DESIGN OF STEEL BUILDINGS FOR DECONSTRUCTION

HÄMEEN AMMATTIKORKEAKOULU
HÄME UNIVERSITY OF APPLIED SCIENCES

Bachelor's thesis

Hämeenlinna University Centre

Construction Engineering

Spring 2021

Jesse Kinataama

HÄMEEN AMMATTIKORKEAKOULU
HÄME UNIVERSITY OF APPLIED SCIENCES

Construction Engineering | Abstract

Author Jesse Kinataama
Year 2021
Subject Design of Steel Buildings for Deconstruction
Supervisor Zhongcheng Ma

This study is a review of empirical evidence on Design of Steel Buildings for Deconstruction to reveal the current concerns, trends, and way forward. The aim of this literature review is to understand the general construction principles that promote the design for deconstruction (DfD) and focus on the general principles and technical considerations for design for deconstruction, the environmental impact and assessment methods of deconstruction activities, the benefits and barriers for deconstruction and reuse/recycling, and the economic and social dimensions of DfD.

The study highlights important developments, concerns, and possible remedies in the contemporary world. It has been revealed that DfD is a growing practice with several challenges and benefits but still development is required both in the physical and software aspects to improve DfD.

There is a lot more to do since regulation is still not strict and many of the actors in Europe are following guidelines for economic gains with little concern for the environment.

Keywords Design for Deconstruction, design Process
Pages 34 pages

Contents

1 INTRODUCTION

This thesis focuses on Design for Deconstruction (DfD) at end of life of a building as an integral approach that could offer a possible way forward. DfD is a practice easing the deconstruction processes and procedures through planning and design. Deconstruction is the process of demolishing a building but restoring the use of the demolished materials. The deconstruction process essentially changes the traditional waste management process. The DfD process is an important strategy to conserve raw materials, gives an overview of advantages and challenges and provides recommendations. It also gives examples of successful applications with an overview of possible environmental savings. Different materials, structural parts, elements, and whole buildings are presented.

1.1 BACKGROUND

Research related to design for reuse (DfR) has investigated the environmental effects and design strategies of new structures using reusable materials (Hradil, Talja et al., 2014; Burgan & Sansom, 2006). Nevertheless, materials are rarely reused in the Architecture, Engineering and Construction (AEC) sector, and there is a lack of information on reusable materials and their properties. There is no official service that provides a list or status of reusable materials, and even if reusable materials are sought, it is difficult for designers to grasp information on their properties (Rose, 2019). Therefore, the case for construction using reusable materials and the process of design are not well-defined. In addition, project stakeholders including the owner are concerned about the economic uncertainty of using reusable materials (Densley, Cooper & Cullen, 2017). Designers in particular are reluctant to reuse because they are concerned that their designs and material procurement strategies may be compromised by limitations in the shape and quantity of available reusable materials (Allwood, Cullen et al., 2012). The opportunity to enhance the sustainability of the AEC sector is therefore lost because reusable materials are not used in practice, despite the environmental benefits and existence of policy incentives for reuse.

Burgan and Sansom (2006, p.1182) state that ‘‘sustainable development requires that the end of life impact of buildings is minimised’’.

Deconstruction is a very good way of minimising the end of life impact of a building. Step 3 on the Delft ladder, ‘‘element reuse’’, can be achieved by deconstructing buildings rather than demolishing them, as deconstruction involves taking the building apart piece by piece which means the parts are much more likely to be reusable (Tingley, 2013). This tactic can be used for both existing buildings and in the design of new buildings. Deconstruction of existing buildings can be difficult and may not yield high recovery rates. Analysis of the building techniques and the site conditions can help assess whether it is worth deconstructing an existing building.

1.2 OBJECTIVES

The main objectives of this thesis are as follows.

- To examine the general principles and technical considerations for design for deconstruction.
- To explore the environmental impact and assessment methods of deconstruction activities.
- To assess the Benefits and barriers for deconstruction and reuse/recycling.
- To show the Economic and Social Dimensions of DfD.

2 METHODS

This literature review was performed in three steps: (1) A scientific article review, (2) a professional guideline and common practice review, and (3) the categorisation of the results. The theme of DfD is closely related to many research areas, general principles for design for deconstruction in general; technical considerations in DfD; environmental assessment methods –scope within them for rewarding material reuse and/or design for deconstruction; benefits and barriers for deconstruction and reuse/recycling; economic and social dimensions of DfD. For this study, a review of scientific articles and the professional guidelines was important in filtering out those articles and guidelines that were not directly focusing on DfD and the identified study objectives. Themes were generated and grouped to inform the outlay of the discussion.

