APPLYING THE DESIGN-FOR-DECONSTRUCTION APPROACH TO PRODUCE SUSTAINABLE TEMPORARY EMERGENCY STRUCTURES

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ABSTRACT

APPLYING THE DESIGN-FOR-DECONSTRUCTION APPROACH TO PRODUCE SUSTAINABLE TEMPORARY EMERGENCY STRUCTURES

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Critical situations such as man-made disasters, mass migrations, war and natural disasters that occur today bring with them many problems and needs that need to be rehabilitated. Most of the urgent needs that arise are situations that require many additional structures such as shelter, education units and storage. However, the trace that every construction and structuring leaves on our world is too great to ignore. In addition, with increasing environmental damage, climate changes and resource depletion, it has become even more important to reduce the negative effects on our world as much as possible. In addition to the effects of the construction industry on regular buildings, the effects of temporary structures hastily established to create an evacuation system and to meet needs in emergency situations, are even more harmful and important when compared to the lifespan of permanent structures. This is due to the fact that emergency temporary structures are currently designed and constructed without end-of-life planning, and without considering the potential secondary effects of the materials used, aimed for fast construction rather than sustainability.

This study aims to serve as a guide for designers and those in the construction industry, ensuring the most effective use of the limited time during the emergency period and assisting in the design of sustainable structures. By creating a design flow through literature reviews, research, data collection and case study design solutions, it is aimed to help designers make the most effective decisions in terms of sustainability and to help the design achieve the result without the need to change each decision later. Thus, emergency temporary structures can be more sustainable designs and the use of the limited time, which is one of the most important factors of emergencies, can be used more efficiently.

Keywords: Emergency Structures, Temporary Structures, Sustainable Architecture, Design for Deconstruction, Design Solutions

ÖZ

SÜRDÜRÜLEBİLİR GEÇİCİ ACİL DURUM YAPILARINDA DEKONSTRÜKSİYON-İÇİN-TASARIM

YAKLAŞIMININ UYGULANMASI

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Günümüzde meydana gelen insan yapımı felaketler, toplu göçler, savaş ve doğal afetler gibi kritik durumlar, rehabilite edilmesi gereken pek çok sorunu ve ihtiyacı da yanında getirir. Ortaya çıkan acil ihtiyaçların büyük bir kısmı barınma, eğitim birimleri, depolama gibi pek çok ek yapılanma gerektiren durumlardır. Fakat her inşaatın ve yapılanmanın dünyamız üzerinde bıraktığı iz yok sayılamayacak derecede büyüktür. Bunun yanı sıra artan çevre hasarları, iklim değişiklikleri ve kaynakların azalması ile, dünyamız üzerinde oluşacak olumsuz etkileri olabildiğince azaltmak daha da önem kazanmıştır. İnşaat sektörünün ortaya çıkardığı bu etkilerin normal yapılarda olmasının yanında, acil durumlarda tahliye sistemi yaratmak ve ihtiyaçları karşılamak üzere hızla kurulan geçici yapıların yarattığı etkiler, normal yapıların ömürleri ile kıyaslandığında daha da zararlı ve mühim olduğu ortaya çıkmaktadır. Bu durum, acil durum geçici yapılarının günümüzde ömür-sonu planlamasının yapılmadan, ve kullanılan malzemelerin potansiyel ikincil etkileri ve sürdürülebilirlikten ziyade daha çabuk inşaa edilebilir olarak tasarlanıp inşaa edilmesinden kaynaklanmaktadır.

Bu çalışma, tasarımcıları ve inşaat sektöründekiler için, acil durum sürecindeki kısıtlı zamanın en etkili şekilde değerlendirilmesini sağlayan ve sürdürülebilir yapıların tasarımında yardımcı olan bir rehber görevi görmeyi amaçlamaktadır. Literatür taramaları, araştırmalar, data toplamaları ve örnek tasarım çözümleri ile bir tasarım akışı ortaya çıkarılarak, hem tasarımcıları sürdürülebilirlik açısından en etkili kararları vermeye hem de her verilen kararın daha sonra tekrar değiştirilmesine gerek bırakılmadan tasarımın sonuca ulaşmasına yardımcı olması hedeflenmektedir. Böylece hem acil geçici yapılar daha sürdürülebilir tasarımlar olabilir hem de acil durumların en önemli etkenlerinden biri olan kısıtlı zamanın daha etkili kullanılması sağlanabilir.

