



# End-of-Life (EoL) Management in Multi-Storey Building Structures Using Design for Deconstruction Approach: A Review

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## Abstract

In structural design, deconstruction is an age-old concept of reusing existing structural components to create new facilities. It is an alternative to the negative impact of construction and demolition waste around the world, essential for creating a sustainable environment. This study shows the potential of responsibly managing building materials to minimize the consumption of new raw materials by using existing materials from demolished sites and finding ways to reuse them in another construction project. A comprehensive review is presented to indicate the utilization of design for deconstruction in multi-story structures, and the challenges and other factors influencing this approach in minimizing waste are likewise indicated. The result reveals that despite efforts in mitigating demolition waste through deconstruction, there has not been a progressive increase in the level of design for deconstruction implementation because the system is still far from reaching its waste minimization potentials since less than 1% of existing buildings are fully deconstructable in several developing countries. Therefore, new strategies that encourage designers to consider design for deconstruction must be encouraged most importantly in developing countries.

**Keywords:** Building Construction, Deconstructability, Multi-storey Structures, Sustainable Development, Waste Minimization

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## I. INTRODUCTION

Rapid urbanization worldwide has led to a significant rise in construction and demolition waste (C&DW), with demolition waste accounting for as much as 90% in some countries. The high volume of demolitions each year has widespread environmental and economic consequences, as building materials often end up unrecoverable and are disposed of in landfills [1, 2]. In addition, 3 billion tons of raw materials are consumed annually by construction activities worldwide, accounting for 40% of total global consumption. Likewise, construction production requires 170 tons of primary materials and products, 125 tons of quarry products and 70 tons of secondary recycled and reclaimed products annually. However, producing and delivering these products uses 6 million tons of energy and 23 million tons of greenhouse gases (GHG) are emitted. Studies around the world have found that at least 9%

of materials originally purchased for construction processes end up as waste due to on-site waste. In addition, waste from construction, demolition, and renovation work accounts for up to 40% of the total waste generated in most countries around the world. Furthermore, such waste, called construction and demolition waste (C&DW), accounts for 15-30% of the waste sent to landfills in most countries [3-5].

In Europe, for instance, buildings are responsible for 36% of greenhouse gas emissions and around 40% of total energy consumption, while generating enormous amounts of waste at the end of their life. Meanwhile, collapses or damage to existing buildings during strong earthquakes have resulted in significant economic costs and loss of life [6, 7]. Since demolition and reconstruction are neither an economically viable nor environmentally friendly solution, the European Green-Deal emphasizes the need for EU member states to initiate a wave of renovation of their buildings. In addition, the New European

Bauhaus initiative envisages safe, sustainable, and beautiful renovated buildings in which people can live together. Olson [8] opined that these environmental issues related to construction materials have attracted increasing attention in the construction industry in several countries in recent decades. While certification bodies for environmentally friendly building are already calling for basic measures to slow down the depletion of resources

Therefore, the growing awareness of the environmental impacts of construction waste has led to an improvement in waste control, which is an important response in construction project management and the sustainable design of most building structures in several developing countries [9-11]. This study examines various works of literature on DfD application to highlight the use of deconstruction design in multi-storey buildings, as well as the challenges and other factors affecting this approach to waste minimization.

## II. LITERATURE REVIEW

Recently, greater attentions have been started to put on the end-of-life (EoL) phase of buildings. Recycling, reuse and incineration of deconstructed wastes can help relieve the landfill burden and recover some energy from existing building materials in order to reduce environment impacts and/or reduce energy consumption [12]. The concept EoL refers to the final stages of the use phase of a product or material. The treatment and disposal of building materials at the end of their life is an increasingly important issue to minimize waste, carbon emissions and landfill use. Typically, building materials are broken down at the end of their life cycle and sent to landfills. This could indicate that the economic value of building materials drops to minimal. However, the end of the life of a building does not necessarily mean the end of the life of the building materials. Particularly in the current situation of urban development, renovation and restructuring, large parts of the constructed buildings are being demolished with spatial or functional rather than structural or material quality problems. For this reason, a building, as a collection of building materials, is still functional at the time of demolition. Therefore, either the entire building or the building materials it contains have a financial value that cannot be ignored.