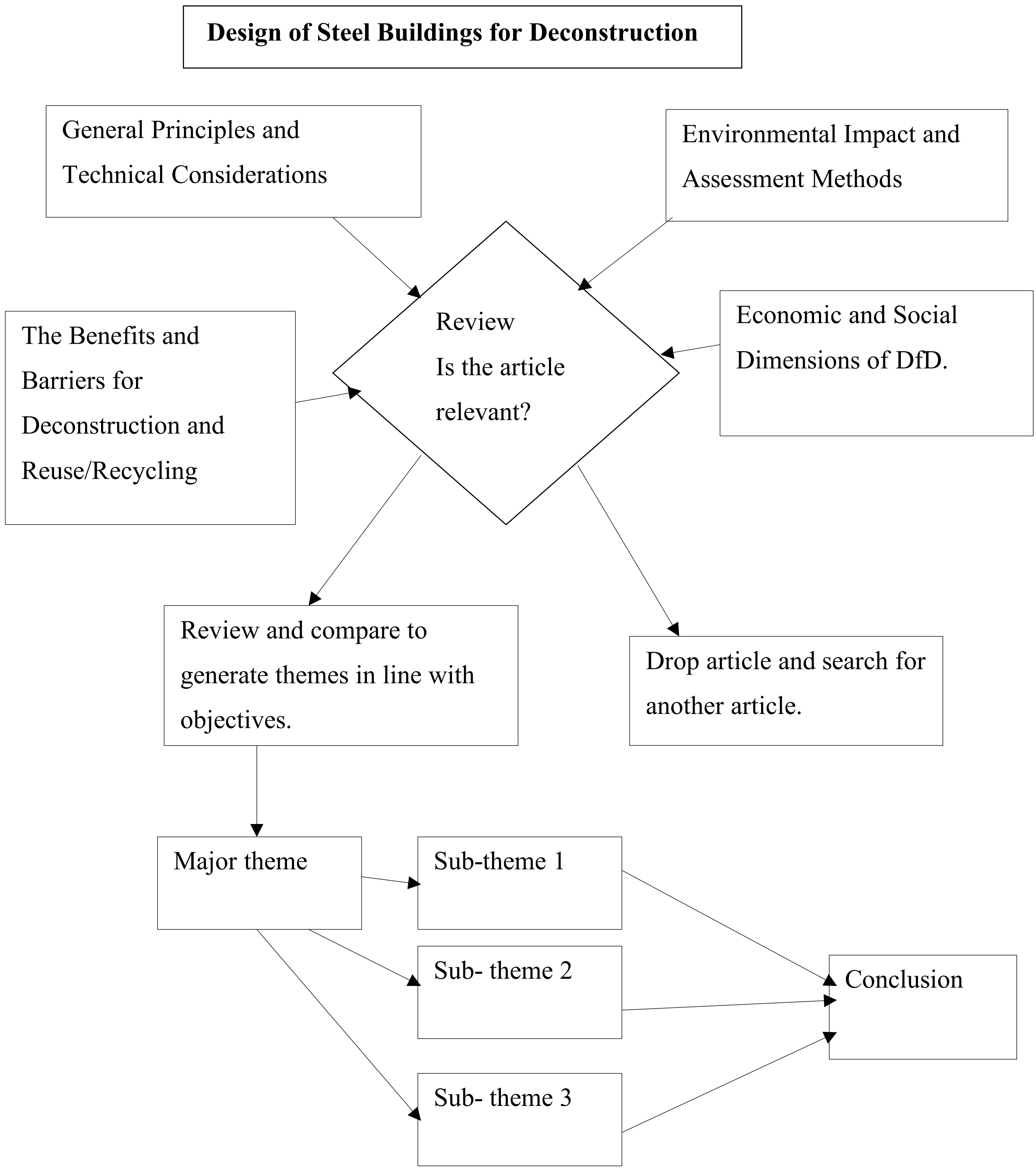


Figure 1. Methodology

The figure above shows how data was collected from various documents that were reviewed and later used in the compilation of the report.

3 KEY FINDINGS FROM LITERATURE REVIEW

3.1 General Principles for Design for Deconstruction

If existing steel buildings are to be deconstructed with reuse of elements as an aim, then the connection types between elements becomes important. Bolted connections are the easiest to take apart without damage to the steel. Where steel is used in composite construction with concrete, deconstruction can be difficult –as it can be very challenging to separate the steel from the concrete without damaging it. Contamination from fire protection can also be a problem in the reuse of steel structural components, where fire protection is sprayed onto the elements, removal of this can be uneconomical, particularly when potentially hazardous materials have been used. The use of intumescent paint or cementitious slurry as fire protection methods are not only difficult to remove from the steel but also add to the environmental impact of the reused steel. Therefore, encasing steel in fire resistant materials is more suitable if reuse of the steel is desired, as the encasing materials can be easily removed, and the steel then deconstructed and reused.

Technological development in HVAC-systems (Heating, Ventilation and Air-Conditioning systems) and sealing methods has enabled a decrease in buildings' operational energy consumption to very low levels up to the extend known as passive-house projects. These changes have induced the relevance of widening the scope of energy saving from a former exclusive focus on operational energy in the use phase to the inclusion of process energy – i.e., energy for mining, processing, transportation, assembly and building site operations. Through the processes, the assembled building and its materials come to represent an accumulated energy capital (embodied energy or grey energy) which should be administered appropriately. Therefore, resources consumed in relation to buildings must be viewed in a lifecycle perception which implies a perspective beyond operation and amortization – the management hierarchy proposed is: Reduce, Reuse, and Recycle (the 3 R’s). Three significant challenges evoke from this perspective:

Sophisticated integral building management combined with high quality cladding systems as well as optimally tailored thermal mass and minimal weight for reducing the embodied energy should be designed; for this purpose, finding an advanced, cost-effective solution combining structural steel with concrete should be focused on (Braun, Hauf et al., 2010).

Disassembly methodologies must be developed and employed in contemporary building practice to enable future reuse of building parts with the lowest possible consumption of energy for transformation. The understanding of a building's structures as a capital amount of embodied energy, certainly includes the existing building stock, and hereby the relevance of treating construction waste in an upgrading processes (Shen, Tam et al., 2010).

3.2 Common principles in the design for deconstruction process

- Design for prefabrication, preassembly, and modular construction: Prefabricated units are easily deconstructed and can be transported in large units. Additionally, modular construction materials allow for large quantities to be transported in one journey.
- Simplify and standardize connection details: This allows for efficient construction and deconstruction and reduces the need for multiple tools (Guy, Hewitt et al., 2004).
- Simplify and separate building systems: Separating out the distribution systems within non-structural walls can allow for selective removal of the low-value components. Consolidating plumbing services will also reduce the lengths of pipe required.
- Consideration of worker safety: The design should aim to reduce potential hazards and the use of potentially hazardous materials.
- Minimize building parts and materials: The design should aim to minimize the amount of building materials and equipment required (Webster & Costello, 2005).
- It is also important to select fittings, fasteners, adhesives, sealants etc. that allow for disassembly.
- Design to allow for deconstruction logistics: Small design tweaks can allow for significant improvements in waste-removal efficiency.
- Reduce building complexity: This will reduce costs and improve buildability as well as simplify the deconstruction process.

- Design with reusable materials: Consideration of materials that are adaptable and will be useful in the future. Materials such as wood, steel members, brick and carpet tiles can easily be reused or refurbished.
- Design for flexibility and adaptability: The design should consider any future renovations or adaptations that may be required to extend the life of the building.

