIDS provides a publicly accessible database that helps identify building elements that could be reclaimed for reuse and recycling and those that must be sent to landfills. When it comes to cost, companies attempt to use materials that are as durable as possible and have the right certifications (Tleuken et al., 2022). Usage of easily dis-assimilable structures as construction structures is common practice in the industry. Further to that, researchers have found that DfD concepts are being used in the adaptive reuse of buildings as well.

In its design process, the designers bear the responsibility of arriving at a cost-effective and useful adaptive reuse design. A typical construction asset may have multiple adaptive reuse designs, planning for the targeted components' disassembly will vary depending on the design. It is feasible to carry out the deconstruction planning in detail using a proposed disassembly plan, including scheduling the deconstruction works, estimating resource allocation, and calculating the related budget (Sanchez et al., 2019). A study by Roxas et al. (2023) summarised DfD guidelines under three major themes i.e. (i) Simplification of building design, (ii) Materials and connections, and (iii) Deconstruction details and information, for the adopting process of DfD in the construction industry, particularly during the planning stage. Moreover, Zoghi et al., (2022) propose a method for selecting the suitable construction material based on DfD factors.

Table 1: DfD principles (Adapted- Roxas et al., 2023)

Themes	Principles
Simplification of Building Designs	Minimise the number of building components and component types
	Modularisation
	Standardisation
	Use of off-site construction and prefabrication
	Use of lightweight components
	Use of tools and equipment
	Reduction in the number of structural systems
	Utilisation of dry construction
	Realisation of accessible technical installations
	Utilisation of an open building design
	Incorporation of a structural grid
	Consider the interchangeability of building components
Materials and Connections	Use of reusable materials
	Use of environmentally safe materials
	Simplification of the connections
	Utilisation of mechanical connections
	Ease of removal of connections
	Minimise the number of connections and connection types
	Design materials and connections for longevity and durability
	Accessibility of components and connections
	Determine the performance of each material at the building's end-of-life
	Avoid applying secondary finishes
	Storage of spare parts for unforeseen minor revisions
	Determine and apply the optimal material size
	Identify the lifespan of each material
	Reduce the different types of materials
	Use of non-hazardous material
	Avoid using composite materials
Deconstruction Details and information	Documentation of technical plans, drawings, and pictures
	Database of materials, components, and building information

Themes	Principles
	Instructions for materials to be reused and recycled
	Incorporate the type and method of deconstruction in the design
	Viewing a building as a multi-layered structure possessing distinct lifespans
	Determine the parts of the building system to be deconstructed
	Consideration of parallel disassembly in the design
	Allow easy accessibility to the entire building
	Create a deconstruction and waste management plan

Consequently, DfD has both opportunities as well as barriers (Tleuken et al., 2022).

The study done by Aidana et al., (2022) states some of the basic benefits such as DfD in the industrial market are reducing the time required for building demolition and labour involved in demolition works. DfD will bring economic incentives.

3.2.1 Advantages of DfD Applications

Research studies have consistently viewed DfD as a fundamental concept for developing circular economy practices in the construction sector. As such, they are advantageous for sustainable building and circularity techniques. Given that, these applications both directly and indirectly address the circular economy's guiding concepts and guidelines (Wuni & Shen, 2020). Despite this, some of the most significant benefits of DfD fall into one of four broad categories i.e., (i) social, (ii) economic, (iii) environmental, and (iv) strategic (Andrade & Bragana, 2019). Table 2 provides a summary of the advantages of DfD applications identified by different authors along with an overview of the bibliographical analysis on the positive effects of DfD applications.

