Design for Deconstruction: Social Justice Implications of Circular Construction

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Summary Page

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ARC Firm:	ZGF Architects LLP 925 Fourth Avenue, Suite 2400 Seattle, WA 98104 Telephone: (206) 623 -9414 URL: https://www.zgf.com
ARC Fellow:	Idris Soliu Ph.D. Candidate University of Washington Telephone: (206) 797 8626 Email: idris.soliu@outlook.com
Firm Advisor:	Lona Rerick Principal, Project Performance Team ZGF Architects Telephone: (503) 863-2429
Faculty Advisor:	Catherine De Almeida Associate Professor Department of Landscape Architecture University of Washington Telephone: (206) 543 -7897

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Abstract

Construction and demolition waste from the standard linear (take-make-use-dispose) approach often ends up in landfills, usually in marginalized communities. This business-as-usual practice of construction waste management disproportionately affects underrepresented groups through environmental hazards and economic exclusion, thereby contributing to social inequality. In contrast, Design for Deconstruction (DfD) has the potential to be a circular economy strategy that balances building design with future disassembly, promotes material reuse and reduces landfill waste, and potentially positively impacts social justice outcomes. This project explores how DfD can facilitate social justice in managing construction and demolition waste within the built environment through circular building design. Ten DfD principles were initially identified from the literature, followed by case studies where these principles were previously applied, as well as the barriers to implementing the principles in construction projects. This study employed a mixed research approach by integrating case studies and a cross-sectional survey of design and construction firms with experience in demolition and deconstruction projects. The results uncovered interchangeability and repairability, material specification, and design with workers in mind as the top DfD principles currently being implemented by construction industry practitioners based on the ten principles investigated. The findings also found that the high cost of deconstruction and the absence of policy support were the most critical barriers hindering the DfD in the Pacific Northwest construction market. The study concludes with frameworks for waste diversion for new and existing buildings to mitigate the impact of current practice and achieve a sustainable built environment.

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List of Acronyms

CE	Circular Economy
C&D	Construction and Demolition
DfD	Design for Deconstruction
U.S.	United States
SPU	Seattle Public Utilities

Chapter 1: Introduction

1.1. Introduction

The current economic model is driven by a take-make-use-dispose system of production and consumption known as a linear economy. This principle focuses on material extraction, production, and disposal at the end of material and product lifecycles. Operating under the linear approach across industries has substantially increased material extraction and generated billions of tons of waste in landfill sites (Kio et al., 2022). The activities of the built environment are responsible for 50% of raw material extraction and contribute approximately one-third of global CO2 emissions; construction and demolition (C&D) account for a sizable percentage of waste in landfill sites globally. (Zaman et al., 2023). For instance, the built environment accounts for 40% of the total waste generated in landfills globally, with the United States responsible for the most significant portion, followed by Japan and Germany, occupying the second and third positions. (Santos et al., 2024)

In the United States, C&D waste contributes significantly to waste generation, accounting for an estimated 25% to 45% of the solid waste generated by weight. (Esa et al., 2017). The C&D waste includes construction, renovation, and demolition materials, such as concrete, wood, metals, steel, drywall, bricks, plaster, tiles, glass, and plastic. Concrete is the most significant contributor, accounting for 69.7%, followed by asphalt concrete at 15%, wood at 7.1%, and other materials, contributing 8.1% (Keena & Friedman, 2022). When examined by sector, buildings accounted for 184.3 million tons or 32% of the total C&D waste, roads and bridges contributed significantly more at 250.2 million tons or 44%, and 135 million tons (24%) of C&D waste is attributed to "other structures," a category of waste generated from infrastructure such as communication, power, transportation, sewer and waste disposal, water supply, conservation, and manufacturing facilities. (Naomi Keena & Anna Dyson, 2020).

Out of the 569 million tons of waste generated annually in the United States, a majority (90%) comes from renovation and demolition activities, while only 10% is attributed to new construction. However, over 75% of construction and demolition waste is sent to landfills each year, excluding hazardous materials, and has the potential for reuse (Boston Reuse, 2023). These landfill sites are usually located in marginalized communities, disproportionately affecting the underrepresented groups by exposing them to environmental hazards, health risks, and economic exclusion, thereby contributing to social inequality in the management of construction and demolition waste (McKinney et al., 2015).

According to Nelson (2004), the total built-up space in the United States will be nearly 427 billion square feet by 2030, of which close to 82 billion square feet will be from renovating existing structures and about 131 billion square feet from new construction. This implies that about 19% of the structures in the year 2000 will be renovated from 2000 to 2030, and more than 50% of the existing buildings will have been built since 2000 and will be demolished and reconstructed in the near future. These massive demolition and reconstruction activities will be a significant source of waste in marginalized communities if an alternative approach is not implemented. One way of mitigating the challenge is to design buildings for recovery and reuse in a secondary loop, a concept known as Design for Deconstruction *(DfD)* within Circular Economy strategies.

DfD is a circular economy strategy that balances building design with future disassembly, promotes material reuse, reduces landfill waste, and contributes to environmental sustainability and social equity. The concept became popularized due to growing interest in the Circular Economy in the global arena. Circular Economy (CE) emerged as an alternative to the prevalent unsustainable take-make-dispose operation across sectors, including the built environment. The model is envisioned to replace the linear model with strategies to circulate materials and products through a cascading and regenerative model (Garcia-Saravia Ortiz-de-Montellano et al., 2023). In the context of the built environment, the CE aims to maintain the value of materials through a closed-loop system, increase the recovery rate at the end of life, and reduce solid waste in the landfill site. Adopting CE offers several benefits; for instance, it is estimated to create millions of jobs with accrued benefits of over $2.04 trillion (€1.8 trillion) by 2030 (Stahel, 2013), reduce solid waste in landfills, reduce CO2 emissions, and support United Nations (UN) Sustainable Development Goals (Uvarova et al., 2023). These objectives could be achieved through various circular strategies, including design for deconstruction, modularity, standardization, flexibility, and adaptability, to name a few.

Previous studies have remarked that design professionals can significantly mitigate waste generation by being proactive at the planning and design stage of the project. (Cruz Rios & Grau, 2020; Pittri et al., 2023). The decisions made at the early stage of the project usually have consequences for marginal communities. For instance, during the planning and design stage, the design team often considers building materials, functionality, aesthetics, structural stability, maintainability, and environmental impact of the building. While there has historically been little attention to the end-of-life phase, there is an increasing interest in understanding how materials and components can be deconstructed and reused to reduce the waste stream. This lack of end-of-life consideration contributes to the significance of solid waste generation in landfills.

Meanwhile, DfD can significantly reduce the waste stream by incorporating a disassembly strategy in the design process. The goal is not only to dismantle buildings to recover materials but to incorporate a systematic disassembly of components to reuse in the secondary loop, as opposed to when structures are destroyed and landfilled. This strategy reduces the total environmental footprint of the building and offers socio-economic benefits. For instance, implementing DfD in the built environment could eliminate embodied carbon from extracting and manufacturing new materials, minimize environmental pollution during demolition activities, reduce waste in landfills, create employment opportunities for skilled and unskilled labor, and improve secondary markets (Kanters, 2020). In addition, DfD can mitigate the impact of conventional waste management practices in the landfill, particularly in addressing the social consideration of sustainability, such as the social justice implications of construction and demolition activities resulting from the linear method. While design for deconstruction can provide these benefits if fully implemented in the construction projects, mainstreaming the concept in the design process is relatively challenging, and fewer buildings are designed using this approach.

These limitations in the scalability of design for deconstruction to mitigate the impact of social inequality of C&D waste on marginalized communities serve as motivation for this project. As a result, this project investigates the potential of Design for Deconstruction in mitigating social inequality in managing C&D waste in the built environment.

The overarching research question is: *How can Design for Deconstruction mitigate the impact of construction and demolition waste in marginalized communities?*

The subsidiary Research questions are:

1. What are the challenges of implementing design for deconstruction in construction projects?
2. What are the drivers for implementing design for deconstruction in construction projects?
3. What alternative strategy is available to achieve social equity in managing construction and demolition waste in the built environment

The corresponding objectives of the study are:

1. To assess the impacts of conventional construction waste disposal on marginalized communities and explore how design for construction practices can mitigate these impacts.
2. Identify and analyze the barriers to implementing design for deconstruction in construction projects and propose strategies for overcoming the barriers.
3. Examine the drivers for implementing Design for Deconstruction in the built environment
4. Propose an alternative approach that facilitates social equality in managing construction and demolition waste in the built environment

This work aims to align waste management practices with sustainability goals by addressing the often overlooked social justice considerations. The study contributes to the broader discourse on sustainable and equitable construction practices by examining the potential of design for deconstruction practices to mitigate social inequities in managing construction and demolition waste and propose actionable solutions.

1.2. Methodology

A mixed-methods approach was employed in the study. At first, a literature review was conducted to identify the gap in the intersection of design for deconstruction, social justice, and waste management, followed by an analysis of three case studies that successfully integrate design for deconstruction in their projects. The result of the case study and literature review was used to develop a questionnaire survey, followed by data collection, analysis, and concluding recommendations as indicated in **Figure 1**. The methodology is discussed in detail in the following sections.

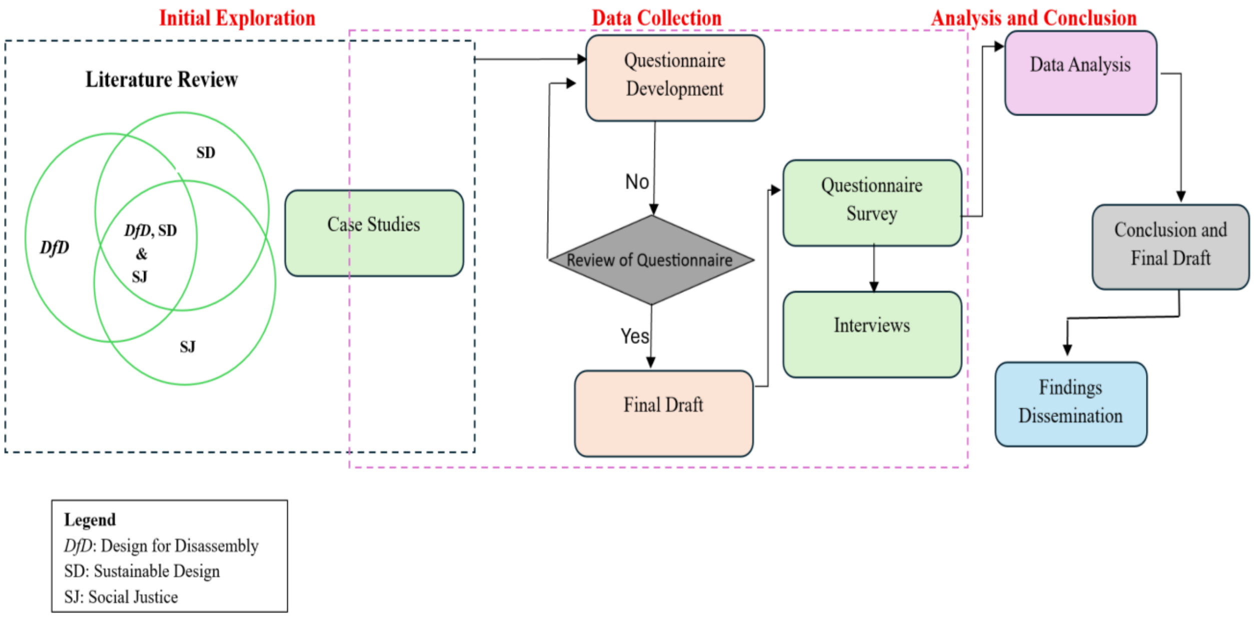

Figure 1. Research Methodology Showing the Research Process

1.2.1. Literature Review and Case Studies

A literature review was conducted to explore the transition toward more sustainable and socially equitable construction practices. This review focused on identifying gaps in existing literature, particularly at the intersection of DfD, social justice, and conventional waste management practice. It provides insight into the social justice implications of construction waste disposal in marginalized communities and highlights the various DfD principles and challenges reported by previous scholars. Following the literature review, three case studies of building projects successfully implementing DfD principles were identified and analyzed. The first case is the construction of a bank headquarters in the Netherlands, in which the building was constructed using mechanical connections to facilitate material separation for deconstruction and material recovery in the future. The second case involves remodeling an existing building in the United Kingdom. The last case is a demolition project in Washington State, in which the building was deconstructed entirely, and the materials were salvaged and donated to a charity organization. The result of the literature review and case studies serves as the basis for developing a questionnaire for the project. A detailed description of the case studies is provided in Chapter 4.

1.2.2. Questionnaire Development

The questionnaire survey was developed based on literature and case study findings, then refined with input from faculty and firm advisors. This process was undertaken to eliminate ambiguous language and ensure appropriate terminology in the survey. The survey is structured into four distinct sections. Section A solicits respondents' background information, including their professional role on projects, the type of organization they work for, the type of projects their organization specializes in, and their years of experience in the construction industry. Section B explores the application of DfD principles in construction, Section C assesses the barriers to implementing design for deconstruction, and the last section examines the drivers for implementing DfD principles in construction projects.

1.2.3. Data Collection Strategy

Participants for the study were selected using convenience sampling, guided by the advisor's familiarity with key construction stakeholders in the Pacific Northwest, and practitioners were contacted via email to solicit their participation in the survey. The participants include ZGF Pacific Northwest staff, the design and construction firms in the Puget Sound area, and other ARC participating firms. This approach is justified for three key reasons: first, to ensure that the sample allows for the collection of relevant data; second, to employ specific sampling techniques that consider participants well-suited to addressing the research objectives; and lastly, to determine the number of participants necessary to generate sufficient data (Symon & Cassell, 2012).

1.2.4. Data Analysis

Quantitative data was analyzed using descriptive statistics to summarize trends and patterns within the data to provide a clear overview of key findings. Sections A to C of the survey were analyzed using descriptive statistics. In contrast, in Section D, thematic analysis was employed to identify recurring themes and insights related to the driver for implementing the design for deconstruction principle by design and construction firms. The results were synthesized to provide a comprehensive understanding of how design for deconstruction can promote material circularity and mitigate the impact of demolition waste in underrepresented communities to achieve social equity in managing construction waste. Finally, conclusions were drawn based on the combined findings to recommend more sustainable and socially equitable construction waste management practices.