3.3 Strategies for design for deconstruction

- Ensure there is an integrated set of as-built drawings.
- Design buildings so that elements are layered according to anticipated lifespan.
- Use connections that can be easily removed.
- Avoid the use of adhesives, resins and coatings which compromise the reuse potential.
- Develop a deconstruction plan during the design process.
- Design components and joints to be durable, so that they can be reused.
- Provide identification of component types.
- Use a standard structural grid.
- Design for maximum flexibility to preserve the building.
- Whole design team, client and contractor need to be on board.
- Ensure structural systems can be easily deconstructed.
- Identify the design life of elements.
- Provide access to all parts and connection points.

- Use the minimum number of connectors and limit the different types.
- Minimise the different number of materials used.
- Design the geometry to be simple.
- Allow extra time to ensure DfD is incorporated.
- Train contractors in DfD where required.
- Establish targets for the percentage of buildings that can be reused.
- Where possible design in passive measures instead of active service elements.
- Provide full inventory of all materials and components used in the building.
- Size components to suit the means of handling.
- Use prefabrication and mass production where possible.
- Select easily separable materials with good reuse potential.
- Avoid composite systems.
- Plan service routes so that they can be easily accessed and maintained.
- Use modular design.
- Allow for safe deconstruction.
- Provide adequate tolerances for disassembly.
- Avoid secondary finishes that cover connections.

3.4 Example in design for deconstruction – Parking Marignane

One recent example of the economic and sustainable design for reuse is given by the Parking Marignane in Marseilles, France. The overall parking concept consists of two parking spaces with 5000m^2 each, providing parking space for 1000 places each on a ground floor and upper deck (figure 2A). The main aim during the design has already been to deconstruct and reuse at least one of the parking spaces at the airport of Marseilles in the future.

Consequently, a steel structure has been designed to enable easy and non-destructive dismounting. The columns are circular hollow sections and the beams IPE 300 (B). All steel members have been galvanized for corrosion protection. The galvanization has been chosen specially to provide robustness of the protection during use, dismounting, transport and 2nd life erection. As slab, COFRADAL200 elements have been chosen to design a light slab system with a high degree of prefabrication, which is easy and fast to be placed. Focus has additionally been put on the connections used. All connections are bolted and therefore detachable (D and E). Furthermore, the column – beam connection has been designed with beams on top the of column to assure easy dismounting. Further the slab – beam is connection detachable (E); the slab elements have been attached by clamps. Finally, also the installations are fixed by detachable connections.

A

B

C

D

E

F

Figure 2: Design and construction of the Parking Marignane, Marseilles, F.

For further case studies with various construction types, see (Guy & Timothy, 2003) and Seattle (2006).

4 TECHNICAL CONSIDERATIONS IN DfD

4.1 General Design and Construction Principles

Many of the reviewed articles and professional guidelines mentioned a set of general design and construction principles. There is no internationally agreed definition on design for deconstruction and neither are there any requirements on the use of DfD principles in the building code in any country. In many of the reviewed documents, the following themes were mentioned:

- Overall building design
- Materials and connections
- Construction and deconstruction phase
- Communication, competence, and knowledge in the design process.

4.1.1 Overall building Design

According to Akinade, Oyedele et al. (2017); Tingley (2012); Crowther (2005); and Guldager and Sommer (2016), the whole building design has a large impact on the potential for design for deconstruction. The following design principles for building design in relation to DfD were identified:

- Use a simple, modular design.
- Use an open, flexible building system that is allows the functions to change in the future.
- Use a modular structural grid.
- Design building so elements are layered according to their anticipated lifespan.
- Make sure stability is maintained during deconstruction.
- Separate mechanical, electrical, and plumbing (MEP) systems.

Not only do these building design principles facilitate the deconstruction of the building, but they will also allow for adaptive reuse of the building (the reuse of a building for another purpose than it was meant for) which will allow for a prolonged use of a building.

Although it was mentioned that the design of the building should preferably be modular and simple, and even though complex shapes could complicate the deconstruction of building materials and components, this does not necessarily mean it will lead to less architectural freedom for architects. (Akinade, Oyedele et al., 2017; Tingley, 2012; Crowther, 2005; Guldager & Sommer, 2016; Guy & Ciarimboli, 2006).

4.1.2 Materials and connections

Selecting the right materials, connections, and components for DfD is probably the most important design aspect for the design team for achieving a high degree of DfD (Akinade, Oyedele et al., 2017; Crowther, 2005; Guldager & Sommer, 2016; Guy & Ciarimboli, 2006; Sassi, 2008). The following main principles concerning materials and connections were mentioned in the literature.

- Minimize the number of different materials, connections, and components.
- Design joints that are accessible and durable.
- Use mechanical joints (bolts, nuts) instead of other types of joints.
- Use nontoxic, non-composite, durable, and high-quality materials that can be reused.
- Avoid use of binders, adhesive, resin, and secondary finishes.
- Use recycled and recyclable materials.
- Use lightweight materials.

For every building, the design team needs to think about materials and connections. Applying DfD principles in the design of the building will require additional competence about designing connections that can be reversed.

4.1.3 Construction and Deconstruction Phase

Most of the building stock is planned to stand for a considerable amount of time, while the end-of-life of a building is normally not considered. This has been highlighted by various authors including Tingley (2012); Crowther (2005); Guldager and Sommer (2016); Guy and Ciarimboli (2006); Jaillon and Poon (2010), Sassi (2008). With DfD, it is obvious that not only the construction phase is important, but also the reverse construction in the deconstruction phase. In literature, the following main principles regarding the construction and deconstruction phase are mentioned.

- Develop and design a deconstruction plan already in the design process.
- Use prefabricated components and materials.
- Make sure components are sized to suit handling.
- Deconstruction should be possible with common tools and equipment.
- Allow for parallel disassembly.
- Ensure access to building components.

The implications of these main principles are mainly on how the physical deconstruction will take place, using common available tools and with components that have a reasonable size. Prefabrication will ease the construction of dry joint connections.

4.1.4 Communication, Competence and Knowledge

Akinade, Oyedele et al. (2017); Tingley (2012) and Lacovidou et al. (2018) agree that DfD will have an impact on the design process, the communication between key players, needed competence, and knowledge. In the reviewed literature, the following main principles are mentioned.