Table 2: Advantages of DfD applications

Advantages	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11
Resource Efficiency		√			√		√	√		√	
Cost Savings	√		√	√	√	√		√			√
Environmental Benefits	√	√	√		√	√	√	√	√		√
Flexibility and Adaptability	√		√						√	√	
Improved Safety			√				√	√		√	
Regulatory Compliance		√			√		√		√		
Enhanced Reputation and Marketability	√			√		√		√			√

A1-(Cruz et al., 2015), A2-(Sanchez et al., 2019), A3-(Akanbi et al., 2019), A4-(Akinade et al., 2020), A5-(Bertino et al., 2021), A6-(Dams et al., 2021), A7-(Roxas et al., 2023), A8-(Thormark, 2007), A9-(Roberts et al., 2023), A10-(Salama, 2017), A11-(Ostapska et al., 2021)

According to the authors, DfD applications can be identified with many advantages, where DfD focuses on designing buildings and structures with the end of their lifecycle in mind. This approach allows for the efficient recovery and reuse of materials, reducing the overall demand for raw materials and minimising waste generation. It has directly impacted resource efficiency and DfD supports cost perspectives. By designing structures that are easier to deconstruct and dismantle, DfD can lower the costs associated with demolition, waste disposal, and material procurement for future projects. Additionally, salvaged materials can often be sold or reused, providing additional revenue streams (Thormark, 2007). Moreover, DfD contributes to environmental sustainability by reducing the environmental impact associated with construction activities. It minimises the consumption of natural resources, decreases energy consumption, and lowers greenhouse gas emissions by reducing the need for new material production and waste disposal. Additionally, DfD encourages modular construction techniques and the use of standardised components, making it easier to modify, expand, and/or repurpose structures in response to changing needs or preferences. This flexibility enhances the longevity and adaptability of buildings, reducing the need for new construction projects and conserving resources. Apart from that, adopting DfD principles demonstrates a commitment to sustainability and responsible resource management, which can enhance an organisation's reputation and attract environmentally conscious clients, investors, and stakeholders. DfD can differentiate construction projects in the marketplace, offering a competitive advantage in an increasingly sustainability-focused industry (Salama, 2017).

In summary, DfD applications offers numerous benefits to the construction industry, ranging from cost savings and environmental sustainability to improved safety and marketability. By prioritising the efficient use of resources and the reduction of waste, DfD contributes to a more sustainable and resilient built environment.

3.2.2 Barriers and Strategies in Implementing DfD Applications

The literature identifies the barriers to the implementation of DfD applications in the construction industry. Accordingly, the comprehensive study conducted by Akinade et al., (2020), has identified 26 barriers to implementing DfD in the construction industry and those barriers have been classified under five major categories as stated in Table 3.

Table 3: Barriers to DfD applications (Adapted- Akinade et al., 2020)

Categories	Barriers
Lack of stringent legislation for DfD	Lack of Government legislation for deconstructed facilities.
	Design codes generally favour specifying new materials
	Low Building Research Establishment Environmental Assessment Method (BREEAM) point for DfD
Lack of adequate information in building design	Lack of information about recoverable materials
	Lack of disassembly information
	Inadequate information about cost-effective material separation methods
Lack of a large enough market for recovered components	No standardisation and grading system for salvaged materials
	Perceived perception and risks associated with second-hand materials
	Low-performance guarantees for recovered materials
	Degraded aesthetics of salvaged materials
	Damaged or Contaminated materials during recovery
	Storage consideration for recovered materials
	Transportation considerations for recovered materials
	No information exchange system for salvaged materials

Categories	Barriers
Difficulty in developing a business case for DfD	Cost of product re-certification
	The additional cost of design that makes the project more expensive
	Insurance constraints and legal warranties of reclaimed materials
	DfD will increase the design time
	Changing industry standards and construction methodology
	Believe that DfD could compromise building aesthetics and safety
	The overall benefit of DfD may not happen after a long time
Lack of effective DfD tools	Lack of DfD analysis methodologies
	Existing DfD tools are not BIM-compliant
	No tools for identifying and classifying salvaged materials at the end-of-life
	Performance analysis tools for end-of-life scenarios are lacking
	Limited visualisation capability for DfD