Anahtar Kelimeler: Acil Durum Yapıları, Geçici Yapılar, Sürdürülebilir Mimari, Dekonstrüksiyon İçin Tasarım, Çözüm Detayları

To My Family

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CHAPTER 1

INTRODUCTION

During times of emergencies formed by natural and human-made disasters like floods, earthquakes, migrations, fires, epidemics, or chemical disasters; meeting the urgent needs of the society needs to be done as fast and effective as possible. Today we see that constructing temporary structures or transforming existing buildings to meet urgent needs are the most prevalent and preferred solutions. Temporary structures or transformations can provide quick solutions for needs like sheltering, storing, education, and health facilities. But when examined in many countries including ours, it is seen that such temporary buildings are usually designed without the considerations of sustainability guidelines including the use of local resources and possible future uses for the structures (Limoncu & Yüksel, 2013). Without such considerations, not only are we creating waste and damaging our nature, but we are also damaging our economy, creating possible resource scarcity and the resulting buildings lack the needed performances suitable for the conditions they will be used in. Therefore whilst the construction of temporary structures is a necessity for meeting emergency needs, they should be planned and sought out before the emergency occurs, or at least they should be designed according to sustainability guidelines.

1.1 Background Information

Temporary structures that are built-in times of emergencies besides creating fast solutions when needed can also cause damage to nature, soil, resources, economy and also can create problems for users if not designed suitable for existing and possible future conditions. The use of materials and designs that are not suitable for the conditions that the structures are to be situated in means that the used materials, elements, and parts of the design will most likely have the need to be replaced and renewed several times in the duration of use (Huang & Long, 2015). Renewing and replacing of materials may be necessary for the period of a structure's usage for maintenance, enlarging, or remodeling which is usually the result of an unplanned designing phase (Salgın, Balanlı, Taygun, 2015). Every material that is used for a temporary structure, if not planned with details, can become wastes, produce harmful gasses and "be responsible for undesirable impacts" (Johnson, 2007, p.1) on the environment and unnecessary use of resources and energy will cause high impacts on nature with unsustainable results (Reddy, 2009). This lack of planning in constructions, demolitions, and usage period increase the generated waste immensely as well, so the designs should be done with planning; calculating the possible durations of use, functions, future functions, recycling, and maintenance levels to decrease the damage done to the environment and resources. Sustainable architecture is about minimizing the impact on the environment by decreasing the amount of energy and resources used throughout the whole life-cycle of a building including its construction, transportation, manufacturing of materials and elements, use periods, maintenance, and deconstruction or demolition (Guideline for Sustainable Building, 2001). If every stage of the design of a temporary emergency structure is considered with details including the end-of-life scenarios, we can create more sustainable and durable structures with higher performance values, less environmental and economic impacts, and the resulting design will be readying us for future disasters and emergencies.

1.2 Problem Statement

With diminishing amount of resources and increasing global warming and with the building sector being responsible around 30% of primary energy worldwide (Atmaca, 2017) and 35.9% of waste generation in the EU (Eurostat, 2018), it is crucial to design new structures in the most sustainable way with recyclable materials, reusable elements with deconstructable and maintainable qualities while considering every life stage of the structures. The importance of considering the possible impacts of every phase of a structure increases when the designed structures are planned to be temporary structures with a much shorter use period at around 5 to 10 years than regular buildings that are usually planned to have 80 years of service time (Grosso & Thiebat, 2015). For temporary structures, various sustainability measures exist, and the possible alternatives for the structure change depending on the function, location, and end of life scenario of a structure. However, there is yet to be a study that brings together all aspects of sustainability and guides future designs to be reusable in terms of structure, elements and materials to minimize the impacts of them in an efficient way.

1.3 Aim and Objectives

The research attempts to create a guide that can help designers and decision makers to achieve the highest level of efficiency in terms of sustainability during the construction, use and deconstruction phases of a structure while considering the end of life of the structures; through a workflow and method where the climatic, geographic and user requirements are answered by bringing together the possible solutions and simulation tools. During the research, answers for the following questions will be searched for;

- What are the existing sustainability and DfD measures for a temporary structure?
- How did other researchers tackle the design of temporary structures ?
- What are the most common errors and right applications that were done that affect the salvage rate of a structure?
- What are some possible disassemblable connection types of a structure?
- What must be the steps of the designing temporary emergency structures?