- Information, documentation about used materials, and deconstruction method (and as-built drawings) need to be stored.
- Component types should be identifiable.
- Material types should be identifiable.
- The design team needs to have the right competence, training, and will work with design for deconstruction.

The identification of materials is also discussed by Iacovidou, Purnell and Lim (2018), who propose the use of smart technology (radio-frequency identification). Such an identification enables to look at more specific details of materials rather than relying on ‘as-built’ drawings.

5 TOOLS FOR DfD

According to Czmoch & Pekala (2014), currently there are not many tools on the market that support the design team to design for deconstruction. At the same time, the rise of Building Information Modelling (BIM) in the construction sector is noticeable. In 2017, more than 60% of the architectural practices in the UK used BIM (National Building Specification, 2017). Such a BIM model does not only contain a 3D specification of the geometry and its location in the building, but it can also contain additional information about the used materials. The development of BIM evolves from a platform to store and model a 3D towards a more sophisticated model, where different actors can schedule projects (BIM 4D), estimate costs (BIM 5D), focus on sustainability (BIM 6D), and where the facility management is controlled (BIM 7D). (Czmoch & Pekala, 2014).

BIM 7D has clear benefits for DfD, because it has detailed information on, for instance, material specifications, time of the next maintenance, exact location for each building embedded element, etc. Therefore, BIM can play an important role in the development of DfD tools.

Akinade et al. (2015) developed and presented a BIM-based tool for deconstruction. It is based upon a mathematical model describing, for instance, the set of materials, components, and connectors; how and if they are reusable, etc. By assigning a certain Deconstructability Assessment Score (BIM–DAS), they described a model to determine the extent to which a building could be deconstructed right from the design stage. Akinade et al. (2017)] assessed existing DfD tools and identified essential functionalities of a BIM-based tool for DfD. By conducting focus group interviews, they identified seven key functionalities:

- Improved stakeholders’ collaboration
- visualization of deconstruction process
- identification of recoverable materials
- deconstruction plan development
- performance analysis and simulation of end-of-life alternative

- improved building whole life management and
- interoperability with existing BIM software.

6 ENVIRONMENTAL ASSESSMENT METHODS

6.1 Life cycle assessment and relevance of design for deconstruction

Tingley (2012) shows that the lifetime of structures is limited by economic questions, identification with the building, socio-political constraints, change of architectural needs and reuse of area. At end of their life, buildings must be deconstructed. An end-of-life scenario can be broken down into three separate sub-phases:

- Environmental impact of deconstruction activities (dust, noise, etc)
- Re-use and recycling rates of materials
- Environmental impact of waste processing activity (e.g., scrap processing).

Recycling is hereby defined as the end-of-life recovery and reprocessing of a product (e.g., by re-melting of steel construction products to form new steel products) and Reuse is defined as the end-of-life recovery and reuse (e.g., of steel construction products as a product filling the same function with or without some reprocessing). The recycling rate (within a defined system) is defined as “The tonnage of a product recycled / Tonnage of the product arising on demolition sites”. The reuse rate is similarly defined by replacing the word recycled with reuse.
In the following each end-of-life scenario is shortly reviewed (Tingley, 2012).

6.1.1 Environmental impact of deconstruction activities

Kamrath and Hechler (2010) shows that the disassembly technique is a new discipline within the field of architectural or engineering practice and theory. It is not a part of the current daily routine or responsibility among professional architects to plan for, or to explain how buildings are demolished, or how materials can be reused, and respectively recycled. However, from a resource perspective, it is a crucial ability to cultivate the implementation of a documentation for possible disassembly such as the documentation of operational energy use in building regulations, which today is required in most countries.

6.1.2 Re-use and recycling rates of materials

Nga and Chau (2015) note that large quantities of Construction and Demolition (C&D) waste, produced from construction related activity, are resulting in a significant burden on the industry. Thus, the architect and/or engineer of construction needs to answer already in design how he can stimulate high reuse and recycling rates of materials at end of life. The design for deconstruction is thus defined as the "design of a structure (product) for deconstruction in basic materials at end of life to enable a resubmission of the materials in the resource loop with appropriate labor and energy investment (Nga and Chau, 2015). End-of-life scenarios are hereby:

- Building reuse or relocation
- Component reuse or relocation in a new building
- Material reuse in the manufacture of new component
- Material recycling into new materials.

The ultimate target is to aspire towards a zero-waste economy, leading to buildings which do not consume non-renewable sources of energy.

6.1.3 Environmental impact of waste processing activity (e.g., scrap processing)

The recycling of C&D waste only partially addresses the problem because it can lead to considerable consumption of resources in re-processing and transportation. Although, in addition to reduced resource extraction and waste creation, environmental impacts can be significantly reduced due to recycling (e.g., 50% less CO_2 emission for steel due to recycling estimated via the closed loop analysis (Hettinger et al., 2011).

6.2 BREEAM

BREEAM stands for Building Research Establishment Environmental Assessment Method and it is the certification method for a sustainable built environment. Building Research Establishment Environmental Assessment method (BREEAM) was one of the earliest environmental assessment methods, first launched in 1990 (Parker, 2009), and is now one of the most widely used assessment methods. It is the main tool used in the UK and is used increasingly across the world. Several alternative schemes for different building types have been developed and implemented, examples of some of these are: BREEAM: healthcare, offices, industrial, multi-residential, education, prisons, courts, and the code for sustainable homes (BRE, 2010 b). BREEAM has been the world-leading sustainability assessment method for planning projects, infrastructure, and buildings for over 30 years. The BREEAM Awards is an annual celebration recognising the projects and organisations that, in the view of the independent judging panel, are leading the way with significant achievements in sustainable building design, development and management. There are five BREEAM technical standards, of which the most used is '*New Construction*' for homes and commercial buildings (Darren, 2021). The other four technical standards are: In-Use (for commercial buildings), Refurbishment & Fit-Out (for homes and commercial buildings), Infrastructure (for civil engineering and public realm projects), and Communities (for master planning).