Chapter 2: Literature Review

The increasing demand for sustainable construction practices and resource efficiency has increased interest in DfD. This approach facilitates the recovery and reuse of building materials at the end of the building life cycle. As global construction waste continues to increase, with significant environmental and social impacts, particularly on landfill communities, DfD presents a viable strategy to support circular economy objectives and reduce the ecological footprint of buildings (Lynch, 2022). This chapter explores existing literature on DfD, focusing on its historical evolution, foundational theories, and relevance in contemporary architecture and construction.

The chapter also outlines the key principles that underpin effective DfD implementation identified from previous studies, such as specifying reusable materials, designing accessible and mechanical connections, and separating structural systems from services. These principles are crucial for enabling buildings to function as temporary structures and as material banks, reservoirs of components that retain value and usability beyond a single lifecycle (Lima et al., 2023). Drawing on scholarly work, industry reports, and case examples, this chapter comprehensively explains the strategies, challenges, and opportunities associated with designing buildings for future disassembly and material circularity.

2.1. Principles of Design for Deconstruction

Deconstruction is a systematic dismantling of a structure to salvage building materials and components for second use. The process involves careful, piece-by-piece disassembling of buildings, known as selective demolition or disassembly. The primary objective is to maximize the recovery and reuse of building materials to prevent demolition at the end of the building's life cycle. While the process might be considered expensive, its advantages outweigh the costs if the value of the building materials is preserved at the end of life (Zaman et al., 2023).

Adopting selective demolition retains material value and facilitates reuse, recycling, and repurposing in a second life. The historical genealogy of deconstruction shows that the Native Americans practiced deconstruction through their migratory patterns by building their shelters to be easily disassembled(Kanters, 2018). Building deconstruction is not a new practice. A more recent example of deconstruction is the Seagram Building in New York City, which uses metals, glass, stone, and concrete in the construction process to facilitate the dismantling and revitalization of future buildings (Cruz-Rios & Grau, 2020). Using bolts and nuts for connections instead of adhesive binding agents is a significant factor in implementing deconstruction into the construction project. This facilitates easy dismantling of structures rather than complete demolition.

The concept of deconstruction can be traced to Jean Prouvé's work on Tropical House in 1949 and Rural Studio in modern architecture (Kanters, 2018). The technique has become more popular due to increasing attention to adopting a CE. The model is envisioned to keep material usage in circulation at the highest possible value through principles of circularity, thereby reducing the pressure on limited natural resources, eliminating waste in the landfill, and other externalities such as greenhouse gas emissions and biodiversity loss. The model categorized materials into technical and biosphere products, as shown in **Figure 2**. The biological cycle returns the material and product to the biosphere at the end of life, while the technical cycle does not.

Most building materials belong to the technical division and are expected to be shared, maintained, repaired, reused, upgraded, and recycled (Kanters, 2020). This categorization is based on the European waste pyramid hierarchy, which classifies waste into prevention, reuse, recycling, recovery, and landfill, with prevention and reuse occupying the highest position and aligning with the design for deconstruction principle.

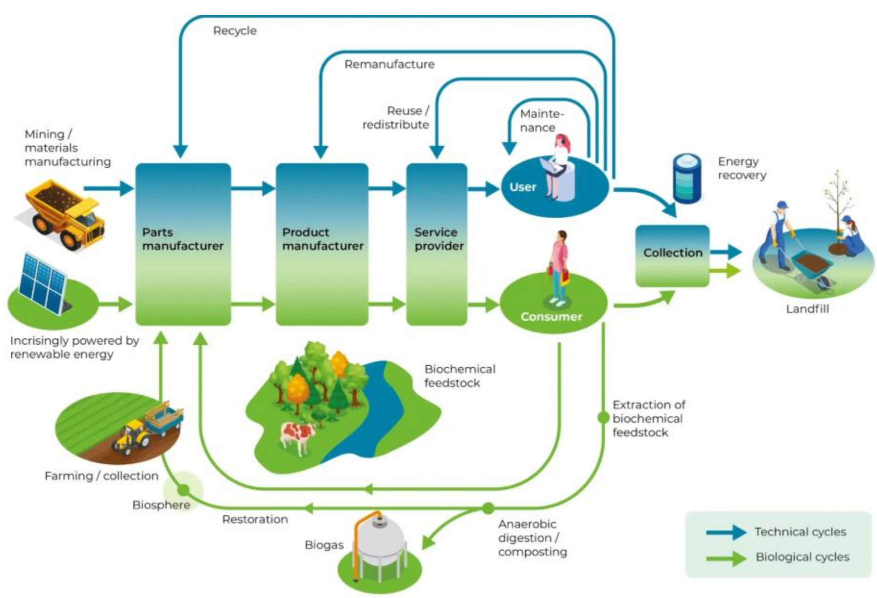

Figure 2. Circular Economy Indicating Technical and Biological Material Flow (Rozen, 2023)

The principles of DfD aim to design out waste and ease future disassembly to optimize the reuse of building materials and eliminate waste in landfills. In practice, materials are salvaged from structures and used in new constructions to save resources on material extraction, processing, manufacturing, and landfill fees. This approach also reduces CO2 emissions when manufacturing new components, reduces environmental footprint, and creates economic opportunities for the secondary market. While the practice is beneficial, it has yet to gain mainstream adoption due to several challenges. **Figure 3** shows how the deconstruction process facilitates material circularity and reduces landfill waste. The process changes the waste management practices from landfilling to reutilization and material conservation.

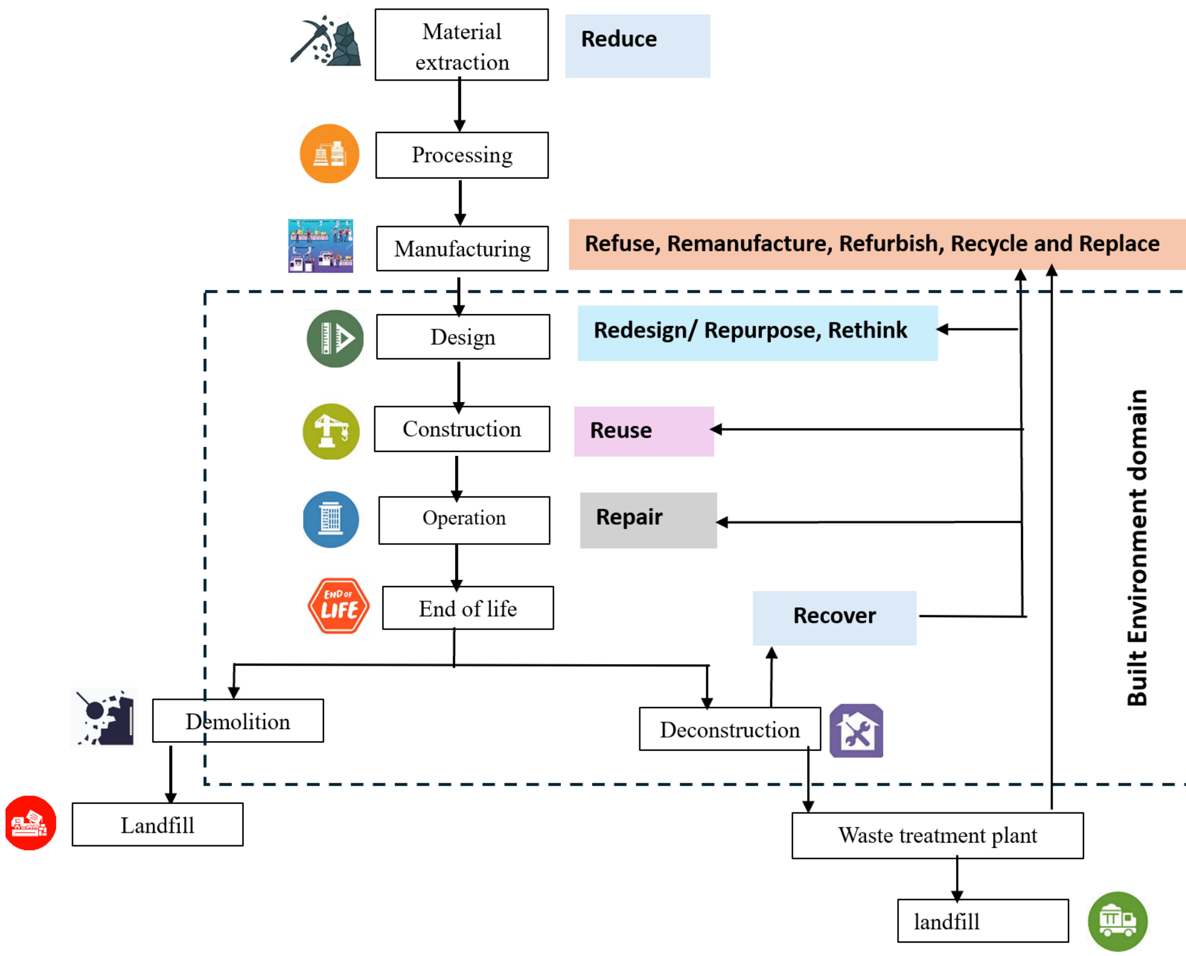

Figure 3. Construction Material Lifecycle Through Deconstruction Practice

Many structures are designed without consideration of their potential for future reuse or recycling, which results in rigid designs that are difficult to dismantle. At present, less than 1% of the existing structures are demountable due to inadequate consideration by designers (Kanters, 2018). As a result, construction professionals often need help deconstructing these buildings, leading to inefficient or incorrect procedures, material damage, and a significant waste stream in the landfill site. To overcome these barriers, designers must integrate deconstruction principles early in the design process (Akinade et al., 2020). This approach requires a thorough understanding of how building components can be efficiently dismantled, reused, or recycled at the end of their lifecycle. Incorporating these principles facilitates easier and cost-effective deconstruction and promotes material circularity by extending the life cycle of materials and reducing construction waste. Various authors put forward the following principles. The key design for deconstruction principles includes:

2.1.1. Specify Building Materials with a Precautionary Approach

Specifying building materials with a precautionary approach means making deliberate, informed choices about materials from the outset of a project, with consideration for their entire life cycle from production and use to eventual recovery or disposal. As Crowther (2000) emphasized, this forward-thinking strategy supports sustainability and long-term resource efficiency, aligning with the goals of DfD and the circular economy. This approach encourages using durable, non-toxic, easily disassembled, and recyclable or reusable materials. Materials should be selected not just for their performance during the building's operational life, but also for how well they can be recovered and repurposed after the building is dismantled. For instance, natural materials like timber or metal, especially those used in modular, mechanically fastened systems, are often more suitable for reuse than composites that rely on chemical adhesives or mixed ingredients that are difficult to separate.

2.1.2. Design Accessible Connection*s*

Designing accessible connections is a fundamental principle of DfD that promotes both ease of disassembly and worker safety. This principle calls for careful consideration of how building components are joined and how those joints can be accessed, modified, or undone over time. As Brad (2010) suggests, connections should be designed to be physically and ergonomically accessible, allowing them to be located, assessed, and detached using standard tools or manual methods, without the need for highly specialized or costly equipment. In practice, this means avoiding concealed or welded connections that require destructive techniques for removal, such as cutting or grinding, which can be labor-intensive, time-consuming, and potentially hazardous.

Instead, using mechanical fasteners such as bolts, screws, or clips ensures that connections can be easily reached and reversed without damaging surrounding materials.

2.1.3. Use Mechanical Connections

Using mechanical connections such as bolts, screws, and nails is essential for facilitating disassembly and supporting material reuse in DfD. Unlike chemical adhesives and binders, which form permanent bonds and complicate separation, mechanical fasteners allow for non-destructive removal of components. This preserves material integrity and reduces time, labor, and cost at the end of a building's life (Tzourmakliotou, 2021; Webster, 2007). Chemical connections can also release harmful substances, posing health and environmental risks during application and disposal. Using standard tools, mechanical connections are safer, reversible, and easier to manage. They enable buildings to function as material banks and support circular construction by maintaining the usability of components for future projects (Balogun et al., 2023).

2.1.4. Separate Structure from the Services

Separating mechanical, electrical, and plumbing (MEP) systems from the structural framework is a key principle of DfD that enhances a building's adaptability, maintainability, and material recovery potential. As Akinade et al. (2020) emphasize, designing these systems independently of the building's core structural elements, such as beams, columns, and slabs, makes them significantly easier to access, maintain, and eventually remove without damaging other components. This separation allows MEP systems to be removed quickly during routine repairs or upgrades, which avoids the need to disturb structural components or undertake demolition. In the context of deconstruction, it facilitates the selective removal and reuse of high-value components such as HVAC units, conduits, switchboards, and plumbing fixtures, which are often wasted when embedded in walls or slabs.

2.1.5. Design with Workers and Labor in Mind

Designing with workers and labor in mind means prioritizing construction methods, materials, and components that are easy to handle, install, and disassemble using human-scale effort or basic equipment. As Cruz Rios & Grau (2020) highlight, this approach makes C&D processes more efficient and promotes inclusive labor participation. By specifying manageable materials and avoiding complex design, the design will accommodate a broader range of skill levels, enabling experienced professionals and entry-level workers to safely and effectively participate in the construction and disassembly process. This strategy will enhance productivity, reduce physical strain, and simplify the separation of parts during disassembly while lowering the labor intensity and cost associated with DfD (Akinade et al., 2020).

2.1.6. Simplicity in Structure and Form

Adopting simple structural systems and forms is a foundational strategy for facilitating ease of construction, adaptability, and eventual deconstruction. According to Boston Reuse (2023), designs incorporating open spans, regular grids, and straightforward geometry are easier to construct with fewer errors and less material waste. Such simplification also supports efficient disassembly, as standardized forms and dimensions are more predictable and easier to manage during deconstruction. Additionally, simplified structures are more adaptable to change, enabling future reconfiguration or reuse with minimal disruption.