In structural engineering, dismantling is an ancient concept of reusing existing structural components to create new facilities. It is an alternative to the evils of demolition around the world and essential to creating a sustainable environment. It is also called “reverse construction” [13]. The purpose of deconstruction is to use construction materials responsibly to minimize the consumption of new raw materials by using existing materials from demolished sites and finding ways to reuse them in another construction project. The demolition of building structures creates a huge amount of waste in most countries, which can be reused through reprocessing or reprocessing of materials, reducing the use of new resources and allowing the materials to have a new life cycle. Traditionally, the raw building material was processed into the desired product, but the new definition of manufacturing is to take salvaged items, make repairs, make improvements, or adapt them to society's needs. About 25% of demolition waste can be reused and 70% can be recycled.

Sustainable design for demolition results in an increased diversion rate of demolition waste from landfills, which can potentially be reused from existing building components [14-17]. It provides useful materials, facilitating material recycling in recycling centers, re-manufacturing companies, and building materials inventories. Buildings designed for deconstruction are easier to maintain and adapt to new users, which in turn protects the building envelope or adapts the interior spaces to new needs. Buildings designed with deconstruction in mind are often easier to maintain and adapt to new uses. Maintaining the building envelope or adapting interior spaces to new needs ensures that new buildings have little impact on the environment [18]. Current developments in sustainable design include the use of high-quality, long-lasting materials. However, designing for deconstruction is a difficult concept for architects as they view their buildings as timeless, and no architect intends to invest intensive work in creating a building that will then be demolished. The main problem with dismantling today is that architects or builders of the past designed their creations to last forever and did not take the necessary precautions for dismantling in the future. Even today, materials are not manufactured with recycling in mind [19-21].

Even though architects want to design sustainable buildings that can later be reused for other purposes, builders do not want to opt for new construction techniques because they are used to it and prefer traditional techniques. Architects can contribute to environmental protection by designing buildings that facilitate adaptation and renovation [22, 23]. The aim of the DfD is to use old building materials responsibly in order to minimize raw material consumption. By capturing materials removed during renovation or demolition of buildings and finding ways to reuse them in another construction project or recycle them into a new product, the overall environmental impact of the EoL of building materials can be reduced [24]. Designing for deconstruction details at the beginning of a project allows one building to serve as a resource for the next at the end of its useful life and helps close the loop on resource use. Furthermore, future risks and costs are considered by ensuring that components and products can be maintained and replaced quickly and easily [25-27]. This is particularly important if they are no longer acceptable under future environmental legislation, which is becoming increasingly common. Architects and engineers can contribute to this process by designing buildings that facilitate adaptation and renovation.

However, adopting DfD principles during the design stage of a construction project can ensure building flexibility for adaptive use and easy component and material dis-assembly for reuse and recycling. While at the building design stage, DfD will ensure that both the asset management and building removal processes are conducted more efficiently with minimum resource consumption and environmental impact [28]. In addition, the use of innovative connection systems in modular construction for new buildings, which can be rapidly disassembled and re-used explores the concept of design-for-deconstruction and re-use which implies the continuous re-use of the existing buildings by extending their lifetime and the structural elements of new/retrofitted buildings at the end of their lifetime. However, the effectiveness of re-use concepts applied to the building envelope should be validated

experimentally in full-scale prototypes. However, circular economy principles applied to a building system mean an ability to closely couple the recovery and reuse of products from end-of-life buildings to stock replacement and maintenance [29].

The design process should focus on future reuse by integrating the building into a closed loop. To enable reuse of a building, the building and its components should not become worn or obsolete and still be able to interact with other structural components [30]. In addition, to ensure the economic viability of reusable structures in their first life cycle, it was considered that the economic viability and speed of execution and dismantling of the structure should be at a similar or (at least) acceptable level compared to a traditional non-reusable one and non-disposable solution. The longevity of a building is determined by the building's ability to maintain its structural integrity over a long period of time, as well as its attractiveness in terms of function and style. The structural integrity of a building is determined by the durability of the materials and the quality of construction. Attractiveness is determined by the building's ability to adapt to changes over time. Finding a balance between durability and adaptability when designing a building; leads to building flexibility, an important quality in buildings constructed according to the principles of sustainable construction [31–34].