6.3 The Code for Sustainable Homes

The Code for Sustainable Homes was also developed by BREEAM and became operational in 2007. From May 2008, all new build homes in England must have a code rating (BRE, 2010 d). Credits can be achieved within the code in nine different categories: energy & CO2emissions, water, materials, surface water runoff, waste, pollution, health &wellbeing, management, and ecology. Weightings are applied to these categories to adjust the relative values of credits in them. Dwellings can achieve levels of certification from one to six, where six is the highest level. There are certain mandatory standards that must be achieved for each level of certification (Communities & local government, 2008 b). Within the code for sustainable homes, there is some scope for gaining credits for material reuse, but little for design for deconstruction.

6.4 LEED

LEED is an environmental assessment method developed by the US Green Building Council; it stands for Leadership in Energy and Environmental Design. It is used throughout the United States of America and increasingly on an international scale, with many countries developing their own versions. The first pilot version of LEED for New Construction and Major Renovations was launched in 1998, and since then it has undergone various updates, as well as the addition of assessment methods for specific building types, for example schools (USGBC, 2009a). The current, 2009 version, has one hundred and ten points that can be obtained, with four levels of certification: certified, silver, gold, and platinum. The points in the 2009 version are split into seven different categories: sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation in design and regional priority. Fourteen out of the one hundred and ten points are awarded in the materials and resources category, which is the area where embodied energy is addressed (USGBC, 2009b).

6.5 Green Star

Green Star is an environmental assessment method that is mainly used in Australia, although some other countries like New Zealand and South Africa also use it (GBCA, 2009c), or are developing it for their use. The method was built on existing systems like BREEAM and LEED (GBCA, 2009a), and so is younger than these other two methods, with the initial pilot rating tool being released in 2003by the Green Building Council Australia (GBCA). There are three different ratings that are certified by the GBCA: a four-star rating which signifies '*best practice*', a five-star rating which represents '*Australian Excellence'* and a six-star rating to demonstrate '*World Leadership'*. There are nine different categories in which points can be earned: management, indoor environmental quality, energy, transport, water, materials, land use & ecology, emissions, and innovation. Environmental weighting factors are applied to each category, before the total number of points achieved is calculated.

7 COMPARISON OF ENVIRONMENTAL ASSESSMENT METHODS

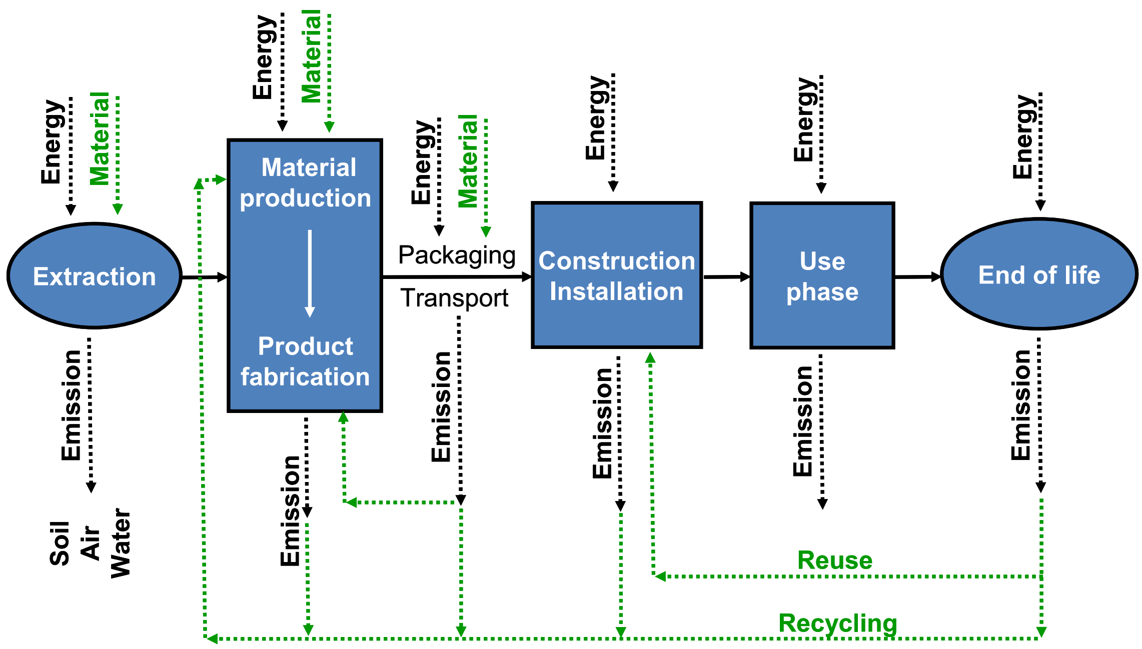
It can be argued that there is some scope for rewarding material reuse within BREEAM, the Code for Sustainable Homes, LEED, and Green Star. Each of the assessment methods address this issue in different ways; it could be argued that LEED and Green Star both more actively encourage this practice of reuse by having credits that are specifically devoted to rewarding it, which might mean that projects would consider using reused materials specifically to earn these credits. Whereas BREEAM and the Code for Sustainable Homes reward material reuse as part of an assessment of the environmental impact of all the materials used, which means the points could be earned without reusing materials. Green Star is the only assessment method which rewards design for deconstruction and can be seen to be the most progressive assessment method when it comes to the consideration of the embodied energy of a project.

Saleh (2009) suggests the addition of a credit to LEED to reward the design for deconstruction, with a maximum of three points available. He outlines a possible assessment scheme, and suggests that at a minimum, design teams should prepare a deconstruction plan and design a baseline ten percent of the building for deconstruction. An alternative way in which design for deconstruction could be encouraged within all the assessment methods would be to include a prerequisite clause that states that the building’s end of life must be considered and planned for at the design stage, to minimize waste materials and maximize material reuse. This is an important consideration, particularly as buildings seem to have shorter and shorter life spans, demolition or deconstruction can often occur in the designer’s life span. In additional to this, buildings are repositories of valuable materials, even more so as natural resources gradually become scarcer and more expensive, so it makes sense to design to be able to recover these materials easily and with minimal damage to them.