2.1.7. Interchangeability

Incorporating interchangeability through modular and standardized design ensures that building components can be easily removed, replaced, or reused across different projects. As Kamali & Hewage (2016) note, this principle is central to circular construction, as it extends the life cycle of materials and minimizes waste. Using interchangeable systems allows for greater flexibility during maintenance, upgrades, or repurposing of the building and reduces the dependency on customized or proprietary parts. This design strategy supports long-term material value retention, promotes resource efficiency, and simplifies logistics in both construction and deconstruction phases.

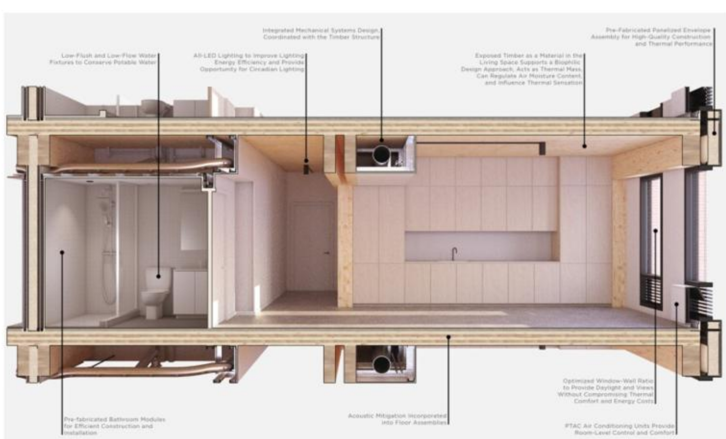

Figure 4. Interchangeable design for Component Modularity (Generate, 2021)

2.1.8. Safe Deconstruction

Ensuring safe deconstruction starts at the design stage. When designers consider worker safety, equipment use, and site logistics early on, they help to reduce the physical and operational risks associated with renovation, disassembly, or eventual demolition. As Ostapska et al. (2024) emphasize, incorporating wide, clear movement paths, organizing spaces for material handling, and planning for safe access to components will make the work environment safer and increase the efficiency and cost-effectiveness of the deconstruction process.

Complex and hazardous tasks such as cutting into sealed wall cavities or accessing deeply embedded mechanical systems can be avoided by designing buildings with future disassembly in mind. This reduces the need for specialized equipment or risky manual interventions and allows workers to perform tasks with standard tools in a structured, ergonomic environment. Ultimately, buildings designed for safe deconstruction are easier to maintain, more adaptable over their lifespan, and less costly to dismantle, contributing to worker well-being and sustainable material recovery (Bertino et al., 2021).

2.1.9. Document Materials and Deconstruction Methods

Alongside physical design strategies, comprehensive documentation ensures a smooth and organized deconstruction process. As Brad (2010) outlines, keeping accurate and detailed as-built drawings, including specifications of materials, structural elements, and connection types, lays the groundwork for future disassembly. These documents should highlight the sequence of disassembly steps, the locations of mechanical fasteners, and the characteristics of major building systems. Adequate documentation reduces uncertainty for contractors and laborers, minimizes errors during dismantling, and helps avoid damage to reusable components. It also supports better planning for material sorting, transport, and reuse, thereby improving the overall success of a circular deconstruction process. When properly documented, buildings become “material banks,” ready to be mined and reintegrated into future construction projects (Pearlmutter et al., 2020).

2.1.10. Provide a permanent identification system for building components

To complement physical documentation, a permanent digital identification system ensures long-term traceability and easy retrieval of key information about each building component. This process involves integrating tools like QR codes, barcodes, or RFID tags into the building during or after construction to allow for real-time data capture about part specifications, material composition, environmental ratings, and maintenance history (Balogun et al., 2023). These identifiers should align with international data sharing and lifecycle management standards to enable seamless integration with Building Information Modeling and other digital asset management platforms. This digital traceability facilitates better resource planning and end-of-life recovery and helps future project teams quickly assess which components can be reused, repaired, or recycled. It reduces the risk of material downcycling due to a lack of knowledge about its properties and enhances each material's economic and environmental value.

2.2. Challenges to Implementing Design for Deconstruction

While demolition destroys the building, deconstruction selectively removes the building components and materials for reuse. Demolition typically involves the rapid destruction of a building and disposal in landfills; deconstruction focuses on carefully dismantling, disassembling, recovering, and removing building components (Pearlmutter et al., 2020). This principle aims to preserve a building's materials to maximize their potential for reuse, recycling, and repurposing to reduce the waste stream in landfills. Previous studies underscore the profound influence of design decisions on the volume of waste generated during construction and the end-of-life stages of a building (Botchway et al., 2023).

It has been observed that waste management strategies are often implemented reactively and only considered once construction has commenced on the job site. This lack of a proactive waste management strategy during the design stage generates massive landfill waste. To address this, waste reduction efforts should be initiated during the design phase, where critical decisions about materials, construction methods, and system layouts are made. Design professionals can embrace more effective waste management strategies by adopting an initiative-taking and sustainable approach, such as design for deconstruction. The principle emphasizes designing buildings with future disassembly and material recovery in mind. By prioritizing modular designs, reversible connections, and recyclable materials, design for deconstruction will extend the material lifecycle and minimize the waste stream in marginalized communities.

Despite the numerous advantages of design for deconstruction, the practice has yet to achieve widespread adoption among design professionals. Its limited uptake can be attributed to several challenges construction practitioners face when adopting innovative ideas. Key barriers include a lack of awareness and knowledge about DfD principles (Cruz Rios et al., 2021). Insufficient training for designers and construction professionals, and the persistence of traditional design and construction methods prioritizing immediate cost and convenience over long-term sustainability. The absence of regulatory incentives and unclear industry standards to support deconstruction practices discourages their implementation (Hart et al., 2019). Other barriers include economic pressures and tight project timelines, as stakeholders may view it as requiring additional effort, time, or upfront investment.(Akinade et al., 2020)

Several significant barriers were identified in the early stages of implementing design for deconstruction. These included the widespread use of composite systems for building connections, the low cost of disposing of demolition debris compared to deconstruction, and the lack of specialized tools for deconstruction activities (Couto & Couto, 2010), the absence of building codes requiring or supporting the use of recycled materials in new designs, and the inability at the time to quantify the environmental and financial benefits of deconstruction accurately (Roxas et al., 2023).

Most existing buildings were constructed using composite systems and irreversible fasteners, making deconstruction challenging without resorting to destructive demolition. These components were designed to withstand the forces encountered during construction but posed significant obstacles to efficient disassembly (Kanters, 2018). Additionally, the need for purpose-made tools for deconstruction is another major challenge. Unlike traditional demolition, which uses well-established equipment, deconstruction requires innovative tools for selective and careful disassembly (Balogun et al., 2023). Further to that, economic factors also played a critical role in the slow adoption of deconstruction practices.

Traditional demolition, followed by disposal, is considered less expensive than the time- and labor-intensive process of dismantling structures and carefully salvaging materials selectively (Lynch, 2022). The absence of building codes specifying how to incorporate recycled materials into innovative designs posed another significant challenge. Another significant barrier is the lack of a method to assess deconstruction's environmental and financial advantages to persuade stakeholders of its benefits compared to conventional demolition (Lima et al., 2023).

However, some of these challenges have been addressed over time, yet others have evolved into contemporary issues. For example, uncertainties regarding the quality of recycled materials, negative perceptions of their reliability, and the financial advantages of demolition over disassembly continue to hinder adoption. Additional concerns include risks associated with using bolted connections in earthquake-prone areas, the potential for corrosion in reinforced concrete, which may complicate reuse, and the limited demand for deconstructed materials (Cristescu et al., 2020). Several studies have highlighted additional barriers to the adoption of design for deconstruction. Among these is the need for more strict legislation mandating deconstruction practices, which limits their widespread implementation (Cruz Rios & Grau, 2020). Another challenge is the need for a robust market for secondary materials and components, as noted by Akinade et al. (2020). Without a significant demand for reclaimed materials, stakeholders have little incentive to adopt deconstruction strategies.

The lack of adequate information during the design phase compounds the problem, as critical decisions regarding deconstruction-friendly designs are often overlooked (Rios et al., 2015). Additionally, developing a strong business case for DfD remains a challenge. Stakeholders may need help to justify the upfront costs and effort required to incorporate DfD principles into building designs and demolition processes (Lima et al., 2023). Cost is another factor that influences both the adoption of DfD and the development of supportive policies. O'Grady et al. (2021) emphasized that financial considerations are a significant barrier, particularly when deconstruction practices are perceived as more expensive than traditional methods. Furthermore, factors related to design requirements, such as the use of irreversible connections or complex structures, play a crucial role in the widespread adoption of DfD. Addressing these challenges is essential to promote broader acceptance of design for deconstruction to achieve material circularity in the built environment.

Table 1. Summary of Barriers to Implementing Design for Deconstruction in the Built Environment.

Barriers	Sources
Awareness of deconstruction practice	(Bertino et al., 2021; Pittri et al., 2024)
Policy to support deconstruction practice	(Durmisevic et al., 2021; Roxas et al., 2023)
Building codes requirement for recovered materials	(Pittri et al., 2024)
Specialized tools and equipment for deconstruction	(Tingley & Davison, 2011)
Client interest	(Boston Reuse, 2023)
Low disposal cost of demolition debris	(Akbarnezhad et al., 2014)
Lack of a large market for recovered material	(Akinade et al., 2020)
Storage considerations for recovered materials	(Dimitra Tzourmakliotou, 2021)
High cost of building disassembly	(O'Grady et al., 2021)
Limited training on the deconstruction procedure	(Rios et al., 2015)
Reliance on the traditional method of construction	(Akbarnezhad et al., 2014; Lima et al., 2023)
Absence of adequate tools for design for deconstruction	(Lynch, 2022)
Stakeholders' interest	(Boston Reuse, 2023; O'Grady et al., 2021)

2.3. Social Inequality in the Management of Construction and Demolition Waste

The current waste management practices disproportionately affect marginalized communities where landfills and waste facilities are primarily located. These facilities are often sited in low-income or minority neighborhoods due to systemic inequities known as "environmental racism" (Anderton et al., 1994). The neighborhood hosting these facilities often comprises minority populations, and race remains the most significant factor in determining facility locations. According to Bullard et al. (2008), communities of color are disproportionately concentrated in areas with the most facilities. These racial disparities continue as a widespread issue across the United States, reflecting systemic social inequities that continue to impact marginalized communities.

Although solving the social inequality problem ultimately may not be feasible, the built environment has the potential to play a significant role in mitigating the environmental, economic, and social impact of systemic inequality, particularly by addressing the waste generated from construction and demolition activities that end up in landfills. For instance, building debris alone accounts for 10-20% of the total weight of materials disposed of in landfills (Mah et al., 2018);

this reflects a significant impact of construction activities on waste streams. In the United States, construction and demolition activities generate approximately 600 million tons of waste annually (Boston Reuse, 2023). Demolition activities contribute approximately 90%, while new construction accounts for 10%. Concrete constitutes the most significant portion, representing 67.5% of the total waste, followed by asphalt at 17.8%. Wood accounts for 6.8%, and all other materials comprise 7.9% (Chen & Dagestani, 2023). This figure surpasses the quantity of municipal solid waste produced annually, indicating the role of construction activities in reducing waste streams. However, some of this waste is recovered and processed for reuse in the secondary loop; about 130 million tons are disproportionately disposed of across more than 1,500 landfill sites in the United States (Powell et al., 2015). These landfills are often situated in or near communities of color, resulting in environmental, economic, and social inequalities in managing construction and demolition waste.

Figure 5. Construction and Demolition debris in the Landfill

2.3.1. Environmental Impact

Disposing of construction and demolition waste in landfills poses significant environmental challenges to the local community. First, landfills occupy valuable land, limiting space for alternative uses such as agriculture or urban development. The leachate produced by decomposing materials can seep into groundwater, contaminating the soil and groundwater, and the gas emissions from waste decomposition pollute the environment (Wang et al., 2024). These pollutants pose serious risks to both ecosystems and human health. Construction and demolition waste contains non-inert materials such as insulation, fixtures, wiring, cables, lamps, and bulbs, laden with hazardous substances such as brominated flame retardants, mercury, lead-based paints, and metal-treated wood preservatives.

Exposure to these toxic substances poses significant health risks, such as asthma, respiratory conditions, and chronic illnesses (Li et al., 2016). Insulation material, like asbestos, poses severe respiratory risks when inhaling its fibers, and prolonged exposure to it can lead to asbestosis, lung cancer, or mesothelioma (Yu et al., 2018). Similarly, mercury in fluorescent lamps and certain electronic fixtures can harm the nervous system and kidneys, mainly when leached from contaminated water sources near landfills. Lead-based paints, commonly found in older structures, can cause developmental issues in children and neurological damage in adults if ingested or inhaled during demolition (Zhang et al., 2008).

Furthermore, brominated flame retardants, used in insulation and wiring, persist in the environment and accumulate in living organisms, potentially causing endocrine disruption and reproductive health issues (Yu et al., 2018). Metal-containing preservatives in treated wood contribute additional toxic risks, mainly when disposed of in landfills without adequate containment measures. These hazardous materials pose a serious risk to the communities in the landfill sites. In addition, the minority population near the landfill sites is primarily prone to other environmental hazards, including wildfire, air pollution, and water and soil contamination.

2.3.2. Economic Impact

Disposing of reusable materials leads to the unnecessary loss of valuable resources, necessitating the extraction and processing of virgin materials to replace the discarded ones. This practice is not only economically inefficient but also increases the overall costs of construction projects and accelerates the depletion of limited natural resources. The energy cost in extracting, manufacturing, and disposing waste is another economic concern (Victar & Waidyasekara, 2023). Transporting waste to landfills and manufacturing new materials both demand significant energy resources. This process results in the loss of embodied energy; the energy initially used in manufacturing materials that reusing materials could otherwise conserve. This energy loss increases the carbon footprint of construction projects and highlights missed opportunities for integrating material circularity into the built environment.

The growing volume of demolition waste annually can significantly reduce the available landfill space, which calls for an urgent need for sustainable waste management solutions. This challenge on landfill capacity highlights the importance of adopting material circularity to minimize disposal. Additionally, landfilling has critical economic consequences, particularly for nearby communities. The stigma associated with living near landfills further increases the social and economic disparities, leading to lower property values, reduced investment in local infrastructure, and community isolation (Norton et al., 2007). This economic disparity also impacts revenue generation; for instance, the undervaluation of properties near landfills could decrease tax revenues for municipalities, further affecting regional development and investment opportunities.