Designing a building for longevity can save costs and reduce the negative environmental impacts associated with operations, maintenance, and the material consumption during renovations and the resulting waste generation. On the other hand, if the decision to demolish a building is made long before the expected end of its life, the above may be reversed, i.e. short life. This highlights the crucial point that if a building is to be durable, durability must be balanced with adaptability [35]. However, an innovative approach encourages designers to incorporate DfD principles from the design phase of construction projects to ensure that the subsequent phases of reconstruction, repair and building removal are carried out efficiently. DfD considers end-of-life scenarios for building systems, products, etc. services in a holistic manner that includes both asset management and building dismantling processes). This approach reinforces the need to consider the life cycle of a building as represented in the sustainable building model.

A new perspective that is increasingly being discussed is to see buildings as a future resource pool for building materials. Instead of demolishing old buildings, disposing of C&DW, and extracting new materials from finite natural resources to build new ones, many environmentally conscious construction professionals are beginning to consider buildings as one of the preferred sources of building materials [36, 37]. The reasons for this include the lower energy and emissions reductions associated with material provision as well as the conservation of the embodied energy contained in secondary materials. When considering buildings as a future source of raw materials, DfD is a key element for material recovery. According to Phillips et al. [38], Design for Deconstruction (DfD) is not only about the recovery of building components at the end of their life, but also about processes that enable buildings to be easily assembled and dismantled. Despite efforts to reduce demolition waste through deconstruction, there has not been an increasing awareness in DfD applications especially in developing countries [39, 40].

In construction projects, DfD must address a holistic view of the project goals. This could be reducing waste through material recycling, reusing components or even complete building relocation. However, a thorough understanding of these objectives is required to understand the dimensions of the problem: the stakeholders, the decomposition factors and the project life cycle must be seriously considered. Only with an understanding of these dimensions can the heuristic design principles be used appropriately to achieve the project goals. This study presented the usage of DfD in multi-story structures, and the challenges and other factors influencing this approach in minimizing waste.

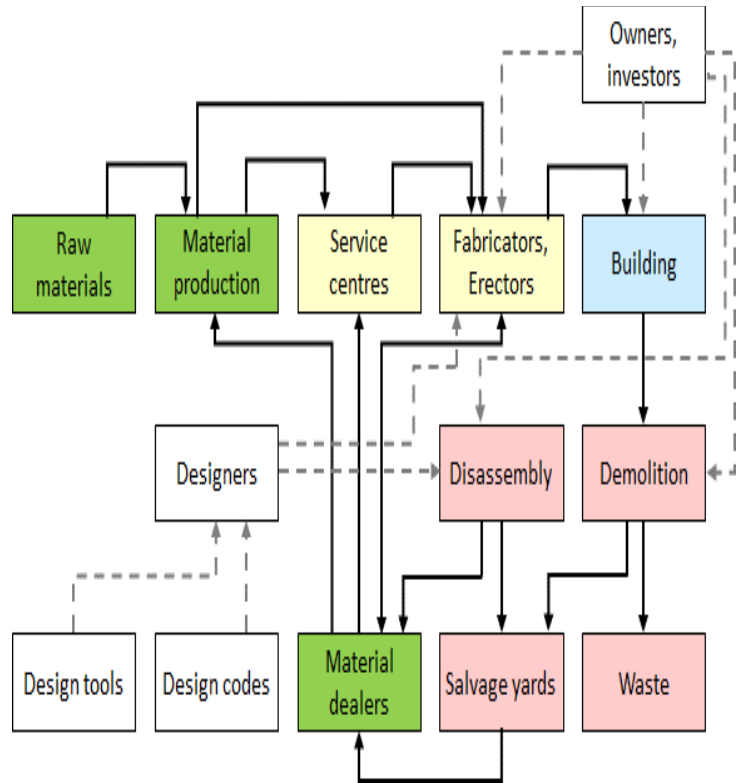


Fig. 1. Major role in the reuse process and interaction [25, 34].