1.5 Disposition

In this research, the first section gives background information regarding the research topic, research problems and aims. The second section consists of literature review where various impacts of temporary structures, design principles, various end-of-life scenarios, designing for deconstruction, element connections, existing calculation and simulation tools are examined and explained. This part also includes examples of some case 3 studies regarding deconstruction processes and has collective information charts. In the third section of this paper, materials and methods are explained and the fourth one presents the results and discussion. The last section is the conclusion that gives brief information about the overall study and its findings.

CHAPTER 2

LITERATURE REVIEW

2.1 Temporary Structures & Their Functions During Emergency Situations

Temporary structures' origins trace back to nomad tents and with the development of the construction industry, they have become a type of architecture (Chen, Wang, Chen, 2021). Through time, many proposals using characteristics of a temporary structure were given such as movable "cabin houses" by "plug-in-city" (Sadler, 2005) and renewable prefabricated buildings (Schalk, 2014).

While temporary structures can be used for many things, Grosso and Thiebat (2015) explain that the demand for temporary structures has grown due to world events such as festivals and sports events becoming more common.Different reasons and demands for temporary buildings also occur all around the world due to recurring disasters.(Wang & Chen, 2021). These emergency needs have been seen with COVID-19 when we saw Fangcang shelter hospitals being built in China (Chen, Zhang, Yang, Wang, Zhai, Bärnighausen, Wang, 2020), COVID-19 hospitals being built in Istanbul, containers being arranged after 2023 Hatay Earthquake (Telegraph, Lovett, 2023) and emergency post-disaster housings built after 17 August 1999 and 12 September 1999 earthquakes in Turkey (Arslan, 2007). And while Post-disaster housing is defined by United Nations Disaster Relief Coordinator (1982) as housing applications to meet urgent sheltering needs of civilians post-disaster, Quarantelli (1995) states that temporary sheltering and temporary housing terms have been used ambiguously and interchangeably, and he makes a distinction between them by offering four stages starting from the first and fastest response to re-normalization as emergency shelter, temporary shelter, temporary housing and permanent housing.

He describes “emergency sheltering” as seeking urgent refuge for short periods like hours or a day. “Temporary sheltering” is again taking refuge for short periods but differs from “emergency sheltering” with “behavioral aspects” and better arrangements like food and placements. Author then suggests that “temporary housing” and “permanent housing” are different from each other with sharper distinctions and the overlapping occurs when planned temporary housings are later turned into permanent housings.

Arslan and Cosgun (2008) also bring to the fore that insufficient infrastructure for tent cities, climatic conditions, protection of survivors and also the required time needed for permanent houses create the requirement for temporary housings.

However, Johnson (2008) states that because of the impacts of temporary structures, such projects become problematic and can become a “headache” as the author states, when it could be a valuable resource for the community with strategic designs.

2.2 Environmental Impacts

The building sector has big impacts on emissions released and consumption of earth’s resources (Sarı, Alkan, Biçer, Bilgin, 2014) as housing constructions are also some of the most resource intensive projects (Utama, Gheewala, 2009). The environmental impact of construction sector have also been mentioned as a totality of utilization of natural resources, consumption of energy and the the created large amounts of waste (Purchase, Al Zulayq, O’Brien, Kowalewski, Berenjian, Tarighaleslami, Seifan, 2022).

Due to the impact the construction sector has on the environment Ramesh, Prakash and Shukla (2010) bring out the importance of the construction industry to achieve a sustainable development, which would create lower impact on the environment as well as economical and social gains.

From cradle to grave, all phases of a building's life cycle have been mentioned to have direct and indirect impacts on the environment with embodied energy and operating energy (Ramesh, Prakash, Shukla, 2010). Authors also explain that since all phases of a building's life cycle impacts the environment, adopting a multi-disciplinary approach including the matter of emissions, used materials and their reuse and recycling potentials and analyzing buildings from a life cycle point of view is crucial. Arslan and Cosgun (2007) also emphasize the importance of consideration of all phases of the lifespan of a building including site selection, design, construction, operation and demolition.