2.3.3. Social Impact

Beyond the economic and environmental risks associated with traditional waste management practices in the built environment, a social dimension is often overlooked in construction and demolition waste management discussions. Residents in these areas are exposed to various threats, including pollution, hazardous materials, and environmental degradation, which impact their health and quality of life. Living near waste facilities often subjects communities to persistent odor, noise pollution, and diminished aesthetic value, creating conditions that degrade their living environment. Such circumstances affect physical health and contribute to mental stress and decreased community well-being (Petts, 2000). Another critical social impact is the lack of equitable economic opportunities.

While sustainable waste management practices have the potential to create employment, systemic barriers often exclude marginalized populations from accessing these opportunities. Instead of benefiting from these initiatives, many communities experience job losses or are forced to migrate due to the proximity of waste sites, resulting in community displacement. These foul odors in landfill neighborhoods discourage the establishment of health-promoting amenities such as grocery stores, parks, sports facilities, and walking trails, depriving residents of essential social amenities for physical and mental well-being (Norton et al., 2007).

However, these communities could benefit from waste recovery and recycling initiatives. For example, materials recovered from demolition projects could be repurposed to provide affordable housing or infrastructure improvements. Proximity to landfills could also create business opportunities. For instance, deconstruction and material recovery can create opportunities for local employment in sorting, refurbishing, and reselling salvaged materials. Training programs in sustainable construction, material handling, and recycling can empower residents with new skills, benefiting underserved populations economically and socially (Webster, 2007). Despite this potential, such benefits often need to be more utilized due to a lack of inclusive planning and community involvement. Addressing these disparities requires a shift toward equitable waste management policies that actively involve local stakeholders, prioritize social equity, and emphasize the redistribution of benefits to affected communities.

2.4. Construction and Demolition Waste Management in Seattle

C&D activities contribute significantly to the waste stream in Washington State. C&D waste includes wood, concrete, glass, metals, asphalt roofing, gypsum, and other materials generated by construction and demolition activities. In Washington State, construction and demolition activities generate approximately 4 million tons of waste annually. Seattle accounts for 560,000 tons, making the city the highest waste generator in the last ten years, as shown in **Figure 6.** (Seattle Public Utilities, 2020). In response, various programs have been put in place to cushion the impact of this waste. Still, a significant portion of waste ends up in landfill sites.

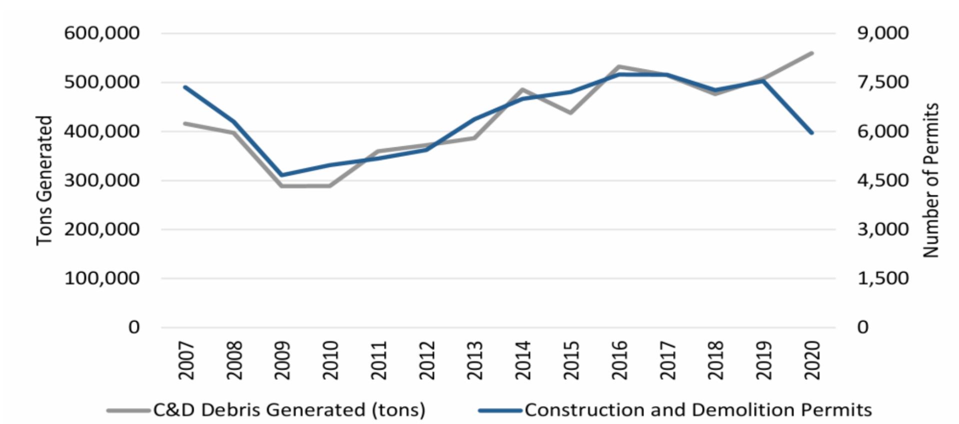

Figure 6. C&D Waste Generated and Seattle Building Permit (Seattle Public Utilities, 2020)

For instance, Seattle Public Utilities (SPU) mandates that C&D contractors and debris haulers deliver materials containing significant amounts of disposal-banned materials to designated facilities for reprocessing. These facilities must comply with state and local permitting regulations to recover essential construction and demolition materials from waste diverted from landfills. They must also report the quantities and movement of materials for reuse, recycling, and those going to landfills. Additionally, SPU requires that all demolition, construction, or alteration projects with a work area of 750 square feet or more submit a Waste Diversion Report upon project completion. This report must outline the quantities of construction and demolition materials generated and specify where they were sent for salvage, reuse, recycling, or disposal. The construction and demolition waste management in Washington State has three phases: collection, reuse, recycling, transfer, and disposal.

2.4.1. Waste Collections

The Seattle Municipal Code restricts the collection and hauling of construction and demolition materials to dispose of dumpsters and drop-boxes by contractors specifically selected by Seattle Public Utilities. The City of Seattle has maintained a contract for collecting disposed construction and demolition debris since 2001, with the most recent contract awarded to Waste Management, Inc. in 2019. Despite this arrangement, C&D material collected by Waste Management accounts for less than 1% of the total C&D debris generated in the city (Seattle's Solid Waste Plan Update, 2022). Most of the construction and demolition debris is managed through alternative options such as construction contractors who often self-haul the debris they generate, private third-party haulers transporting significant volumes for recycling, and loading directly into intermodal freight containers for rail transport to landfills.

Construction and demolition waste can be collected and hauled by four entities in Seattle, including city contractors, self-haulers, third-party private haulers, and intermodal haulers.

2.4.1.1. City-Contracted collector

This is the city contractor assigned to collect and haul waste for reuse, recycling, or destined for landfilling. Waste Management, Inc. is authorized to haul C&D debris from construction sites within Seattle limits for disposal. However, companies are not required to use the city-contracted hauler if they choose to transport their waste or if the hauling is part of another service the company provides.

2.4.1.2. Self-haulers

A private individual or company can collect C&D materials intended for recycling or reuse, which is classified as diversion. The C&D contractors involved in demolition, new construction, or remodeling projects are self-haulers when transporting C&D debris from their projects to a city-operated or privately owned transfer station in Seattle. However, the collected materials must contain no more than 10% of non-recyclable or non-beneficially used material by volume (Seattle's Solid Waste Plan Update, 2022).

2.4.1.3. Third-Party Private C&D Debris Haulers

These companies provide hauling services to construction or demolition contractors to collect waste generated on-site by charging fees for their services. This category can transport only C&D debris intended for recycling and must deliver the materials to approved recycling and receiving facilities.

2.4.1.4. Intermodal Haulers

Intermodal haulers supply large freight containers to construction or demolition sites for collecting C&D debris, which is then transported to railheads for long-distance shipment to landfills. The City's collection contract does not include C&D debris hauled in intermodal containers. Construction contractors are free to hire any private company for intermodal hauling services. Demolition contractors often use intermodal containers with a capacity of 100 cubic yards.

2.4.2. Reuse and Recycling

Due to the diverse nature of construction and demolition debris recycling, SPU closely monitors local processing capacities for current and potentially recyclable materials. SPU monitors markets for materials already banned from disposal and explores opportunities to expand these bans to include additional recyclable materials. For instance, SPU evaluates the markets for plastic wrap, asphalt shingles, and carpets to determine the feasibility of implementing future disposal bans, as these materials have demonstrated recycling potential in the past. SPU is also working on increasing the local processing capacity for recyclable material. These efforts involve expanding the supply of structural lumber for reuse instead of disposal or increasing the availability of clean wood for higher-value applications, such as wood composite products or pulp and paper manufacturing. This approach diverts materials from lower value "beneficial use" end markets, such as industrial boiler fuel, to more sustainable and productive alternatives (Seattle's Solid Waste Plan Update, 2022).

In the Seattle area, various facilities meet city qualification standards to receive and process C&D debris for reuse or recycling, ensure compliance with local regulations, and promote sustainable material management. The SPU classified C&D recycling facilities into three categories: (1) salvage and reuse facilities, (2) source-separated recyclers, and (3) mixed C&D recycling facilities. The salvage and reuse facilities for building materials recover and sell used building materials and components such as structural lumber, metal, windows, doors, and other salvageable materials. Notable facilities specializing in secondary building materials and components include Ballard Reuse, Second Use Building Materials, and Earthwise Building Salvage.

The Source-separated C&D debris recycling facilities focus on processing materials already separated at the job site, such as clean wood waste, concrete, gypsum scrap, metal, or tear-off asphalt shingles. These facilities play a crucial role in regional C&D debris recycling, offer lower tipping fees than disposal sites, and are mainly located outside Seattle. Examples of source-separated facilities include Ace Metals, Binford Metal Recycling, Bloch Steel Industries, and Lynnwood Recycling, which specializes in metal recycling. All Wood Recycling and Cedar Grove can recycle various materials, including asphalt paving, concrete, rocks, metals, land clearing debris, yard waste, pallets, and wood. Miles Resources focuses on recycling concrete, while Resource Recovery Services, Inc. and New West Gypsum specialize in drywall recycling.

The Mixed C&D waste recycling facilities process mixed materials, such as wood waste, metal, gypsum scrap, carpet, packaging materials, and aggregates that are collected together.

These facilities report significant success in their operation. Nine such facilities are operating in the Seattle-Tacoma region, and one facility is authorized to receive and transfer mixed debris to a certified recycler. Some facilities process mixed construction and demolition materials, including DTG, the Republic Black River Transfer Station, and Maltby Container and Recycling.

2.4.3. Waste Disposal

The third waste management phase in Seattle is disposal through the transfer stations. The C&D materials generated in Seattle that are not directly transported to the railhead in intermodal containers will be processed through the City's C&D disposal system (flow control) at designated transfer stations. At these transfer stations, the city manages debris brought by residents and small businesses in self-haul loads in the same way as general garbage. This category accounted for

60,000 tons of C&D waste self-haul in the 2017-2018 self-haul waste composition study (Seattle's Solid Waste Plan Update, 2022).

While some C&D debris enters Seattle's waste stream through public transfer stations, most non-recyclable C&D materials are disposed of through private transfer stations, which generally offer lower tipping fees than the City's facilities. Private transfer stations are often equipped to manage large, self-unloading trucks. Additionally, two railheads accept large intermodal containers from demolition sites in Seattle and directly transport them to landfills. **Figure 7** indicates the existing C&D waste movement in Washington State.

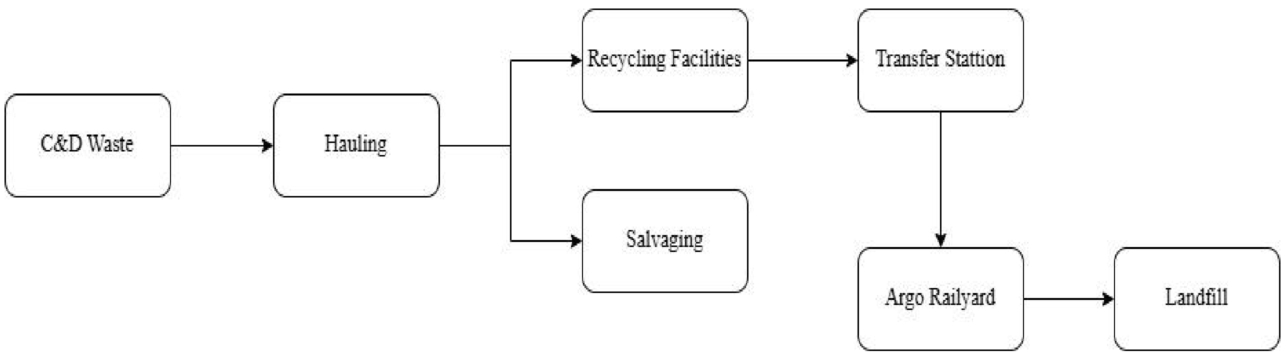

Figure 7. Construction and Demolition Waste Movement in Washington State

Chapter 3: Case Studies

3.1. Case Studies

The selected case studies, the Early Learning Center, the Triodos Bank Headquarters, and Exchange House, provide insights into how design for deconstruction can facilitate the reuse of building materials and components through circular buildings. This approach can significantly reduce the volume of C&D debris sent to landfills, mitigating the impacts on marginalized communities. Beyond environmental and economic advantages, such as reducing air, soil, and water contamination and creating secondary markets, these case studies emphasize the social benefits of design for deconstruction. The focus on social benefits aligns with the primary goal of this study, which is to explore how circular building design can contribute to sustainable and inclusive development while addressing environmental justice.

3.1.1. Early Learning Center

The proposed Early Learning Center in Port Angeles, Washington, is designed to serve 96 children under five years. The project secured funding from county, city, and federal agencies to achieve sustainability goals, such as waste reduction credits and LEED certification. The project will span 8,000 square feet, covering three existing structures. The lead consultant, GLY Construction, implemented deconstruction rather than demolition to meet the waste reduction credit requirement. Two existing structures were carefully deconstructed, salvaging materials and components such as windows, doors, cabinets, and other elements. These salvaged materials were donated to Habitat for Humanity at Clallam County for repurposing and resale as secondary building materials, successfully diverting 40 tons of demolition debris from landfill sites.

The third building was sold to a private owner and relocated six blocks away, showcasing an innovative reuse strategy that avoided demolition entirely, as shown in **Figure 8**. Moving structures also helps save valuable resources and lessens environmental impact by reducing the demand for virgin materials for new construction, eliminating demolition costs, and reducing waste in landfills. While the project successfully diverted waste from the landfill through the deconstruction approach, several challenges were reported, particularly in relocating the third building. These included stakeholder coordination and logistical challenges, such as relocating power lines, implementing road closures, and safety hazards during the relocation of the building. These challenges are consistent with barriers identified in various studies.

Although the original structures were not designed for deconstruction, the project team could salvage significant materials and divert waste from landfills. This case highlights the importance of integrating design for deconstruction principles into future projects to facilitate material recovery and reduce construction and demolition waste in landfills.

Figure 8. Relocating a Building to a new lot through Deconstruction at Port Angeles (GLY Construction).