8 BENEFITS AND BARRIERS FOR DECONSTRUCTION AND REUSE/ RECYCLING

8.1 Life cycle assessment and relevance of design for deconstruction

The information here is adopted from Chini and Nguyen (2003) who note that Cradle-to-grave is the full Life Cycle Assessment from manufacture (cradle) to use phase and disposal phase (grave), see Figure 3. All inputs and outputs are considered for all the phases of the life cycle. For buildings, 50 years of design life is generally imposed - so far, it has been assumed that ca. 80% of the energy input and emission arise in this use phase (service life) of the building.



Source: Dincer and Rosen (2021).

Figure 3: A Scheme for the cradle-to-grave analyses.

Technological development in HVAC-systems (Heating, Ventilation and Air-Conditioning systems) and sealing methods has enabled a decrease in buildings' operational energy consumption to very low levels up to the extend known as passive-house projects. These changes have induced the relevance of widening the scope of energy saving from a former exclusive focus on operational energy in the use phase to the inclusion of process energy – i.e., energy for mining, processing, transportation, assembly and building site operations. Through the processes, the assembled building and its materials come to represent an accumulated energy capital (embodied energy or grey energy) which should be administered appropriately. Therefore, resources consumed in relation to buildings must be viewed in a lifecycle perception which implies a perspective beyond operation and amortization – the management hierarchy proposed is: Reduce, Reuse, and Recycle (the 3 R’s).

Deconstruction as opposed to demolition can have several benefits that are built on the idea of reusing materials. According to Chini and Nguyen (2003) the benefits of deconstruction can be split into three main categories: social, economic, and environmental. The social benefits are that deconstruction will provide employment opportunities, as well as further training prospects for those already involved in the construction industry. It will also produce materials which should be low cost and good quality, these should ideally be used within the community in which the deconstruction takes place. Deconstruction may also generate other benefits for those sectors that support it e.g., if large amounts of materials are salvaged then it may provide the possibility of a local shop that specializes in reused materials.

Several studies have been done to assess the potential of reused material shops. Odom (2003) concluded that reused material shops can be successful if there is sufficient deconstruction in the area or if the company is affiliated with a deconstruction company. Odom states that ‘‘wherever building material waste is generated, used building material stores also need to exist’’ (2003, p.185). This idea of selling the salvaged materials links back into Chini and Nguyen’s thoughts on the economic benefits of deconstruction, selling the materials is one benefit –if the contractor sells these themselves then the return is additional profit for the job. Some older materials that can only be found in existing buildings may also be of higher quality or have better workmanship than new materials and so these old materials may sell for a higher price. Deconstruction can also allow demolition contractors to expand their business and potentially employ more labourers.

Finally, the environmental benefits of deconstruction according to Chini and Nguyen (2003) are that it allows reuse of materials which both saves energy and minimizes the waste sent to landfill, it preserves natural materials (to some extent) and potentially can decrease disturbance to the site. According to Kestner and Webster (2010), design for deconstruction is arguably the most important green design strategy for achieving material sustainability through closing the materials loop''. This in combination with the potential energy savings makes design for deconstruction a very important sustainability strategy for future buildings.

Many benefits are associated with deconstruction and reuse/recycling. However only a fraction of construction elements can be reclaimed and reused for their original purpose as barriers against deconstruction are still present. The benefits of design for deconstruction include reduction in the whole-life environmental impact of a project, minimizing construction waste, minimizing costs, helping the local economy, reducing transportation, reducing carbon impact, minimizing pollution, and reducing the quantity of materials being taken to landfill (Tingley, 2012). Environmental benefits of deconstruction include reduced primary resource use; reduced waste to landfill; opportunities for recycling; reduction of site impacts caused by demolition (compaction, dust etc.) (Tingley, 2012).

Economic benefits include profits due to on-sale of salvaged goods and reduced landfill costs, small business development to handle salvaged material for reuse (NAHB 2000), promotion and increased sales of "*green products*" to be accounted for in e.g., Life Cycle Assessment (LCA) (Tingley, 2012).

Social benefits include creation of jobs in deconstruction (opportunity for unemployed and unskilled workers), training workers for the construction industry, preservation of cultural values and reflection of a trend to sustainable living in the population. Aesthetic qualities of reused former local materials may be used for architectural identification or the aged look may be celebrated (Guy & Timothy 2003), provision of low-cost materials to low-income communities, Increased networking stimulated as deconstruction opens the potential to make stronger communities through greater communication (Tingley, 2012).

Legislation related benefits include contribution to meeting local authorities and central government obligations for waste targets, zero waste, Kyoto targets and energy efficiency targets (Tingley, 2012).

8.2 Barriers to deconstruction

Today, less than 1% of existing buildings are fully demountable and design for deconstruction is not a mainstream concept (Kanters, 2018). A major problem for DfD and 'circular planning' may be the nature of building projects since they normally have a start and an end (Sanchez and Haas (2018). It might also require a fundamental change of the architects' perception of buildings as defined by Durmisevic and Yeang (2009): (1) buildings should not be conceived as static structures, but as dynamic and open ones that can easily adapt to changing requirements; (2) the transformation capacity of buildings and systems needs to be extended by considering the whole life cycle of the building and building systems; (3) treat building materials as long-term valuable assets through their whole life cycle using reconfiguration, reuse, and remanufacturing options at the building, system, and material levels; (4) consider waste and demolition as a design error; (5) decouple the fixed function–material relationship in buildings via the design of reconfigurable systems; and (6) involve the construction industry in the whole life cycle of the building and building systems There are quite several barriers to deconstruction, according to Guy and Williams (2003) some of which are listed below.

- Perception and education, that is, designers'/public/builder attitude i.e., "new is better" or "new is easier."
- Lack of resources for education on deconstruction
- Lack of research into deconstruction
- Lack of information and tools to implement deconstruction.
- Design for Deconstruction in new buildings is hardly considered (failure of codes to address the reuse of building materials
- In addition, in most construction segments, existing buildings are not designed to be deconstructed.
- Lack of education on design for deconstruction
- Lack of understanding benefits and opportunities associated with deconstruction.
- Lack of understanding and use of LCA tools or concepts.