Apart from the above-mentioned barriers: uncertainty about the quality of the reused material, low demand due to users' negative perception, financial profitability of demolition practices rather than disassembly, earthquake risks when using bolting connections, high risks of reinforced concrete corrosion can be identified as basic barriers to DfD applications (Tleuken et al., 2022). Moreover, DfD in construction faces challenges due to budget constraints, technology limitations, and lack of collaboration amongst construction participants. Conventional methods are preferred for their cost-effectiveness, while DfD can be more successful if its economic profit is quantifiable. In practice, contractors are prone to make decisions at construction sites without much regard for DfD applications. Implementing DfD into construction regulations could address these barriers irrespective of the individual aims of the parties involved (Tleuken et al., 2022). Overcoming barriers to the implementation of Design for Deconstruction (DfD) in the construction industry requires a combination of strategies aimed at addressing various challenges (van Buren et al., 2016). Table 4 summarises different approaches suggested by various authors to overcome the barriers to DfD implementation in the construction industry.

Table 4: Strategies to overcome barriers to DfD implementations

Strategies	A1	A2	A3	A4	A5	A6	A7	A8	A9
Education and Awareness	√	√		√	√	√	√	√	
Regulatory Support		√	√			√		√	√
Financial Incentives			√	√	√		√		√
Supply Chain Collaboration	√			√		√	√		
Technology Integration	√		√	√				√	
Demonstration Projects					√	√		√	
Collaborative Design Processes	√	√				√			√

Strategies	A1	A2	A3	A4	A5	A6	A7	A8	A9
Lifecycle Assessment	√	√		√		√		√	√
Industry Standards and Best Practices			√				√		
Continuous Improvement and Evaluation		√			√	√			

A1-(Silva et al., 2019), A2-(Akinade et al., 2020), A3-(Salama, 2017), A4-(Tleuken et al., 2022), A5-(Charef & Emmitt, 2021), A6-(Pittri et al., 2024), A7-(Anastasiades et al., 2023), A8-(Munaro & Tavares, 2023), A9-(Raja Ghazilla et al., 2015)

According to Table 4, ten strategies have been identified by researchers which can be implemented to overcome the barriers to DfD implementation in the construction industry. Most researchers in their studies imply that educating and making the industry aware of DfD practices is the most viable way of overcoming barriers in this regard and regulatory support and technological integration would further support the cause.

3.3 DFD AND BIM

As stated earlier, there is a relationship between DfD and the circular economy concept (Akinade et al., 2020). According to the findings and statements provided by past researchers, DfD needs to be standardised to achieve circular economic goals. After addressing the barriers to implementing DfD, it is necessary to pay attention to how to evaluate DfD performances and quantify the benefits of DfD concepts. As per the study done by Obi et al. (2021), deconstruction-related practices can be managed by implementing BIM based methodologies, such as BIMfD (BIM for deconstruction). In the same study, authors have stated that BIMfD is still at the earliest stage of it being practised. Specifically in the above study, Obi et al., (2021) have provided a hierarchical BIMfD implementation factor model to support improved deconstruction practices in the construction industry of the UK.

Moreover, in a recent study conducted by Kim and Kim, (2023), stated that there is a lack of tools and methods for evaluating the DfD performances. According to the researchers, there is a specific necessity for a tool for the proper implementation of design for deconstruction concepts rather than using the BIM software as a practice. Additionally, Charef et al., (2019) have come up with a suggestion of a model for deconstruction, named DIM in their proposed conceptual framework for the building life cycle. Therefore, rather than practising DfD along with the BIM, it would be more efficient if there was a specific information model for the deconstruction processes of constructed buildings.

4. CONTRIBUTION FROM DfD TO A CIRCULAR ECONOMY

Circular economy is an innovative concept which has gained much global attention recently (Dwivedi et al., 2020). The concept is popular within the business world and governments of many countries as a possible way to deal with business objectives and a sustainable environment simultaneously (Pomponi & Moncaster, 2017). This concept aims to lessen the strain on natural resources and to develop a more sustainable method of managing useful and valuable materials (Casiano Flores et al., 2018). The general perspective of circular economy is mostly used in construction, waste minimisation and recycling (Hart et al., 2019), resource optimisation (Mhatre et al., 2021) and reusing materials from wrecked or removing structures (Bertino et al, 2021). Yu et al. (2022) explain the historical evidence of the application of CE practices in construction, where the concept was not implemented conceptually with the exact terminologies and procedures as in the current practice.