3.1.2. Triodos Bank Headquarters

The headquarters of Triodos Bank in Driebergen, Netherlands, applied several DfD principles, including designing accessible connections, using mechanization, separating service from structure, and providing a permanent identification system during the design and construction phase (Malba Projects, 2024). The structure is 100% circular, which can be thoroughly deconstructed and reconstructed to serve different purposes or for material recovery and reuse in the future, as shown in **Figure 9**. The building is made of wood and is designed and constructed as a temporary combination of materials and components with a documented identity using material passport technology. Advanced digital technology and data management were used in the design and construction process to provide a digital record of materials and components to facilitate future disassembly and reuse.

The material passports can provide detailed information about the type, quantity, and quality of materials used and their potential for reuse or recycling in the secondary loop. This documentation ensures transparency and facilitates efficient material recovery at the building's end of life. Additionally, the structure is held together using 165,312 screws, bolts, and nuts instead of conventional adhesives or welding, which facilitate deconstruction and reconstruction (Malba Projects, 2024). By designing for deconstruction, the designers consider future reuse in the design process. This approach reduces the extraction of natural materials to produce new material, eliminates the environmental footprint in the manufacturing process, eliminates demolition costs, and ultimately reduces the waste stream in landfill sites.

The Triodos Bank headquarters project demonstrates how circular building design can extend a building's life cycle while reducing its environmental footprint. This project minimizes construction and demolition and benchmarks how design, construction, and data integration can work together to achieve a more sustainable construction practice.

Figure 9. Triodos Bank Headquarters (Malba Projects, 2024)

3.1.3. Exchange House

The Exchange House is a 10-story building on a 32-acre site adjacent to Liverpool Street Station in London, United Kingdom. The building is jointly owned by British Land and GIC, Broadgate United Kingdom, and was remodeled into a mixed-use development. The project prioritized sustainability to support British Land's commitment to achieving a net-zero carbon portfolio by 2030 while creating significant social impact. British Land collaborated with the world's largest environmental, social, and governance reuse marketplace, Globechain, to achieve the project's environmental, economic, and social objectives during the bidding process. Globechain facilitates connections between the various sectors involved in the project, including construction, retail, hospitality, government agencies, nonprofit organizations, small businesses, and individuals, to redistribute salvaged materials and items.

Before the deconstruction took place, the demolition contractor, KpH Deconstruction, worked with the project team to identify strategies on how material reuse could maximize environmental benefits, deliver economic returns, and, more importantly, add social value through materials reuse. This was done in collaboration with Globechain to understand the reuse process, and KpH developed a strategy to address logistical challenges, such as limited loading areas and building insurance requirements. During the pre-demolition audit, KpH identified reusable items, including carpets, floor tiles, ceiling lights, blinds, doors, and telecommunications equipment. These items were salvaged from the building and listed on the Globechain website for redistribution. About 5,889 items, including doors, windows, carpets, and other electrical components, were salvaged and donated to 3,154 people to improve their facilities (WBCSD, 2021). The project balanced the environment with economic benefits and was successful in terms of social considerations.

Figure 10. The Exchange House London during Renovation (WBCSD, 2021)

3.2.Lessons Learned

The presented case studies demonstrate that deconstruction is a powerful strategy to minimize construction and demolition waste, promote circular building design, and drive innovation in secondary markets. The principle can facilitate the material recovery and reuse of building materials and support sustainable resource use in the built environment. It can also address the environmental, economic, and social challenges posed by construction and demolition waste, particularly in marginalized communities, where improper waste management often leads to significant adverse impacts.

3.2.1. Environmental Benefits

Regarding environmental benefits, the studies indicate that deconstruction can significantly reduce the ecological footprint of construction and demolition waste, which often disproportionately affects marginalized communities. For instance, the Early Learning Center project in Port Angeles diverted about 40 tons of waste from landfills by salvaging and repurposing materials and components. Over 137 tons of materials, 14% of all stripped-out materials by weight, were repurposed and diverted from landfills with significant environmental and social benefits at no additional cost (WBCSD, 2021). This effort reduces the pollution of the local community at the landfill site. Similarly, the Triodos Bank headquarters project in the Netherlands, designed and constructed with dismantlable materials, will minimize the extraction of limited natural resources to produce new materials and ultimately reduce landfills' environmental hazards in the long run. These efforts will lower the impact of air, soil, and water contamination in landfills by reusing the materials and components used for construction.

3.2.2. Economic Benefits

Aside from the environmental benefits shown by the case studies, implementing deconstruction also has economic advantages. The principle can also foster the development of a secondary market for salvage building materials. This could serve as a source of livelihood for local communities, thereby contributing to the region's economic growth. For instance, the materials salvaged from the Early Learning Center were donated to Habitat Clallam County to create affordable building supplies for the local community. At the Exchange House, the redistribution of over 5,800 items through Globechain’s network supported charities and community groups and benefited about 3,154 individuals in the communities. These practices demonstrate how deconstruction can contribute to local economic development, reduce construction costs, and ultimately reduce the impact of construction and demolition waste in marginalized communities.

3.2.3. Social Benefits

One key takeaway from the case studies is the benefit of social considerations of deconstruction activities. Beyond the environmental and economic impacts often prioritized in sustainability, the case studies indicate that deconstruction also provides significant social benefits to communities near landfill sites, which can create social equity in addressing environmental justice through inclusive community development. The case studies demonstrate that diverting waste from landfills makes social equity and ecological justice possible. For instance, the Early Learning Center diverted about 40 tons of garbage by salvaging two buildings, and then a third building was deconstructed and relocated to a new location.

Similarly, the Exchange House and Triodos Bank headquarters projects also facilitate social equity in managing construction and demolition waste by reducing the waste sent to landfills through deconstruction. More importantly, donating salvage materials and components to a nonprofit and local community fosters community inclusiveness through deconstruction. For instance, the materials and components salvaged from the Exchange House project were donated to the East London organization to support the survivors of abuse in renovating a community office and the South-East London charity organization to upgrade a school and library serving over 2,000 students. Such an approach can be used to support affordable housing projects within landfill communities and provide shelter for homeless people instead of incinerating waste. It could also foster social equality by addressing environmental justice for construction and waste demolition in underrepresented communities.

In summary, the case studies demonstrate how design for deconstruction can transform waste management practices and benefit marginalized communities environmentally, economically, and socially. These projects highlight the advantages of designing with future deconstruction to facilitate material circularity and promote social equity in the built environment. The lessons learned from these case studies underscore the need to rethink current design approaches to incorporate future deconstruction to minimize the impacts of construction and demolition waste on underserved communities. The current C&D waste management practices in Washington State place little emphasis on deconstruction, which is understandable given that much of the existing building stock was not designed for future disassembly.

While the Seattle Department of Construction and Inspections encourages deconstruction, there is currently no policy to incentivize it, making demolition a more cost-effective option. To address this, SPU is collaborating with King County to assess the feasibility of implementing a residential deconstruction ordinance and a contractor certification program. SPU and King County have established the Deconstruction Advisory Group to draft an ordinance to increase deconstruction practices. This effort draws inspiration from the City of Portland, Oregon, which encourages deconstruction instead of demolition of single-family homes or duplexes built in 1916 or earlier.

Chapter 4: Data Analysis and Discussion of Results

4.1. Descriptive Statistics

This section offers a descriptive analysis of survey responses from thirty construction industry practitioners in the Pacific Northwest. The survey aimed to capture their experiences and perspectives on integrating Design for Deconstruction (DfD) principles into construction projects. Specifically, the study investigates the current extent of DfD strategy implementation, the challenges encountered in adopting these principles, and the drivers that could facilitate broader industry adoption. The respondents, representing various roles across design, engineering, and construction disciplines, shared insights from their firsthand experiences with DfD applications, including strategies like modular construction, material reuse, and reversible design solutions. Additionally, the analysis delves into the critical barriers to DfD adoption, such as regulatory constraints, economic feasibility, and industry resistance to change. This analysis lays the groundwork for understanding the current landscape of DfD implementation in the Pacific Northwest. It provides a foundation for further discussions on overcoming barriers and leveraging emerging opportunities to promote design for deconstruction in the built environment.

4.1.1. Type of Organization

The analysis of industry affiliation reveals that a significant majority (83%) of respondents are employed in design firms, while 17% work in contracting organizations, as depicted in **Figure 11**. This distribution indicates a higher representation of professionals from design-oriented disciplines in the study, likely due to their direct involvement in the early stages of construction projects, where sustainability and material circularity are often integrated. Conversely, the relatively lower participation from contracting organizations may reflect the traditionally execution-focused role of contractors, where design decisions have already been established.

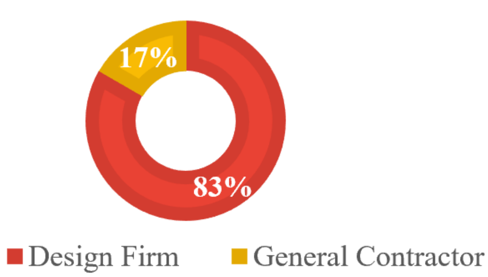

Figure 11. Type of Organization of the Respondents

4.1.2. Professional Experience

The respondents' professional experience distribution shows diverse expertise, as illustrated in **Figure 12**. Notably, over a quarter (27%) of participants possess more than 20 years of industry experience, signifying a substantial presence of experienced professionals with deep insights into industry trends and challenges. The most significant proportion of respondents (40%) falls within the 10 to 20 years of experience range, suggesting that mid-career professionals comprise a significant portion of the surveyed population. Additionally, 23% of respondents have 5 to 10 years of experience, while 10% have less than 5 years in the industry. This varied distribution ensures a balanced perspective, incorporating insights from experienced professionals and emerging industry practitioners.

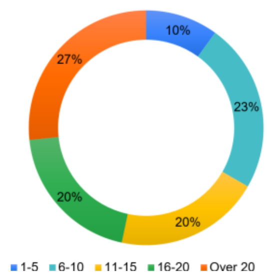

Figure 12. Professional Experience of the Respondents

4.1.3. Professional Role in Projects

An analysis of the job roles of the respondents reveals a strong presence of design and sustainability professionals, as represented in **Figure 13**. More than half of the respondents (53.3%) are architects, underscoring the central role of architectural design in shaping sustainable and circular construction practices. Sustainability specialists account for 20% of the participants, highlighting the growing importance of sustainability expertise in modern construction projects. Additionally, interior designers represent 16.7% of the respondents, emphasizing their contribution to material selection and spatial planning in sustainable buildings. Project managers constitute 6.7%, reflecting their involvement in coordinating sustainability strategies across project lifecycles. Meanwhile, engineers, who represent 3.3%, contribute to the technical aspects of design implementation and construction processes. This distribution underscores the multidisciplinary nature of sustainability in the built environment, necessitating collaboration between architects, engineers, project managers, and sustainability experts.

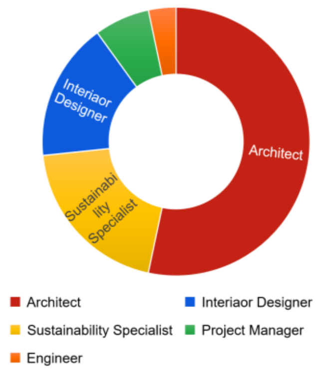

Figure 13. Respondents' Professional Role in Projects

4.1.4. Types of Projects

The survey also examined the various projects the organizations involved undertake, revealing a wide-ranging portfolio, as depicted in **Figure 14**. Commercial construction is the most common project type, making up 19% of all projects. This pattern is consistent with industry trends, where commercial projects often emphasize sustainability certifications and cutting-edge building technologies. Educational facilities are close second at 18%, followed by healthcare facilities and mixed-use developments, each constituting 15%, highlighting the need for integrated, multifunctional buildings and sustainable healthcare infrastructure. Laboratory and ICT facilities account for 13%, and Civic buildings, such as government facilities, make up 11%, reflecting public sector engagement in sustainable construction efforts. The remaining 9% are categorized as “other," covering a variety of specialized projects.

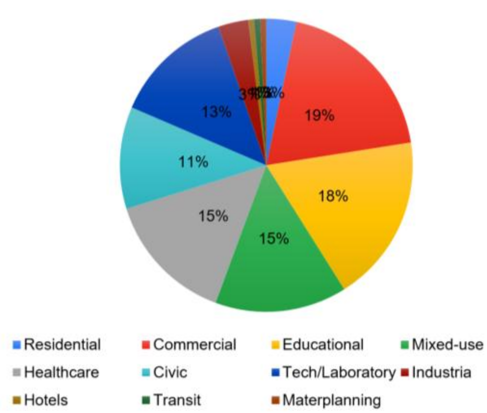

Figure 14. Types of Projects by the Respondent’s Firms

The descriptive analysis shows a well-rounded representation of industry professionals with diverse experience levels and expertise. The prominence of architects and sustainability specialists points to a strong emphasis on design-driven sustainability strategies. Furthermore, the broad range of project types indicates that sustainability principles are being applied across various sectors, from commercial and educational buildings to healthcare and civic structures. These insights offer a valuable basis for further analysis, particularly in exploring how different professional backgrounds and project types impact sustainability and circular construction in the built environment.

4.2. Application of Design for Deconstruction

The survey evaluates the implementation of ten DfD principles (P1–P10) in a construction project, as illustrated in **Figure 15**. The findings indicate varying degrees of adoption among design and construction organizations in the Pacific Northwest. Interchangeability and Repairability (P8) emerged as practitioners' most frequently used principle, with an 80% adoption rate. This preference highlights the importance of materials and components that are easy to replace, remove, repair, and reuse, aligning with practical design considerations.