Market development related barriers include

- High cost of transport and storage of recycled components and materials.

- Uses for some salvaged materials are undeveloped.
- Guaranteed quality/quantities of reused materials are difficult.

Economics related barriers include

- Low cost of some new raw materials.
- Low tipping rates (including landfill) in some countries.
- Deconstruction needs a more skilled workforce than demolition (Kamrath & Hechler 2010).
- Benefits of deconstruction are long term and collective but at first costs focus is dominant.
- Market pressure – the current climate of "as fast as possible".
- Highly speculative nature of many buildings, whereby there is no long-term ownership and adaption, renovation and demolition costs are not borne by the original owner.

8.3 C&D Industry

This method of DfD is a hardly regulated industry; there is lack of communication and networking in the C&D industry and with waste minimization organizations. Demolition is usually a low profit margin industry.

8.3.1 Legislation

Confusion may be present on what government legislation is, relating to environmental responsibility; C&D waste minimization may not be a priority.

8.3.2 Technical Issues

Liability in certification and avocation of reused components or materials not clear (lack of grading system for reused structural elements), lack of documentation on existing buildings to plan for deconstruction, some new materials are subsidized, creating unfair competition with reused materials, increase in use of non-reversible technology, systems, chemical bonds and plastic sealants etc. Seismic areas may make design for disassembly more difficult. New construction systems make recovery more difficult and less financially rewarding.

To increase the share of deconstruction the opportunities need to be outlined in all levels of decision making and the barriers need to be removed – design for deconstruction is one solution.

9 ECONOMIC AND SOCIAL DIMENSIONS OF DfD

9.1 Social benefits

The labor-intensive nature of deconstruction has huge potential in creating jobs for unskilled workers. Unlike demolition, there is no heavy equipment of specific skills required (U.S. Environment Protection Agency (EPA),2008). The current practice of deconstruction is heavily dependent on labor force (Nakajima & Russel, 2014). Minorities and “economically disadvantaged” individuals can be hired to carry out deconstruction work. In one successful case study, 40% of the workers were women (Guy & Ciarimboli,2007). These individuals were trained prior to engaging in the work and this increases their chance of securing jobs in the construction industry. Deconstruction and DfD have the potential to focus on education, by providing examples to the public on the building materials reuse and recycling processes, how a new building can use salvaged materials. The maturity of the reused/recycled material market could reduce the cost of building materials and thus benefit society and economy (U.S. Environment Protection Agency (EPA),2008).

9.2 Economic benefits

Aside from the potential savings (e.g., disposal fees, heavy equipment, re-sales value), deconstruction would stimulate the creation of a brand-new market for the salvage materials, beyond the existent facilities (Kibert & Chini, 2000). Great opportunities could also arise from the servicing and facilitation related to DfD, deconstruction, and the recycling and reusing of construction materials. As these practices become popular and well accepted, the benefits would become more obvious. The manufacturing industry would have the opportunities to make their products to become easier to disassemble and to exploit the new market. Webster (2007) defended that “it is not unreasonable to assume that buildings with DfD features will have greater market value, as well”.

10 SUMMARY AND CONCLUSION

In a world where many natural resources are becoming scarce and an environmentally damaging, design for deconstruction must be advocated for practically with strict enforcement among industry players. This involves increasing reuse and recycling rates, and thus reliance is shifted towards materials that have already been extracted to fulfil the demand. The benefits of DfD if explored well can easily encourage all players to practice only what will preserve and protect the environment. If the design principles once strictly followed, the environment will be saved yet the economic and social benefits will be upheld. Currently, there are gaps causing serious environmental damages, a practice which if not checked is likely to cause further environmental extremes such as pollution, global warming and health and safety challenges. Despite the arguments in favor of design for deconstruction and material reuse it is not a common practice. From an extensive literature review several alternatives were identified to increase the uptake of design for deconstruction, viz., its inclusion in environmental assessment methods and a quantification of the environmental benefits that occur from the designed-in reuse.

11 REFERENCES

Akinade, O.O., Oyedele, L.O., Ajayi, S.O., Bilal, M., Alaka, H.A., Owolabi, H.A., Bello, S.A., Jaiyeoba, B.E., & Kadiri, K.O. (2017). Design for Deconstruction (DfD): Critical success factors for diverting end-of-life waste from landfills. *Waste Manag., 60, 3–13.*

Akinade, O.O., Oyedele, L.O., Bilal, M., Ajayi, S.O., Owolabi, H.A., Alaka, H.A., & Bello, S.A. (2015b). Waste minimisation through deconstruction: A BIM based Deconstructability Assessment Score (BIM-DAS). *Resour. Conserv. Recycl. 105, 167–176.*

Allwood, J.M., Cullen, J.M., Carruth, M.A.,Cooper, D.R., McBrien, M., Milford, R.L. Moynihan, M.C.,& Patel, A.C. (2012). Sustainable Materials: With both Eyes Open; *UIT: Cambridge, UK, 2012. 32.*

Braun, M., Hechler, O., Hauf, G. , & Kuhlmann, U., (2011), "Embodied energy optimization by innovative structural systems". Proceedings of the 25th Final Conference of the Cost Action C., Austria, 2-3February 2011

Building Codes Assistance Project (BCAP). (2010b). Code Status: Missouri. Retrieved March 23, 2010, from http://bcap-energy.org/node/78.

Building Codes Assistance Project (BCAP). (2010c). Code Status: New York. Retrieved March 25, 2010, from http://bcap-energy.org/node/86.

Building Research Establishment (BRE). (2010d). Code for Sustainable Homes. Retrieved May 5, 2010, from http://www.breeam.org/page.jsp?id=86.

Burgan, B. A., & Sansom, M. R. (2006). Sustainable Steel Construction. *Journal of Constructional Steel Research, 62(11), 1178-1183.*

Communities and Local Government. (2008b). The Government's methodology for the production of Operational Ratings, Display Energy Certificates and Advisory Reports. London: Crown Copyright.