To lower the environmental impact of buildings and to increase their environmental performances, exploration of multiple aspects through all phases of their life cycles, including the environmental profiles of the materials used for the building were also mentioned by Shaw, Meo and De Souza (1998). Because a life cycle approach is necessary for the analysis of the resource intensity including all phases of a building (Utama, Gheewala, 2009), Life cycle analysis (LCA) process becomes valuable.

LCA is described by Ramesh, Prakash and Shukla (2010) as a process of quantification and evaluation of both material and energy flows of a system. The authors divide the lifespan of a building as upstream, use and downstream. Upstream includes extraction, production, transportation and construction while downstream includes deconstruction and disposal phases. They explain the process starting with the calculation of impacts such as global warming, ozone depletion and acidification, then with addition of energy consumption and waste generation, impacts of different phases of a building's life cycle on the environment are evaluated.

According to Rauf and Crawford (2015), calculation of energy performance of a building through its life span also includes the energy needed during use stage such as energy needed for heating, cooling, ventilation, hot water and lighting and the embodied energy of materials used. Because these aspects change according to the operation period, authors declare the importance of expected life service of a building to be taken into account during design phases.

The authors also explain that the importance of considering the possible impacts of every phase of a structure increases when the designed structures are planned to be temporary structures with a much shorter use period at around 5 to 10 years than regular buildings that are usually planned to have 80 years of service time.

With construction and demolition wastes (C&D wastes) amounting to 30% of total waste produced globally (Papargyropoulou, Preece, Padfield, R., & Abdullah, 2011), and with high environmental impact of energy-intensive materials used in constructions (Tingley, Davison, 2012), sustainable approach towards temporary structures become more crucial. The importance of sustainable temporary structures and post-disaster temporary housings is further explained by Atmaca (2016) with the rapid growth of demand for post-disaster housings due to increasing immigration and natural disasters. Because of the high use of temporary structures with shorter life spans, they are also seen as opportunities to work on reducing their energy consumption and cost requirements.

According to the US Federal Office for Building and Regional Planning (2001), minimizing the energy consumption, resource use and impact on nature through all stages of a building's life cycle are the goals of a sustainable building. For these goals to be achieved, following principles are offered; (i) lowering the consumption of energy and operation materials (ii) using more reusable or recyclable materials (iii) extended lifetime (iv) returning of materials used to the nature risk-free (v) protection of natural sites and work on space-saving construction (Arslan, 2007).

2.2.1 C&D Waste Production

Demolition wastes (C&D wastes) are described as any waste "produced during construction, renovation or demolition process that is no longer viable for use"

(Purchase et al. 2022). C&D is also defined by Cosgun and Arslan (2011) as a mix of inert and non-inert materials generated from construction, excavation, renovation, demolition and other construction activities. Authors divide inert materials into soft inert materials like soil and hard inert materials like rocks and concrete. They exemplify non-inert materials with timber, plastics, metals and packagings. And due to the lack of waste management framework, 75% of generated C&D are estimated to not be reused or recycled (Yeheyis, Hewage, Alam, Eskicioglu, Sadiq, 2013).

In 2016, the amount of worldwide waste recorded was 2.02 billion metric tons and was already projected to increase to 3.4 billion metric tons by 2050. However, the authors state that the projected number will be bigger if the current trend continues and a 70% increase in worldwide waste generation is expected (Purchase et al. 2022).

In the EU, 46% total waste are calculated to be from C&D (Galvez-Martos, Styles, Schoenberger, Zeschmar-Lahl, 2018) and C&D waste is said to account for 22% embodied construction energy and 19% of embodied carbon (Hammond, Jones, 2008).

C&D methods, and disposing methods like landfill and incineration are contributors to GHG emissions (Galvez-Martos, Styles, Schoenberger, Zeschmar-Lahl, 2018). In addition to this, lands to be used for disposal, costs, damage to environment and conservation of resources create the incentive for recycling C&D wastes (Cosgun, Arslan, 2011).