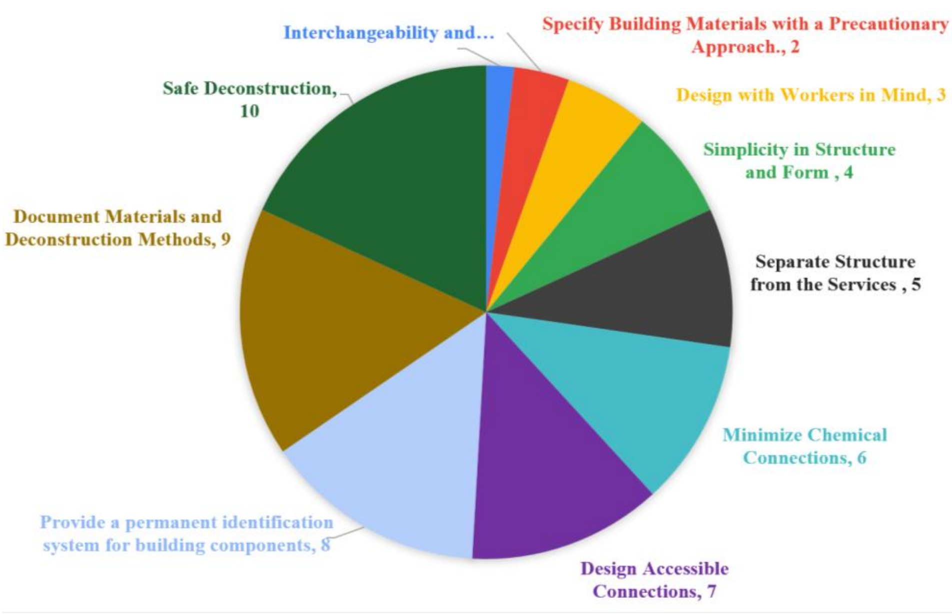

Figure 15. Application of DfD in Construction Projects

Specify Building Materials with a Precautionary Approach (P1) and Design with Workers in Mind (P5) closely follow, with 73% and 70% application rates among the sampled population. This reflects a focus on selecting safe, reusable materials and components that are easy to handle. Simplicity in Structure and Form (P7) and Separate Structure from the Services (P4) were moderately adopted, with 67% and 63% adoption rates, respectively. This suggests that simple designs and independent mechanical, electrical, and plumbing (MEP) systems are feasible and moderately implemented.

Minimize Chemical Connections (P2) (53%) and Provide a Permanent Identification System for Building Components (P10) (33%) showed lower adoption, likely due to reliance on adhesives in some designs and the complexity of labeling systems (Crowther, 2018). The results also indicated that Design Accessible Connections (P3) and Document Materials and Deconstruction Methods (P9) were less common, with 27% and 23% adoption rates, respectively, highlighting the challenges in designing disassembly and preparing as-built drawings. Safe Deconstruction (P6) was the least applied, reflecting limited consideration for future workers' safety during disassembly, possibly due to its long-term focus. The varying adoption rates highlight several challenges.

The high adoption of P8, P1, and P5 suggests that these principles align with existing practices, such as modular design and safety standards, which are widely implemented. Conversely, the lower adoption of P3, P9, and P6 indicates technical and organizational barriers. For example, designing accessible connections (P3) requires expertise in disassembly-friendly systems, which may be lacking in current practice (Citraningrum et al., 2023). Documentation (P9) and identification systems (P10) demand additional time and resources and may necessitate digital technology like a material passport. The limited application of safe deconstruction (P6) prioritizes immediate project needs over long-term considerations, compounded by the perception that deconstruction occurs beyond current stakeholders' timelines. These findings align with previous studies and underscore the Pacific Northwest-specific peculiarity. The high adoption of the interchangeability and repairability (P8) principle by practitioners in the PNW is consistent with Akinade et al. (2020), who identify standardization as a critical success factor for DfD to facilitate material reuse.

The focus on precautionary material selection (P1) and worker safety (P5) aligns with Charef (2024), who notes that material circularity often leverages the broader implementation of existing sustainability standards. However, the low adoption of accessible connections (P3) and documentation (P9) mirrors challenges identified by Cruz Rios & Grau, (2020), who highlight technical complexity and a lack of standardized protocols as barriers to DfD. The limited application of safe deconstruction (P6) is consistent with Hart et al. (2019), who note that long-term considerations are often deprioritized due to immediate cost concerns. Pittri et al., (2024) also examined a similar study in developing countries and uncovered similar challenges with documentation and identification systems, citing resource constraints as a contributing factor for the low adoption.

4.3. Critical Barriers to Adopting Design for Deconstruction

The survey results revealed that the high costs associated with building disassembly are the most significant barrier to implementing DfD in design and construction firms, as shown in **Figure 16**. This reflects the labor-intensive and time-consuming nature of deconstruction compared to traditional demolition. The absence of supportive policies emerged as the second most critical barrier, indicating that regulatory mandates or incentives are essential for firms to adopt DfD in construction projects.

A lack of client interest in using recoverable materials is the third most significant barrier hindering adoption, as illustrated in Figure 18. Storage considerations for recovered materials and limited awareness of DfD practices ranked fourth. This is particularly significant in urban settings where site constraints limit material management, suggesting that logistical challenges and a lack of stakeholder education impede progress. Other notable barriers include the lack of building codes for secondary materials, limited training on deconstruction procedures, and reliance on traditional construction methods, ranked fifth in criticality. Less critical barriers, such as safety concerns and the need for specialized tools, suggest that existing practices may partially address these issues, though improvements are needed.

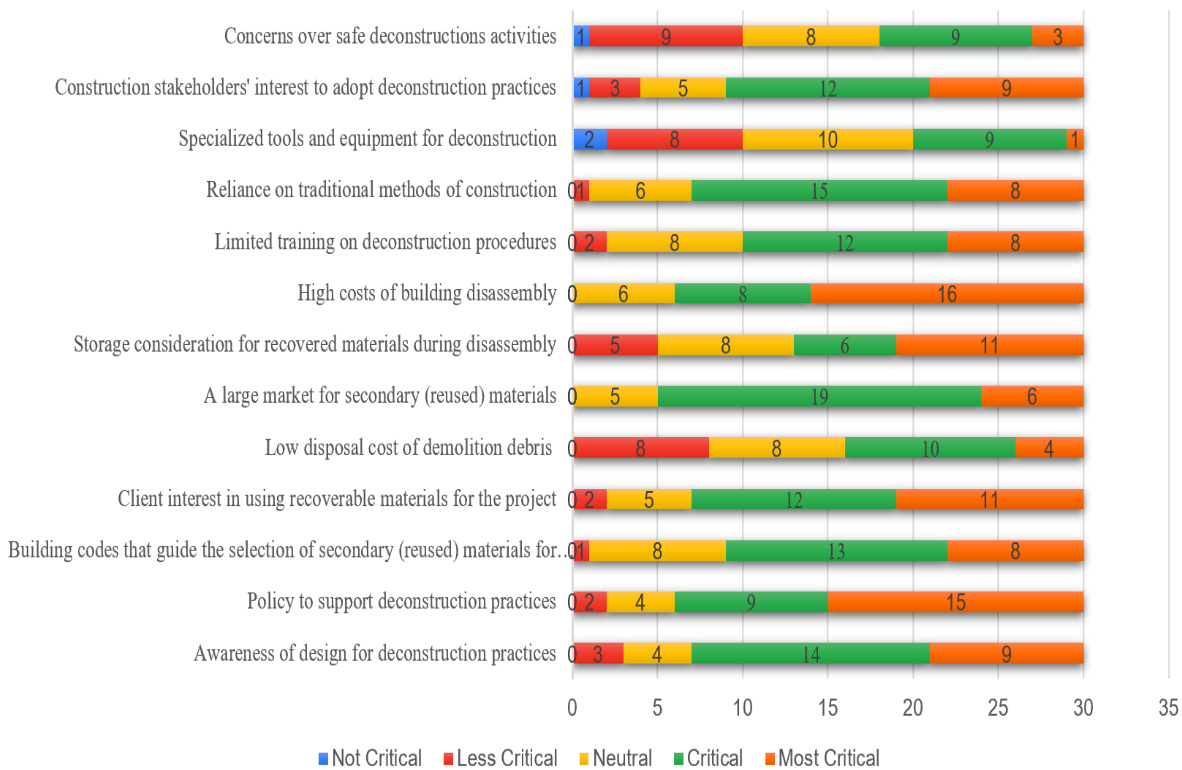

Figure 16. Critical Barriers to DfD in Construction

The identified barriers align with global and regional studies, reinforcing their relevance while highlighting context-specific nuances. High deconstruction costs, the top barrier, are consistently cited in the literature. Dimitra Tzourmakliotou (2021) classifies economic barriers as significant across circular economy practices, noting that labor and hazardous material processing costs drive the cost of building disassembly. Pittri et al. (2023) in Ghana and Hart et al. (2019) Globally, it is affirmed that the perceived expense of deconstruction hinders adoption, particularly without accounting methods for long-term benefits. The lack of policy support aligns with the findings of Salazar Izquierdo et al. (2023), who advocate for policy support to promote material circularity in the United States, and Roxas et al. (2023), who highlight regulatory gaps in developing countries.

The absence of DfD-specific regulations in the Pacific Northwest is particularly notable, given the region's progressive environmental policies, indicating a disconnect between broad sustainability goals and actionable mandates. Client disinterest and stakeholder reluctance are consistent with Cruz-Rios & Grau, (2020), who identified low client support and poor stakeholder experience as barriers in the United States. Storage and market limitations for secondary materials align with Ostapska et al. (2024), although the Pacific Northwest's urban density exacerbates storage challenges. Awareness and training deficiencies echo Akinade et al. (2020), who identify knowledge gaps as organizational barriers. While less critical, building codes and safety concerns align with Tingley & Davison (2011), though the Pacific Northwest's stringent regulations reduce the prominence of safety issues compared to developing countries.

The results reflect global and regional barriers identified in previous studies, underscoring the need for innovation. The Pacific Northwest's focus on sustainability amplifies the importance of policy and client interest as barriers, as stakeholders expect stronger regulatory and market support. Urban constraints heighten storage challenges, distinguishing the region from less dense areas. Competitive pressures and high labor costs intensify economic barriers, contrasting with developing countries where resource scarcity is more dominant (Pittri et al., 2024). The region's access to educational institutions and sustainability networks offers opportunities for targeted training, a potential enabler that is less available globally.

4.3.1. Drivers for Implementing Design for Deconstruction in Construction Projects

The analysis of the drivers for DfD adoption is divided into five thematic areas: policy and standards, education and awareness, market and infrastructure, financial incentives, and technological innovation, using inductive coding. Inductive coding is a qualitative data analysis technique where codes and themes are derived directly from the data, rather than being predetermined (Campbell, 2020). It is commonly employed in exploratory research when the researcher does not start with a hypothesis or a rigid theoretical framework, naturally allowing patterns, categories, and meanings to emerge from the data (Bihu, 2023).

Policy and Standards were frequently mentioned, with respondents advocating for code requirements, policy-based changes, and sustainability initiatives mandating DfD. These suggest that regulatory frameworks could facilitate DfD practices. Education and Awareness opportunities included increasing client awareness, highlighting social and environmental benefits, and providing easy-to-follow guides or playbooks. Respondents emphasized that informed clients and stakeholders are pivotal for adoption, particularly for general contractors reliant on client priorities.

Market and Infrastructure drivers focused on developing a market and repository for recovered material to ensure the availability of reused products and working with recovered materials to promote design for deconstruction value. These address logistical barriers like storage and material demand. Financial incentives were noted as critical, with respondents suggesting integrating DfD into project fees to offer financial compensation for owners and contractors and make deconstruction cost-effective compared to demolition.

Technological Innovation opportunities included using digital technologies for material assessment, developing databases for material tracking, and creating tools to demonstrate DfD in construction projects. Respondents also called for sample specifications and peer reviews by deconstruction specialists to streamline implementation. Notable drivers included the need for client interest mentioned by multiple respondents and the establishment of industry standards to provide proven methods. Using new technologies to test hazardous materials and permit incentives was highlighted as an innovative approach to enhance safety and feasibility.

The identified drivers align with global and regional studies, reinforcing their relevance. Policy and standards are consistent with Cruz Rios et al. (2021), who advocate for stricter U.S. legislation to drive DfD and highlight standardization as a key enabler. Education and awareness, stakeholders' training, secondary market development, and financial incentives echo Bhattacharjee et al. (2024), who identified improved education, stakeholder training, the need for a robust market for reused materials, and financial incentives for deconstruction activities as critical enablers for promoting design for deconstruction practices. Technological innovations resonate with Charef (2024), who notes digital tools as facilitators of circular practices and advocates for advanced deconstruction technologies. The focus on client interests as a driver also mirrors Cruz-Rios & Grau (2020), reflecting regional reliance on client-driven sustainability.

4.4. Cost and Policy Findings

The survey identified cost and policy as the primary obstacles to adopting DfD practices. A subsequent interview was conducted with demolition specialists, vendors of reused materials, and the government agency responsible for waste management in the Seattle area. The analysis highlighted significant cost differences between demolition and deconstruction. Demolition expenses ranged from $7 to $16 per square foot, whereas deconstruction costs were higher, between $10 and $30 per square foot. Respondents consistently pointed to labor intensity (100%

of responses) and the time required (88%) as the main cost drivers, followed by material handling and sorting, as noted by a few. These factors underscore the manual nature of deconstruction compared to mechanized demolition.

Regarding cost offsets, over three-quarters of respondents believed that reselling or reusing salvaged materials could mitigate higher upfront costs, especially for high-value items like hardwood, old-growth timber, or architectural elements. However, about 30% of respondents noted that this depends on local reuse markets or tax incentives. All respondents supported policies to promote DfD, including mandatory deconstruction for specific building types or sizes, and most emphasized priority permitting for DfD projects, along with tax incentives or rebates for salvaged material reuse.

Nearly all respondents (88%) had worked on projects where local authorities mandated or incentivized deconstruction; these included a warehouse deconstruction in Seattle, residential projects in Port Angeles, and ordinance-supported projects in Beaverton and San Jose. Support benefits in these projects included training resources, permit fee waivers, and material resale opportunities, "*though some projects lacked direct support,*" as one respondent noted.

The results also revealed challenges such as inconsistent regulations, a lack of trained crews, safety concerns, coordination issues, and building access, with suggestions for standardized material certification and government support to normalize deconstruction.

4.4.1. Relevance of Study Findings to Advance Social Justice through Design for Deconstruction

The findings highlight the potential of *DfD* to tackle social justice issues in marginalized communities. The widespread adoption of principles such as interchangeability and repairability, and using building materials guided by a precautionary approach, supports safer material reuse, thereby reducing landfill waste and the associated health risks for nearby communities. However, the limited adoption of Safe Deconstruction highlights a lack of focus on future worker safety, posing a significant concern for deconstruction crews. The high cost of disassembly and insufficient policy support impede DfD adoption, as reliance on demolition practices disproportionately affects vulnerable populations. Limited training hampers skill development for workers, particularly those from underrepresented groups, restricting economic and social benefits.