Crowther, P. (2001). Developing an inclusive model for design for deconstruction. Deconstruction and material reuse: technology, economic and policy, Proceedings of the CIB Task Group 39, Deconstruction Meeting, Wellington, New Zealand, 6 April 2001(pp. 1-26). CIB publication 266, paper 1

Crowther, P. (2005). *Design for Disassembly—Themes and Principles; RAIA/BDP Environment Design Guide; The Royal Australian Institute of Architects: Queentown, Australia.*

Czmoch, I., & Pekala, A. (2014). Traditional Design versus BIM Based Design. *Procedia Eng.91, 210–215.*

Densley, T. D., Cooper, S., & Cullen, J. (2017). Understanding and overcoming the barriers to structural steel reuse, a UK perspective. *J. Clean. Prod. 2017, 148, 642–652.*

Durmisevic, E., and Yeang, K. (2009). Designing for Disassembly (DfD). *Archit. Des.2009,79, 134–137.*

Fletcher, S. (2001). *Developing Disassembly Strategies for building to reduce the lifetime impacts by applying a systems approach. Ph.D, The University of Sheffield.*

Guldager, J. K., & Sommer, J. (2016). *Building a Circular Future; 3XN*: Copenhagen, Denmark.

Guy, B., & Ciarimboli, N. (2006). *Design for Disassembly in the Built Environment: A Guide to Closed-Loop Design and Building; Pennsylvania State University: University Park, PA, USA.*

Guy, B., & Ciarimboli, N. (Unknown date). Seattle Guide: Design for disassembly in the built environment. Retrieved August 18, 2010, from http:// your. King county. gov/ solid waste/ green building/documents/Design_for_Disassembly-guide.pdf

Guy, B., & Timothy, W. (2003). *Design for deconstruction and reuse. Final Report. Powell Center for Construction and Environment, Florida, USA. 2003*

Guy, B., Hewitt, C., Horman, M., & Pulaski, M. (2004). *Design for Deconstruction. Modern Steel Construction, June 2004*

Hettinger, AL., Thomas, JS., Hechler, O., & Conan, Y. (2011). *Life Cycle Assessment of Composite Bridges. Final Conference. COST C25: Sustainability in Construction – Integrated Approach to life-time Structural Engineering, Innsbruck.*

Hradil, P., Talja, A., Wahlström, M., Huuhka, S., Lahdensivu, J., & Pikkuvirta, J. (2014). Re-Use of Structural Elements; VTT Technical Research Centre of Finland: Espoo, Finland, ISBN 9789513881979.

Iacovidou, E., Purnell, P., & Lim, M.K. (2018). The use of smart technologies in enabling construction components reuse: A viable method or a problem creating solution? *J. Environ. Manag., 216, 214–223.*

Jaillon, L., & Poon, C. (2010). Design issues of using prefabrication in Hong Kong building construction. *Constr. Manag. Econ.28, 1025–1042.*

Kamrath, P., & Hechler, O. (2010). *Demolition and recycling of demolition rubble after deconstruction.* Final Report WG3. COST C25: Sustainability in Construction – Integrated Approach to life-time Structural Engineering.

Kanters, J. (2018). Design for Deconstruction in the Design Process: State of the Art.

Lennon, T. (2002). *Deconstruction of steel components. Design for deconstruction and material reuse, Proceedings of the CIB Task Group 39 –deconstruction meeting, Karlsruhe, Germany, April 2002.CIB Publication 272, paper 13.*

M&S: Morgan & Stevenson, Scottish Ecological Design Association (SEDA). (2005). Design and Detailing for Deconstruction. Retrieved May 7, 2010, from http:// www. seda. uk. net/ dfd/ dfd. Pd.

NAHB Research Center, Inc., Upper Marlboro, MD. 2000. A guide to deconstruction – An overview of deconstruction with a focus on community development.

National Building Specification. National BIM Report 2017; RIBA Enterprise: Newcastle, UK, 2017.

Nga, W.Y., & Chau, C. K. (2015). The 7th International Conference on Applied Energy – ICAE2015 New life of the building materials- recycle, reuse and Recovery, Energy Procedia 75,2884 – 2891.

Parker, J. (2009). BREEAM or LEED -strengths and weakness of the two main environmental assessment methods. Retrieved March 24, 2010, from http://www. bsria.co.uk/ news/breeam-or-leed/>

Rose, C. (2019). *Systems for Reuse, Repurposing and Upcycling of Existing Building Components; UCL (University College London):* London, UK.

Saleh, T. (2009). Building green via design for deconstruction and adaptive reuse. Retrieved July 13, 2010, from Thesis for Master of Science in Building Construction, University of Florida: http://etd.fcla.edu/UF/UFE0024439/saleh_t.pdf

Sanchez, B., & Haas, C. (2018). Capital project planning for a circular economy. Constr. *Manag. Econ.2018,36, 303–312.*

Sassi, P. (2008). Defining closed-loop material cycle construction. *Build. Res. Inf. 36, 509–519*

Shen, L., Tam, V., Tam, L., & Ji, Y. (2010) Project feasibility study: The key to successful implementation of sustainable and socially responsible construction management practice*. J. Clean. Prod*,*18*, 254–259

Tingley, D.D. (2012). Design for Deconstruction: An Appraisal; Thesis submitted in partial fulfilment of the degree in Doctor of Philosophy, Civil and Structural Engineering Department the University of Sheffield.

Tingley, D.D. (2013). Design for Deconstruction: an appraisal, Thesis submitted in partial fulfilment of the degree in Doctor of Philosophy.

US Green Building Council (USGBCb). (2009). LEED 2009 Weighting Background. Retrieved March 25, 2010, from http:// www. usgbc. org/ Display Page.aspx? CMS Page ID=1971

Webster, M., & Costello, D. (2005). Designing structural systems for deconstruction: how to extend a new building's useful life and prevent it going to waste when the end finally comes. Retrieved July 13, 2010, from 185~http://www.Lifecycle building. org/ files/ Designing % 20 Structural%20Systems%20for%20Deconstruction.pdf.

Webster, M.D. (2007). Structural Design for Adaptability and Deconstruction: a strategy for closing the materials' loop and increaing building's value, New Horizons and Better Practices.