### III. METHODOLOGY AND DESIGN

This study considered more than 100 articles between 2002-2023. Those article which contains extensive-work indicating the viable implementation of DfD capable of advancing the goal of sustainable multi-storey structures with an emphasis on eliminating waste especially in the design phase was selected. This made number of articles to be narrowed down to sixty. The focus is choose those with more emphasis on the concepts of DfD in the design phase, as these greatly contribute to the decision-making process for construction stakeholders and help reduce the cost of Changes during construction operations and during construction operations to reduce the end of life of the building. Literature research shows that there is a large knowledge gap between DfD success factors and deconstruction analysis criteria.

Several complicated factors that play a role in DfD success cannot be covered by simplified defined criteria for assessing the deconstructability of a designed or existing project. Also, 25

actions that promote DfD were collected from the literature altogether while selected literature reviewed where drawn from satisfactory peer review journal articles while database such as

Google Scholar, Sciencedirect, Scopus, Web of Science and the Directory of Open Access Journals (DOAJ) was suitably used to look for these relevant articles.

**Table 1.** Design for deconstruction actions cited in current articles.

| S/ N | Motivator to DfD implementation   | Sources          |
|------|---|------------------|
| 1    | Use reversible mechanical/non-chemical connections  | [20, 41]         |
| 2    | Ensure elements of the building are independent and separable (structure, envelope, services, fit- out) | [4, 23, 42]      |
| 3    | Use standardized elements   | [43, 44]         |
| 4    | Use non-composite floor systems   | [42, 45, 47]     |
| 5    | Permanently mark materials with properties  | [47, 48]         |
| 6    | Ensure as-built drawings are available  | [47, 49]         |
| 7    | Develop a deconstruction plan during the design phase   | [14, 15, 34]     |
| 8    | Avoid the use of resins, adhesives, and coatings  | [41, 42]         |
| 9    | Ensure post-construction ease of access to fixings  | [49, 50]         |
| 10   | Do not use in-situ concrete   | [49, 50]         |
| 11   | Avoid the use of hazardous materials  | [1, 13, 17, 20]  |
| 12   | Use modular elements  | [18, 46]         |
| 13   | Use prefabricated elements  | [20, 22, 29]     |
| 14   | Use lime-based mortar with masonry  | [22, 49, 51]     |
| 15   | Minimal number of materials and components  | [14, 23, 53]     |
| 16   | Early design process thinking (scheme & and design development)   | [15, 26]         |
| 17   | Use components of singular materials  | [49, 52]         |
| 18   | Train all team members on design for deconstruction   | [20, 26, 49, 53] |
| 19   | Establish the feasibility of element reuse  | [26, 29, 54]     |
| 20   | Design in tie-offs for deconstruction   | [14, 19, 48]     |
| 21   | Provide construction plan   | [13, 26, 49]     |
| 22   | Use durable materials   | [4, 13, 49]      |
| 23   | Size components for manual handling   | [4, 49]          |
| 24   | Include information on deconstruction techniques  | [49, 55]         |
| 25   | Do not use structural grout with precast elements   | [33,49, 58]      |

#### IV. DISCUSSION

DfD can contribute to the construction industry and is request to achieve sustainable construction, particularly through natural resource conservation, waste reduction and waste recovery for reuse and recycling. It is important that designers learn to consider design for deconstruction during building design because the decisions made during design influence the deconstructability of a building at its end-of-life. The sustainable construction designs should be used as a guide when designing for deconstruction. Other important factors to take into account are designing for flexibility—that is, balancing durability and adaptability—using building layers, applying design principles for deconstruction, and choosing appropriate materials for building components.

Designing a building with deconstruction in mind primarily aims to maximize recovered materials, minimize waste generation, and enable relatively easy building disassembly at

the end of its useful life. Therefore, in order for buildings to serve as the future's resource pool, architects and builders should use materials and building techniques that will result in a high proportion of salvaged materials that can be recycled and used again. However, the gap between decisions made during a structure's design and those that may be made decades later when the building nears the end of its life is an important roadblock to design for deconstruction. Therefore, planning and building control could be used to set design and building standard requirements that emphasize the potential for reuse.