The literature further explains that waste-to-energy supply chain (Pan et al., 2015), eco-industrial park, waste-to-resource supply chain, cradle-to-cradle, industrial ecology regenerative design (Mahpour, 2018), product-service-system, blue economy, design-for-deconstruction (Akanbi et al., 2019) are used to form the circular economy concept. As noted above, the DfD approach moves beyond traditional demolition methods by intentionally planning buildings for easier disassembly at the end of their lifespan and then reuse in their second life. By using standardised components, and readily accessible connections, most of the valuable materials/components can be separated, salvaged, and reintroduced into new construction projects. This not only reduces the need for virgin materials and lowers environmental impact, yet creates a valuable resource pool for the construction industry, fostering a more circular and sustainable building life cycle. However, there is a lack of awareness of such practices, and regulations and a limited number of information models to understand the deconstruction possibility of materials and their reusability.

5. CONCLUSIONS AND THE WAY FORWARD

In conclusion, this paper provides a detailed explanation of the concept of DfD and circular economy within the construction industry, encompassing its principles, current practices, applications, advantages and implementation barriers, along with strategies to overcome said barriers. Accordingly, this study identifies 37 principles, categorised into three themes, and highlights seven advantages across various categories. Additionally, it identifies 26 barriers grouped into five major categories. Finally, the study outlines ten key strategies proposed to address these barriers and facilitate the successful implementation of DfD in the construction industry. The paper suggests a clear consideration of the potential second use of the materials/components during the design phase will promote a circular economy within construction instead of limiting the component/material life at the deconstruction phase. Moreover, the study indicates the requirement of a standard practice to evaluate the DfD implementations in the construction industry and the current knowledge of it.

This paper looks at theoretical aspects to produce a conceptual framework as the next step of the study which can be used to develop a DIM for Design Decisions integrating CE in Built Assets. Further, this paper motivates future research on eco-industrial parks, blue economy etc. and other supportive concepts of CE in the construction industry.

6. REFERENCES

Akanbi, L. A., Oyedele, L. O., Omoteso, K., Bilal, M., Akinade, O. O., Ajayi, A. O., Davila Delgado, J. M., & Owolabi, H. A. (2019). Disassembly and deconstruction analytics system (D-DAS) for construction in a circular economy. *Journal of Cleaner Production*, *223*, 386–396. https://doi.org/10.1016/j.jclepro.2019.03.172

Akinade, O., Oyedele, L., Oyedele, A., Davila Delgado, J. M., Bilal, M., Akanbi, L., Ajayi, A., & Owolabi, H. (2020). Design for deconstruction using a circular economy approach: barriers and strategies for improvement. *Production Planning and Control*, *31*(10), 829–840. https://doi.org/10.1080/09537287.2019.1695006

Anastasiades, K., Dockx, J., van den Berg, M., Rinke, M., Blom, J., & Audenaert, A. (2023). Stakeholder perceptions on implementing design for disassembly and standardisation for heterogeneous construction components. *Waste Management and Research*, *41*(8), 1372–1381. https://doi.org/10.1177/0734242X231154140

Andrade, J. B., & Bragana, L. (2019). Assessing buildings' adaptability at early design stages. *IOP Conference Series: Earth and Environmental Science*, *225*(1). https://doi.org/10.1088/1755-1315/225/1/012012

Bertino, G., Kisser, J., Zeilinger, J., Langergraber, G., Fischer, T., & Österreicher, D. (2021). Fundamentals of building deconstruction as a circular economy strategy for the reuse of construction materials. *Applied Sciences (Switzerland)*, *11*(3), 1–31. https://doi.org/10.3390/app11030939

Charef, R., Alaka, H., & Ganjian, E. (2019). A BIM-based theoretical framework for the integration of the asset End-of-Life phase. *IOP Conference Series: Earth and Environmental Science*, *225*(1). https://doi.org/10.1088/1755-1315/225/1/012067