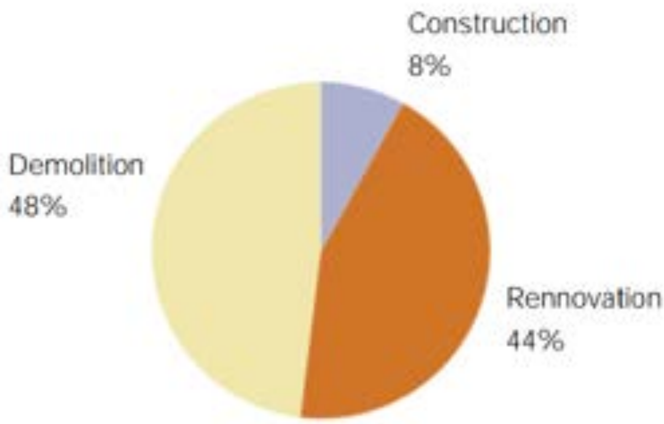


Figure 2.1 Construction & Demolition Debris Characteristic of building-Related Construction and Demolition in the United States, U.S EPA, 1998.

In the Figure 2.1 above, demolition and renovation were given as the most contributing to C&D wastes. And as demolition has the largest percentage in C&D, managing demolition debris becomes more important (Cosgun, Arslan, 2011). However, authors state that different materials and debris being mixed together after demolition is the biggest problem for managing demolition waste and even a careful deconstruction process, some materials can still be mixed together.

In addition to demolition debris directly from the building, even with a deconstruction process, Johnson (2007) states that in Turkey after the 1999 earthquake, the used land was littered with infrastructure, foundations and other debris.

It is stated that a model that sees C&D waste as “valuable resources harvested from the existing buildings” is necessary (Design for deconstruction, epa). The resources that will be acquired from collecting C&D wastes are overwhelmingly from demolition processes and in the projected model, the collected wastes are to be used for new buildings (Johnson 2007).

Strategies were proposed by including all stages of a construction as preconstruction, construction and renovation, collection and distribution, demolition, and material recovery and production (Purchase et al. 2021). The proposed strategies are; (i) enforcement of regulations, raw material taxes, use of economic instruments and prioritization of waste recovery (ii) selective destruction, planning waste management (iii) Practicing collection and segregation, on-site sorting, distributing resources efficiently, recirculation of recyclable materials (iv) choosing deconstruction and material recovery over traditional demolition (v) reuse, recycle and recovery of used materials and energy consumption, waste treatment and both ecological and economic aspects of waste recovery.

2.2.2 Embodied Energy and GHG Emissions

Embodied energy and greenhouse gas (GHG) emissions are declared to occur in all stages of a building's life cycle. Ramesh, Prakash and Shukla (2010) point out that buildings require and use energy from construction to demolition and describe the contributing stages to energy use and carbon emissions as (i) material extraction, (ii) material processing and element fabrication, (iii) construction, (iv) operation and service stage, and (v) end of life.