Deconstruction has been found to have several positive effects on the environment, including the preservation of natural resources, a decrease in the amount of waste transported to landfills, and the re-purposing of materials, which results in energy savings. Reducing resource depletion would result in higher reuse rates and lower extraction of natural resources. DfD is regarded as one of the key elements of the green design approach that closes the materials loop to achieve material

sustainability. This, along with the possibility of energy savings, makes DfD a crucial sustainable building strategy for the future. Furthermore, closing the materials loop is one method of attaining material sustainability. This, along with the possibility of energy savings, makes DfD an essential sustainable building strategy for the future. This strategy doesn't mean to overlook already-existing structures because retrofitting buildings is a top priority for the carbon agenda.

Even though DfD may have imposed additional economic and possibly environmental costs in the short term, but at the much larger scale of the resource life cycle, the long-term benefits are potentially much greater. In addition, DfD is an important part of green design and is a consideration of the entire life cycle of a structure. It contains provisions for the reuse of components at the end of a building's lifespan. However, it should be noted that building design planning DfD is effective when accompanied by other considerations such as sustainable design and recycling. DfD is most effective when it allows maximum flexibility of spatial configuration within a given structure, as it preserves the building structure. Additionally, designers need to think about "future proofing" their details in a way that maximizes the opportunities for reuse of both building assemblies and their sub-components in other buildings to the extent possible. Only if none of these strategies prove to be practical after a cost-benefit analysis should designers resort to a pure recycling strategy.

But despite efforts to reduce demolition waste through deconstruction, there has not been a gradual increase in DfD implementation as the system is far from reaching its waste minimization potential, with less than 1% of existing buildings being fully deconstructable in several developing countries. As an alternative to demolition, dismantling allows waste to be returned to the building's life cycle and allows DfD to save resources, energy, and landfill space, as well as having other positive environmental, economic, and social impacts. The waste can be removed for reuse after dismantling as little damage is done to it. When a building is demolished, the product typically breaks down and the materials are recycled. Furthermore, since it can be difficult to separate these elements to enable their recovery, recycling rates are expected to be affected by the increasing use of composite products that can meet higher thermal requirements. Resources from a building can be recycled and used through DfD.

Looking at several example of DfD implementation in building construction, we view some important lessons. For instance, at the Hub Culture Pavilion in Davos, a mountain resort in Graubunden, the eastern Alps of Switzerland is the ICEhome (Innovation for the Circular Economy house) is case scenario of a structures best designed with the implementation of DfD is the ICE-house. According to Patricia et al [56] designer considered material efficiency by designing the building with a specified life span to avoid building vacancy, demolition, generation of large amounts of waste and to save materials and components for reuse. Also, an extensive overview of state of the art in design and testing of DfD concrete connections for concrete elements using an experimental and numerical simulation approach [57-59]. Sandin et al. [60] utilizes ISO20887-Design for Disassembly principles and constructed Villa Anneberg house. The study investigates how

new design concepts can be developed to make Villa Anneberg, a two-storey light timber house from the Swedish manufacturer Derome, adapted for deconstruction and reuse.

## V. CONCLUSION AND RECOMMENDATIONS

Without a doubt, EoL management in multi-storey buildings is enabled by DfD and is an essential aspect of waste minimization in the construction industry. This study highlights the numerous benefits of using DfD in the literature reviewed. Therefore, it is a crucial step towards reducing energy and material consumption in the construction of buildings as well as the waste generated. DfD offers numerous economic, social, and environmental benefits. It seems reasonable to integrate DfD components into both on-site and off-site manufacturing of multi-story structural materials. While some nations have recognized the importance of DfD and responded accordingly, in many others it is still an issue that is ignored. However, if proper awareness is raised and educators incorporate the knowledge into every education system in developing countries, future decision makers – such as engineers or designers – will graduate with an accurate understanding of DfD and its connection to various buildings.

In the construction industry, where designers generally prefer to use established design principles, this could lead to increased resistance to change. But if a sustainable implementation of DfD is introduced, it will become easier to deviate from previous traditional design principles. The overall cost of the dismantling connector could be reduced if the complexity of the proposed connection system in the multi-story component is reduced. In this study, a state-of-the-art review was presented to demonstrate the use of deconstruction design in multistory buildings. It also highlights the challenges and other factors that influence this approach to waste minimization. As part of the idea of promoting net zero emissions, this study educates construction industry stakeholders, thereby promoting the use of the DfD principles. However, further research can be conducted to indicate empirical evidence an application of DfD.

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