Charef, R., & Emmitt, S. (2021). Uses of building information modelling for overcoming barriers to a circular economy. *Journal of Cleaner Production*, *285*, 124854. https://doi.org/10.1016/j.jclepro.2020.124854

Cruz, F., Chong, W. K., & Grau, D. (2015). Design for disassembly and deconstruction - challenges and opportunities. *International Conference on Sustainable Design, Engineering and Construction*, *118*, 1296–1304. https://doi.org/https://doi.org/10.1016/j.proeng.2015.08.485

Dams, B., Maskell, D., Shea, A., Allen, S., Driesser, M., Kretschmann, T., Walker, P., & Emmitt, S. (2021). A circular construction evaluation framework to promote designing for disassembly and adaptability. *Journal of Cleaner Production*, *316*, 128122. https://doi.org/10.1016/j.jclepro.2021.128122

Davila, D., Manuel, J., Oyedele, L., Ajayi, A., Akanbi, L., Akinade, O., Bilal, M., & Owolabi, H. (2019). Robotics and automated systems in construction: Understanding industry-specific challenges for adoption. *Journal of Building Engineering*, *26*, 100868. https://doi.org/10.1016/j.jobe.2019.100868

Ganiyu, S. A., Oyedele, L. O., Akinade, O., Owolabi, H., Akanbi, L., & Gbadamosi, A. (2020). BIM competencies for delivering waste-efficient building projects in a circular economy. *Developments in the Built Environment*, *4*(December), 100036. https://doi.org/10.1016/j.dibe.2020.100036

Kim, S., & Kim, S. (2023). A design support tool based on building information modeling for design for deconstruction : A graph-based deconstructability assessment approach. *Journal of Cleaner Production*, *383*, 135343. https://doi.org/10.1016/j.jclepro.2022.135343

Lima, L., Trindade, E., Alencar, L., Alencar, M., & Silva, L. (2021). Sustainability in the construction industry : A systematic review of the literature. *Journal of Cleaner Production*, *289*, 125730. https://doi.org/10.1016/j.jclepro.2020.125730

Mahpour, A. (2018). Prioritizing barriers to adopt circular economy in construction and demolition waste management. *Resources, Conservation and Recycling*, *134*, 216–227. https://doi.org/10.1016/j.resconrec.2018.01.026

Munaro, M. R., & Tavares, S. F. (2023). Design for adaptability and disassembly: guidelines for building deconstruction. *Construction Innovation*. https://doi.org/10.1108/CI-10-2022-0266

Obi, L., Osobajo, O., Awuzie, B., Obi, C., Oke, A., & Omotayo, T. (2021). BIM for deconstruction : An interpretive structural model of factors influencing implementation. *Buildings*, *11*(227). https://doi.org/https://doi.org/10.3390/buildings11060227

Oke, A., Ferrão, P., Oke, A., & Aghimien, D. (2019). Sustainable Construction Practices the Zambian Construction Industry Assessing the feasibility of using the heat demand-outdoor Drivers of Practices, and demand temperature for a district heat forecast C. *Energy Procedia*, *158*, 3246–3252. https://doi.org/10.1016/j.egypro.2019.01.995

Ostapska, K., Gradeci, K., & Ruther, P. (2021). Design for disassembly (DfD) in construction industry: A literature mapping and analysis of the existing designs. *Journal of Physics: Conference Series*, *2042*(1). https://doi.org/10.1088/1742-6596/2042/1/012176

Pittri, H., Godawatte, A. G. R., Agyekum, K., Botchway, E. A., Dompey, A. M. A., Oduro, S., & Asamoah, E. (2024). Examining the barriers to implementing design for deconstruction in the construction industry of a developing country. *Construction Innovation*. https://doi.org/10.1108/CI-09-2023-0239

Pomponi, F., & Moncaster, A. (2017). Circular economy for the built environment: A research framework. *Journal of Cleaner Production*, *143*, 710–718. https://doi.org/10.1016/j.jclepro.2016.12.055