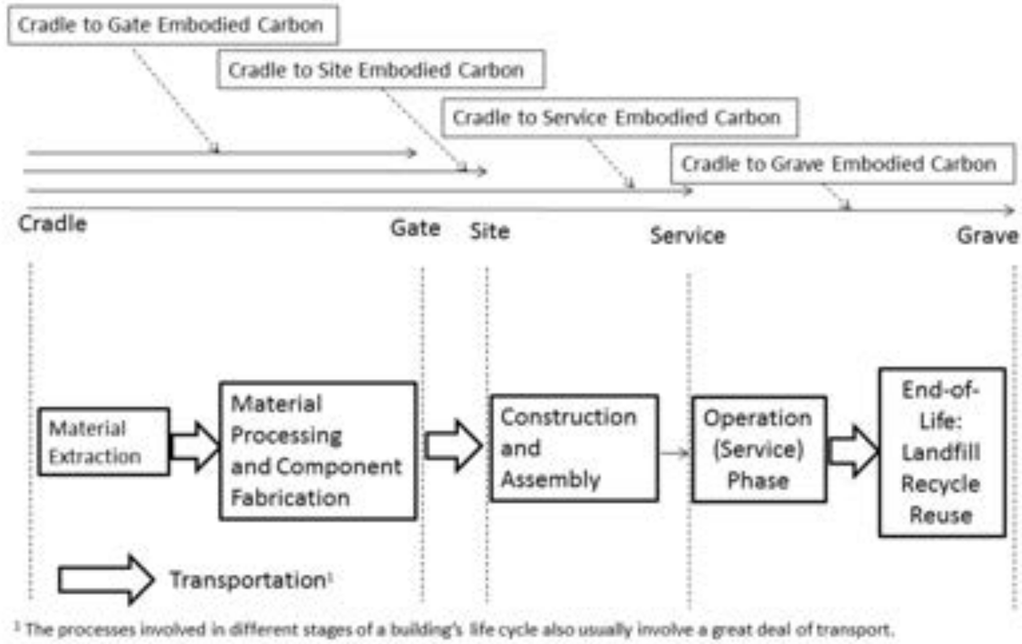


Figure 2.2 Different phases of a building's life cycle, Akbarnezhad, Xiao, 2017

Embodied energy is described as the totality of energy used to excavate raw materials, energy used in manufacturing and the energy needed for transportation to construction site for installations and construction of the building (Ramesh, Prakash, Shukla, 2010).

Greenhouse gasses (GHG) contributing to global warming are water vapor (H2O), methane (CH4), ozone (O3), nitrous oxide (N2O), chlorofluorocarbons (CFCs), and, most importantly, carbon dioxide (CO2) (Lallanila, 2016). CO2 is described as the primary greenhouse gas causing climate change by EPA (2015) as well.

Because CO2 is seen as the primary contributor to GHG, an important area to be targeted in order to decrease CO2 emission is seen as to be buildings which is apparent seeing 40% of carbon emissions in Europe are from energy consumption of buildings (Young, Perry, Manson, 2009). However this percentage doesn't even include emissions produced during construction and demolition stages or materials' embodied emissions. This is why Tingley and Davison (2012) declare emissions contributed by the built environment are larger.

Some countries have been working on reducing GHG emissions such as an agreement of reducing carbon emissions by 17% in 2020 and 83% in 2050 in the Waxman-Markey bill (American Clean Energy and Security Act) passed by the U.S. House of Representatives in 2009 (Islam, Nazifa, Yuniarto, Uddin, Salmiati, Shadid, 2019). Also the EU framework planned for 2030 and 2050 under the Paris Agreement has aims such as limiting the temperature increase to 1.5°C, creating a climate-neutral society and reducing emissions in order to slow down global warming and decreasing impacts (European Commission, 2018).

Researches also have been done creating strategies to deal with the embodied carbon of buildings. These strategies can be listed as; (i) low carbon materials, (ii) material minimization, (iii) material reuse and recycling strategies, (iv) using local sources and minimizing transportation, and (v) using strategies to optimize the construction (Akbarnezhad, Xiao, 2017).