Key drivers like policy mandates, training programs, and material markets could enhance access to sustainable materials and create jobs in deconstruction. Emphasizing social benefits and raising client awareness can engage communities in sustainable practices. Although the higher costs of deconstruction present a barrier, the potential for material resale and policies like tax incentives could offset these costs, making DfD accessible to diverse stakeholders. These findings suggest that DfD can mitigate construction and demolition waste's environmental and social impacts by reducing landfill use, enhancing worker safety, and creating economic opportunities through material reuse markets. The findings propose five solutions: Policy Development, Training Programs, Market Infrastructure, Community Engagement, and Cost Mitigation to advance social justice by reducing landfill waste, improving labor conditions, and ensuring equitable access to sustainable resources.

4.4.2. Policy Development

As revealed by the study, implementing regional DfD mandates and tax incentives can significantly reduce landfill waste, directly benefiting communities near disposal sites, which often include low-income and minority populations. Mandates could require deconstruction for specific building types, such as commercial or residential buildings over a specific size or age, to ensure materials are recovered rather than discarded. For instance, Portland's deconstruction ordinance, cited by respondents, illustrates how local policies can normalize DfD by mandating the manual removal of materials and reducing exposure to hazardous waste. Tax incentives could also help offset deconstruction costs, encouraging firms to prioritize reuse over disposal. Standardized material reuse guidelines, another policy priority, would ensure salvaged materials meet safety and performance standards, making them affordable and accessible to low-income communities for housing or community projects. Implementation requires collaboration among policymakers, industry associations, and environmental justice advocates to prioritize communities disproportionately affected by landfills. Pilot mandates in urban centers like Seattle could test feasibility, leveraging the region's sustainability focus.

4.4.3. Training Programs

Developing inclusive training initiatives targeting underrepresented workers is crucial for creating equitable job opportunities and improving labor conditions. Deconstruction's labor-intensive nature demands skilled workers, yet the findings revealed a lack of trained crews, particularly for safely handling hazardous materials. Training programs, supported by institutions like community colleges or vocational schools, could offer curricula on deconstruction techniques, safety protocols, and material sorting, prioritizing recruitment from marginalized groups, such as low-income or minority communities. These programs would address social justice by providing pathways to stable, well-paying jobs in a growing sector. The training could be funded through public-private partnerships or government grants. For example, one respondent referenced San Jose's training resources, which reduced barriers to deconstruction adoption. Partnerships with community organizations could enhance outreach, integrating certifications into existing construction training frameworks to scale the impact.

4.4.4. Market Infrastructure

Establishing material repositories and markets would make reused materials accessible and divert waste from landfills. The limited markets for salvaged materials of high-value items, such as hardwood and timber, could offset deconstruction costs. Developing a salvaged material market like Seattle's Second Use and Ballad Reuse to store and distribute materials would ensure affordability for community housing projects or small-scale developments. These markets would create demand for salvaged materials, support local economies, and reduce landfill waste, disproportionately affecting marginalized communities. Public funding or partnerships with nonprofits could establish regional hubs, and digital platforms could connect suppliers and buyers to enhance accessibility. Social justice benefits include empowering communities to build sustainable materials and reduce reliance on costly new resources.

4.4.5. Community Engagement

The study reveals that promoting DfD's social benefits through public campaigns and client education can enhance community-driven sustainability. Raising awareness about environmental and social impacts, such as reduced pollution and job creation, can stimulate demand. Public campaigns, spearheaded by local governments or advocacy groups, can emphasize how DfD alleviates health disparities in communities near landfills. Client education, aimed at developers and institutional owners, can highlight lifecycle cost savings and carbon reduction, aligning with organizational sustainability goals. Direct community engagement through workshops or participatory design processes ensures that DfD projects address local needs, such as affordable housing or community centers. This approach empowers marginalized groups and counters historical exclusion from sustainable development.

4.4.6. Cost Mitigation

While the process might be considered expensive, its advantages outweigh the costs if the value of the building materials is preserved at the end of life (Zaman et al., 2023). Subsidizing deconstruction costs and supporting resale markets with tax incentives make DfD viable for diverse projects, including those in underserved areas. Subsidies, such as grants or low-interest loans, can offset labor and time costs, allowing stakeholders to adopt DfD without financial strain. Resale markets, particularly for high-value materials, can generate revenue, with proceeds reinvested into community projects. This solution promotes social justice by enabling small-scale or nonprofit developers to undertake sustainable projects, reducing economic exclusion. Regional policies, like permit fee waivers identified in the study, can incentivize adoption, while partnerships with salvage organizations can stabilize markets. Pilot subsidies in low-income neighborhoods can test scalability to ensure equitable benefits.

4.5. Broader Implications

These solutions collectively address social justice by reducing environmental burdens, creating equitable job opportunities, and facilitating access to sustainable materials. Policy mandates and market infrastructure mitigate landfill impacts and protect marginalized communities. Training programs empower underrepresented workers, while community engagement ensures inclusive decision-making. Cost mitigation enables diverse stakeholders to adopt DfD, fostering economic equity. Implementation requires coordinated action from policymakers, industry, and communities. Regional task forces could oversee policy and training development, while public-private partnerships could fund markets and subsidies. Accordingly, this study proposed an implementation strategy for deconstruction as shown in **Figure 17.**

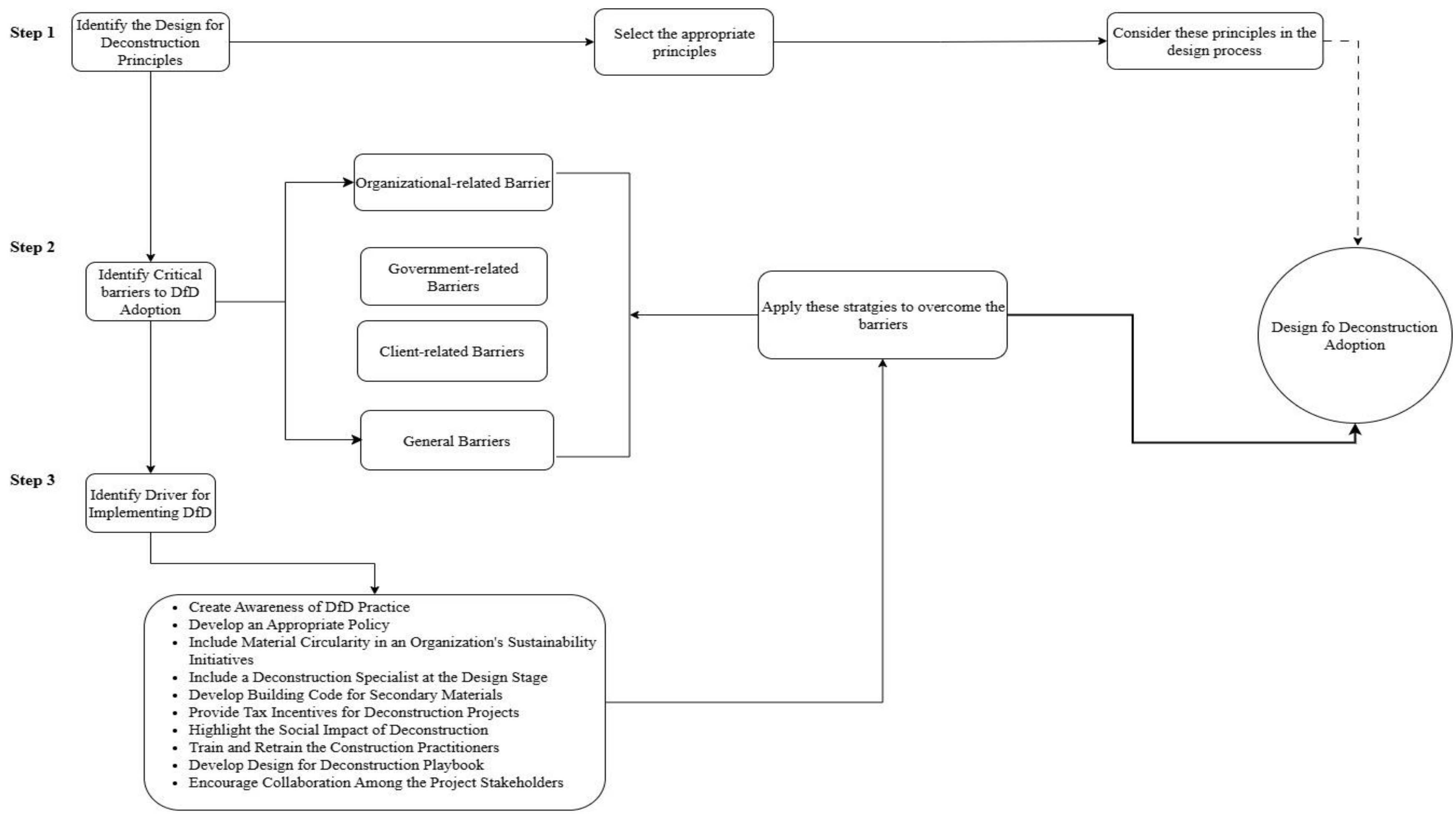

Figure 17. An Implementation Strategy to Promote Design for Deconstruction

The Implementation Strategy shown in Figure 19 presents a clear, step-by-step framework to facilitate the adoption of Design for Deconstruction in construction projects. This framework is organized into three major phases, guiding stakeholders from the foundational concepts of DfD to its practical application. It addresses the systemic barriers identified in the study, which are categorized into organizational, government-related, client-related, and general barriers.

The first phase of the strategy focuses on identifying and applying the core principles of DfD during the design process. This is crucial, as many long-term costs and challenges associated with disassembly can be mitigated through early integration. The strategy advocates the use of materials that are durable, non-toxic, and recyclable. Designers are encouraged to minimize the use of adhesives and instead opt for mechanical connections like bolts and screws, which can be reversed or removed. Separating services such as the HVAC system from structural elements will facilitate easier access during future disassembly.

The approach also supports simplifying building forms, incorporating modular construction, and ensuring documentation is available through tools like material passports and component ID tags. The health and safety of future deconstruction crews should also be considered at this stage to ensure ease of disassembly at the end of the building's life. This phase emphasizes designing with the building’s eventual end-of-life in mind, making reuse, recovery, and recycling feasible and efficient.

The second phase focuses on identifying the key barriers that impede the implementation of DfD, which are categorized into organizational, governmental, and client-related obstacles. Organizational barriers encompass a lack of awareness about DfD, inadequate training among workers, insufficient access to appropriate tools, and concerns regarding the safety and logistics of deconstruction. These issues reflect internal challenges within design and construction firms. Governmental barriers revolve around the absence of supportive policies or regulations, a lack of building codes that permit or encourage the use of salvaged materials, and the underdevelopment of a secondary materials market. Client-related barriers include a low interest in using recovered components and skepticism about the quality or performance of reused materials. This phase is crucial as it prompts project teams to assess which barriers are most pertinent to their work, enabling targeted solutions in the subsequent phase.

The third and final phase outlines strategies to overcome these barriers and implement DfD effectively. These strategies are directly linked to the identified categories of barriers. To address organizational resistance, the strategy recommends increasing awareness through education and outreach, integrating DfD into sustainability goals, and involving deconstruction experts early in the project lifecycle. Governmental barriers can be tackled through policy interventions such as tax incentives, subsidies, or mandates requiring DfD for specific projects. There is also a call for the development of clear building codes and standards that facilitate and legitimize the use of reclaimed materials. For client-related barriers, the strategy highlights the importance of framing DfD in terms of its environmental and social value, particularly its potential to reduce carbon emissions and create jobs through labor-intensive deconstruction processes.

Other key recommendations include developing a practical “DfD playbook to guide consistent implementation and fostering collaboration among all project stakeholders, from designers and contractors to regulators and building owners. Although the proposed Implementation Strategy offers a comprehensive and actionable framework, it does not address existing buildings. Nevertheless, the current building stock significantly contributes to landfill waste. Consequently, a deconstruction strategy is proposed for the current building stock to mitigate the impact of construction and demolition waste on landfill communities, as illustrated in **Figure 18**.