Raja Ghazilla, R. A., Sakundarini, N., Taha, Z., Abdul-Rashid, S. H., & Yusoff, S. (2015). Design for environment and design for disassembly practices in Malaysia: A practitioner's perspectives. *Journal of Cleaner Production*, *108*, 331–342. https://doi.org/10.1016/j.jclepro.2015.06.033

Roberts, M., Allen, S., Clarke, J., Searle, J., & Coley, D. (2023). Understanding the global warming potential of circular design strategies: Life cycle assessment of a design-for-disassembly building. *Sustainable Production and Consumption*, *37*, 331–343. https://doi.org/10.1016/j.spc.2023.03.001

Roxas, C. L. C., Bautista, C. R., Cruz, O. G. Dela, Leoric, R., Cruz, C. Dela, Pedro, J. P. Q. De, Dungca, J. R., Lejano, B. A., & Ongpeng, J. M. C. (2023). Design for Manufacturing and Assembly (DfMA) and design challenges, trends and developments. *Buildings*, *13*(5), 1164. https://doi.org/https://doi.org/10.3390/buildings13051164

Salama, W. (2017). Design of concrete buildings for disassembly: An explorative review. *International Journal of Sustainable Built Environment*, *6*(2), 617–635. https://doi.org/10.1016/j.ijsbe.2017.03.005

Sanchez, B., Rausch, C., & Haas, C. (2019). "Deconstruction programming for adaptive reuse of buildings." *Automation in Construction*, *107*, 102921. https://doi.org/10.1016/j.autcon.2019.102921

Silva, F. C., Shibao, F. Y., Kruglianskas, I., Barbieri, J. C., & Sinisgalli, P. A. A. (2019). Circular economy: analysis of the implementation of practices in the Brazilian network. *Revista de Gestao*, *26*(1), 39–60. https://doi.org/10.1108/REGE-03-2018-0044

Sylvester, A., Tate, M., & Johnstone, D. (2013). Beyond synthesis: Re-presenting heterogeneous research literature. *Behaviour and Information Technology*, *32*(12), 1199–1215. https://doi.org/10.1080/0144929X.2011.624633

Thomsen, A., Schultmann, F., & Kohler, N. (2011). Deconstruction, demolition and destruction. *Building Research and Information*, *39*(4), 327–332.

Thormark, C. (2007). Motives for design for disassembly in building construction. *Portugal SB 2007 - Sustainable Construction, Materials and Practices: Challenge of the Industry for the New Millennium*, *June*, 607–611.

Tleuken, A., Torgautov, B., Zhanabayev, A., Turkyilmaz, A., Mustafa, M., & Karaca, F. (2022). Design for deconstruction and disassembly: Barriers, opportunities, and practices in developing economies of Central Asia. *Procedia CIRP*, *106*, 15–20. https://doi.org/10.1016/j.procir.2022.02.148

van Buren, N., Demmers, M., van der Heijden, R., & Witlox, F. (2016). Towards a circular economy: The role of Dutch logistics industries and governments. *Sustainability (Switzerland)*, *8*(7), 1–17. https://doi.org/10.3390/su8070647

Wuni, I. Y., & Shen, G. Q. (2020). Critical success factors for modular integrated construction projects: a review. *Building Research and Information*, *48*(7), 763–784. https://doi.org/10.1080/09613218.2019.1669009

Yu, Y., Yazan, D. M., Bhochhibhoya, S., & Volker, L. (2021). Towards circular economy through industrial symbiosis in the Dutch construction industry: A case of recycled concrete aggregates. *Journal of Cleaner Production*, *293*, 126083. https://doi.org/10.1016/j.jclepro.2021.126083

Zoghi, M., Rostami, G., Khoshand, A., & Motalleb, F. (2022). Material selection in design for deconstruction using Kano model, fuzzy-AHP and TOPSIS methodology. *Waste Management and Research*, *40*(4), 410–419. https://doi.org/10.1177/0734242X211013904