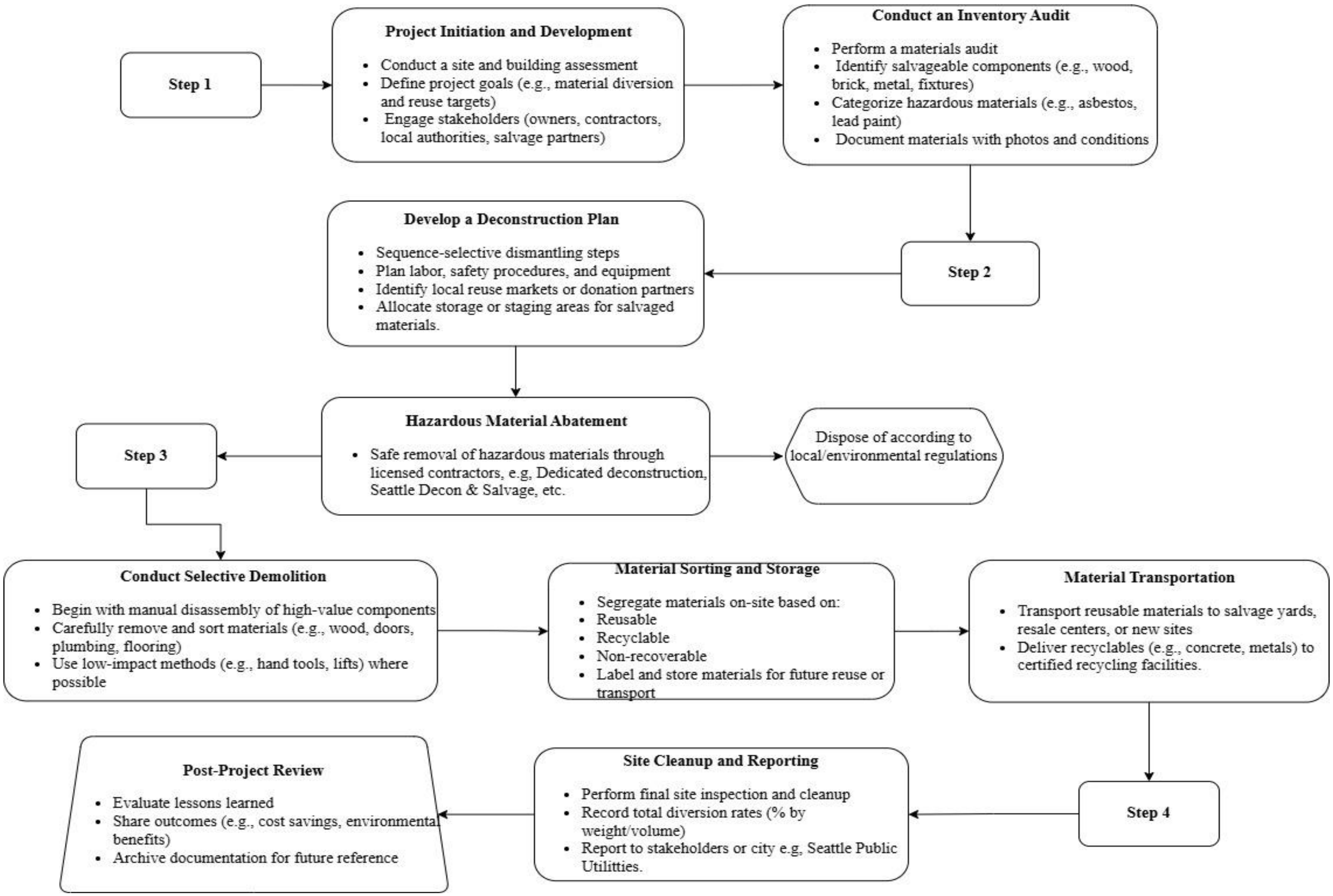

Figure 18. A Deconstruction Framework for Existing Buildings

Figure 18 presents a strategy for implementing the deconstruction of an existing structure to minimize construction and demolition waste while maximizing material reuse. The process begins with Project Initiation and Development, which involves a comprehensive building and site assessment. This includes evaluating the structure's physical condition, material composition, and the feasibility of deconstruction. At this stage, project goals are typically established, focusing on achieving high waste diversion rates, identifying valuable components for salvage, and setting sustainability benchmarks.

This phase also involves engaging stakeholders, such as the building owner, contractors, local authorities, and salvage companies. A crucial aspect of this phase is the Inventory Audit, where a detailed catalog of building materials is compiled. Materials with potential for reuse or resale, such as timber, brick, fixtures, and structural elements, are documented, along with hazardous materials like asbestos or lead, which require specialized removal. This step prepares the team for a targeted deconstruction process.

Following the audit, a detailed Deconstruction Plan is developed. This involves determining the most efficient and safe disassembly sequence, outlining labor and equipment needs, and identifying reuse markets or donation partners for salvaged items. Storage logistics are also addressed, with temporary staging areas for sorted materials established on or near the site to facilitate organization and protect valuable components. If hazardous materials are present, they are removed by licensed professionals in compliance with environmental and safety regulations to minimize risks to workers and the surrounding environment. Once planning is complete, the project transitions into Selective Deconstruction.

The Selective Deconstruction phase emphasizes manual disassembly methods over mechanical demolition to preserve the integrity of reusable materials. Skilled workers carefully remove valuable components like doors, windows, plumbing fixtures, and structural timber. Each item is handled with care to maintain its usability and value. After removal, materials are sorted and stored in reusable, recyclable, or non-recoverable categories. This streamlines the transportation process and ensures that materials are kept clean and uncontaminated, proper labeling and separation support future tracking and reuse efforts.

The next step is Material Transportation, where sorted items are delivered to designated locations. Reusable materials may be taken to salvage yards, resale centers, or reused on-site in other construction projects. Recyclable items like metals and concrete are sent to certified recycling facilities. This step is vital in achieving waste diversion goals and reducing the project's environmental footprint. The last step is cleaning up the site and reporting. After removing the building, the site is cleared of any leftover materials, and a final check is done.

The team then calculates and reports how many building materials were reused or recycled instead of thrown away. This report might be needed by local authorities or used to show that sustainability goals are met. The process ends with a review of the project, where lessons learned are noted, results are shared with others involved, and any good practices are identified for future projects. Keeping this information helps improve and share knowledge within the organization or industry. By planning early, working with others, safely recovering materials, and reporting thoroughly, the strategy turns the end of a building's life into a chance for material recovery, caring for the environment, and making a social impact. It can be used as a model for including deconstruction in broader goals for a circular economy in building.

4.6. Conclusion

The construction industry is a major contributor to global material consumption and waste generation, with construction and demolition waste accounting for a significant portion of landfill inputs. Marginalized communities are disproportionately affected by this waste, often residing near landfills and waste-processing facilities, which exposes them to environmental hazards and perpetuates systemic inequalities. Despite growing interest in sustainable building practices, most current approaches fail to address these social justice dimensions. This study sought to examine how Design for Deconstruction can serve as a viable strategy to reduce the volume of C&D waste while advancing equity for communities historically burdened by the negative externalities of the built environment.

To address this problem, the research employed a mixed-methods approach, combining survey data, case study analysis, and a review of current deconstruction practices. The goal was to assess the viability of DfD as a circular construction strategy that minimizes waste and enables more equitable material recovery and distribution of environmental benefits. The findings demonstrate that DfD holds substantial promise in promoting material circularity by extending the useful life of building components, minimizing landfill dependency, and supporting resource recovery systems that could benefit underserved communities.

However, the study also reveals that the implementation of DfD remains limited by several persistent barriers. Among the most critical are the high costs associated with building disassembly, which include labor, logistics, and the lack of economies of scale. In addition, the absence of supportive policies or regulatory incentives has hindered widespread adoption, as many municipalities have not yet integrated deconstruction mandates or benefits into their planning and permitting processes. The limited awareness and understanding of DfD among clients, contractors, and regulators, and the weak market infrastructure for salvaged materials, compound these challenges.

Despite these limitations, the study reinforces the importance of DfD as both an environmental and socially responsive construction strategy. To move from concept to practice, a coordinated response is required: one that includes policy reforms, industry training, financial incentives, and public awareness initiatives. Ultimately, the research highlights DfD not merely as a technical solution for waste reduction but as a strategic tool for achieving environmental justice and promoting equity in the transition toward a more sustainable built environment.

While the findings provide actionable methods of mitigating the impact of C&D waste on marginalized communities, the study has limitations. One primary limitation lies in the scope and scale of data collection. The study was limited to a specific group of industry stakeholders, which may not fully represent the breadth of perspectives across diverse regions, construction types, or project scales. As such, the generalizability of the findings may be constrained. Furthermore, the framework developed is industry-based and may not apply to all project types. Future research should consider broader and more diverse stakeholder engagement, incorporate quantitative life-cycle data, and explore region-specific case studies to understand better the contextual enablers and inhibitors of design for deconstruction.

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Appendix: Survey Questionnaire

Design for Deconstruction: Social Justice Implications of Circular Construction

You have been invited to participate in an ongoing project on **Design for Deconstruction: Social Justice Implications of Circular Construction**. This is part of the 2024-2025 **Applied Research Project between** ZGF Architects and the University of Washington. The project aims to promote design for deconstruction principles to mitigate the impact of social inequality of construction and demolition waste in marginalized communities.

Project Brief

Construction and demolition waste from the linear take-make-use-dispose approach often ends up in landfills, disproportionately affecting the marginalized communities through environmental hazards and economic exclusion, and contributes to social inequality. This project explores how Design for Deconstruction (*DfD*) can facilitate social justice in construction and demolition waste management through circular construction. The survey is in four sections and is core to achieving the project's objectives. Section A seeks background information, Section B assesses the application of DfD in the design and construction process, Section C explores the barriers, and the last section explores possible opportunities for implementing the *DfD* principles in construction projects.

This survey will take approximately 10-15 minutes to complete.

Thank you,

Idris Soliu (Ph.D. Candidate, University of Washington)
206-797-8626

Lona Rerick
Principal, Project Performance Team, ZGF Architects

Catherine De Almeida
Associate Professor, University of Washington

* Indicates required question

Section A: Background Information

1. 1. What type of company do you work for? *

Check all that apply.

- [ ] Design Firm
- [ ] General Contractor
- [ ] Developer
- [ ] Subcontractor
- [ ] Demolition Specialist
- [ ] Other: ____________________

2. 2. What project types does your organization specialize in? (select all that apply) *

Check all that apply.

- [ ] Residential
- [ ] Commercial
- [ ] Educational
- [ ] Mixed-use
- [ ] Healthcare
- [ ] Civic
- [ ] Tech/Laboratory
- [ ] Industrial
- [ ] Other: ____________________

3. 3. What professional role do you play in projects? *

Mark only one oval.

- Architect
- Landscape Architect
- Interior Designer
- Sustainability Specialist
- Structural Engineer
- Civil Engineer
- MEP Engineer
- Contractor (Design/Build)
- Project Manager
- Demolition Specialist
- Other: ______________________

4. 4. How many years have you worked in the design and/or construction industry? *

Mark only one oval.

- 1-5
- 6-10
- 11-15
- 16-20
- Over 20 years

Section B: Application of Design for Deconstruction in Construction Projects

Instruction:

Review
each of the *Design for Deconstruction* Principles below, and use your professional judgment to indicate their applicability in the design process. Select (Yes) if you apply them or (No) if you do not. Select "Not Sure" if you are unsure whether you are applying these principles in your professional work.

5. P1. Specify Building Materials with a Precautionary Approach. (Selecting materials with ingredients that are safe for reuse) *

Check all that apply.

- [ ] Yes
- [ ] No
- [ ] Not Sure

6. P2. Minimize Chemical Connections (Use bolts, screws, nails, and other mechanical connections instead of glues or adhesives) *

Check all that apply.

- [ ] Yes
- [ ] No
- [ ] Not Sure

7. P3. Design Accessible Connections (Design building elements such as column to beams connections that are easy to locate and reach for disassembly) *

Check all that apply.

- [ ] Yes
- [ ] No
- [ ] Not Sure

8. P4. Separate Structure from the Services (Design MEP independent of structural elements for accessibility and flexibility) *

Check all that apply.

- [ ] Yes
- [ ] No
- [ ] Not Sure

9. P5. Design with Workers in Mind (Selecting materials and components that are safe and easy to handle with standard tools and equipment) *

Check all that apply.

- [ ] Yes
- [ ] No
- [ ] Not Sure

10. P6. Safe Deconstruction (Design for safety of future workers disassembling the building) *

Check all that apply.

- [ ] Yes
- [ ] No
- [ ] Not Sure

11. P7. Simplicity in Structure and Form (Avoid complex design) *

Check all that apply.

- [ ] Yes
- [ ] No
- [ ] Not Sure

12. P8. Interchangeability and Repairability (Select materials and components that are easy to replace, remove, repair, and reuse) *

Check all that apply.

- [ ] Yes
- [ ] No
- [ ] Not Sure

13. P9. Document Materials and Deconstruction Methods (Prepare as-built drawings and deconstruction recommendations) *

Check all that apply.

- [ ] Yes
- [ ] No
- [ ] Not Sure

14. P10. Provide a permanent identification system for building components (Label and document materials and components used for the project) *

Check all that apply.

- [ ] Yes
- [ ] No
- [ ] Not Sure

Section C: Critical Barriers for Implementing Design for Deconstruction in Construction Projects

Instruction

Please
assess the criticality of the following barriers to implementing Design for Deconstruction. Use the rating scale: 1 = not critical; 2 = less critical; 3 = neutral; 4 = critical; 5 = very critical.

15. B1. Awareness of design for deconstruction practices *

Mark only one oval.

	1	2	3	4	5	
Not (	◯	◯	◯	◯	◯	Most Critical

16. B2. Policy to support deconstruction practices *

Mark only one oval.

	1	2	3	4	5	
Not (	◯	◯	◯	◯	◯	Most Critical

17. B3. Building codes that guide the selection of secondary (reused) materials for new projects *

Mark only one oval.

	1	2	3	4	5	
Not (	◯	◯	◯	◯	◯	Most Critical

18. B4. Client interest in using recoverable materials for the project *

Mark only one oval.

	1	2	3	4	5	
Not (	◯	◯	◯	◯	◯	Most Critical

19. B5. Low disposal cost of demolition debris *

Mark only one oval.

	1	2	3	4	5	
Not (	◯	◯	◯	◯	◯	Most Critical

20. B6. A large market for secondary (reused) materials *

Mark only one oval.

	1	2	3	4	5	
Not (	◯	◯	◯	◯	◯	Most Critical

21. B7. Storage consideration for recovered materials during disassembly *

Mark only one oval.

	1	2	3	4	5	
Not (	◯	◯	◯	◯	◯	Most Critical

22. B8. High costs of building disassembly *

Mark only one oval.

	1	2	3	4	5	
Not (	◯	◯	◯	◯	◯	Most Critical

23. B9. Limited training on deconstruction procedures *

Mark only one oval.

	1	2	3	4	5	
Not (	◯	◯	◯	◯	◯	Most Critical

24. B10. Reliance on traditional methods of construction *

Mark only one oval.

	1	2	3	4	5	
Not (	◯	◯	◯	◯	◯	Most Critical

25. B11. Specialized tools and equipment for deconstruction *

Mark only one oval.

	1	2	3	4	5	
Not (	◯	◯	◯	◯	◯	Most Critical

26. B12. Construction stakeholders' interest to adopt deconstruction practices *

Mark only one oval.

	1	2	3	4	5	
Not (	◯	◯	◯	◯	◯	Most Critical

27. B13. Concerns over safe deconstructions activities *

Mark only one oval.

	1	2	3	4	5	
Not (	◯	◯	◯	◯	◯	Most Critical

28. List and rate other barriers you know

____

Section D: Perceived Opportunities for Implementing Design for Deconstruction in Construction Projects

29. Please list any key factors that could encourage your organization to adopt Design for Deconstruction principles in future construction projects.