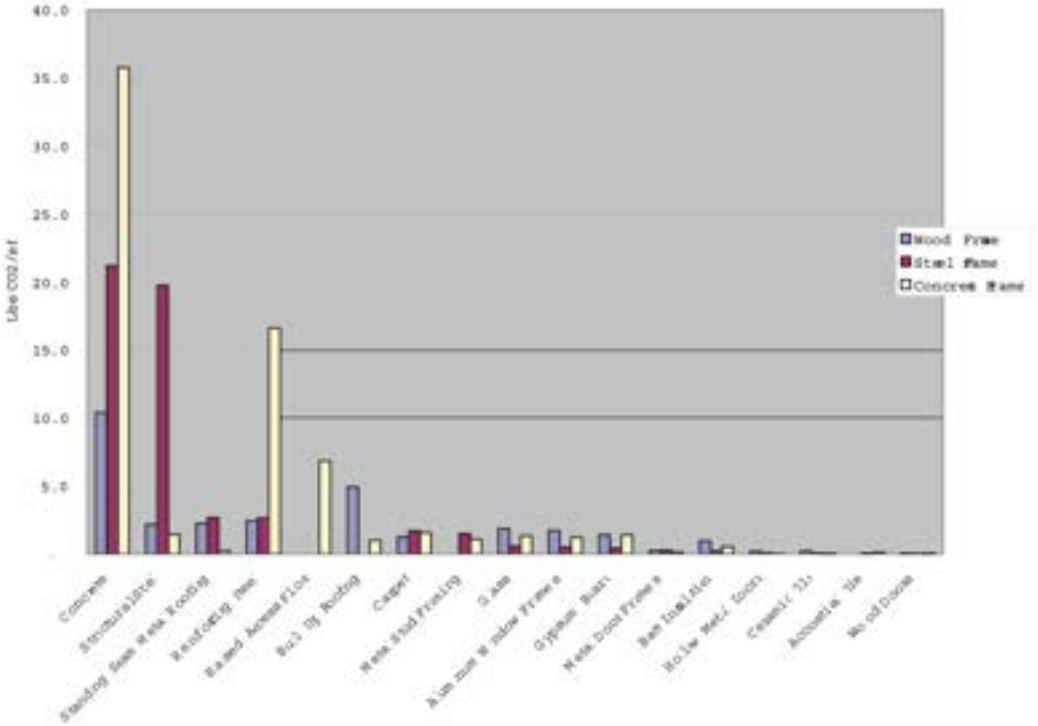


Figure 2.3 Pounds of embodied C02 per square foot for three projects (EPA)

Depending on the used raw materials, location of the quarries for extraction, transportation, extraction and processing operations, construction methods, recycling and reuse processes and location of the disposal sites, the embodied carbon of materials significantly vary (Hammond, Jones, 2008).

Analysis in Figure 2.3 shows three materials to have dominance in CO2 production; concrete, steel and rebar with concrete being the first (design for deconstruction, epa). Dominance of concrete makes sense considering the cement industry contributes about 7% of global CO2 emissions alone itself (Ritchie, Roser, 2020).

To reduce the embodied energy in the materials used in a construction, low energy intensive and locally available materials can be preferred instead of burnt clay bricks, concrete and cement or recycled materials can be used (Ramesh, Prakash, Shukla, 2010). The impact in reducing emissions through the use of recycled materials is also exemplified with a research concluding that CO_2 emissions and energy consumption from virgin raw materials are higher than recycled aggregate (Islam et al. 2019).

Embodied carbon alone making an important contribution to the whole life carbon of a building, becomes more important with lifespan or operation time of a building decreases thus operational emissions reducing in the whole life cycle and embodied carbon/operational carbon ratio becomes higher (Tingley, Davison, 2012). Grosso and Thiebat (2015) also talk about the importance of energy performance and embodied energy of materials increasing if the building has a lower service life than a regular building of 80 years.

This can be exemplified with warehouses with lower operational energy than regular buildings, which its embodied carbon making up as much as 60% of the whole life cycle of the warehouse (Tingley, Davison, 2012). Authors state from this the importance of considering the embodied carbon, and emissions from operational energy.

2.3 Cost Considerations of Emergency Temporary Structures

Housing constructions are the results of decisions made by designers that are significant economically. (Utama, Gheewala, 2009). Johnson, C., Lizarralde, G., & Davidson, C. H. (2006) state that building of safe and also affordable housing is one of the challenges in a post-disaster recovery programme. And this challenge must be overcome with strategic planning especially with the cases of temporary housings which are complex constructions due to their potentials, that require specific attention. This is because temporary housings are proven to be more costly in relation to its lifespan than regular buildings (Geipel, 1991). The cost and lifespan relation is mentioned by Johnson (2008) as well stating that temporary housing projects are unsustainable major investments that will be used for a short period due to their nature, with most are planned to be used for 6 months to 3 years.

If not carefully planned, temporary housings can even cost the same as a permanent housing (Geipel, 1991). This and the burden of temporary housing on the economy can be seen through the situation of Turkey after the 1999 earthquake. Turkey had made an investment of close to 225 million USD that would affect the reconstruction of permanent housing negatively as well. For the permanent housing project, Turkey had to get loans from the World Bank to finance the project. However, temporary housing can also be basic and inexpensive if planned which would leave most resources to be spent on permanent housing as seen from reconstruction programmes in Mexico and Colombia (Johnson, 2007).

In another past research in Turkey, it was revealed that the cost of temporary houses contributed to 10-15% of the construction industry's expenses. However, for a fast reconstruction, rehabilitation and rebuilding of a sustainable community socially, environmentally and economically, energy use in construction should be minimized. Also to minimize costs, protect the environment and not to overuse resources, temporary housings that can be re-used for the same or a different function should be considered (Arslan, 2007). The after-effects of the lack of economic planning with the 1999 earthquake rehabilitation can also be seen with Turkey's GPA chart from World Bank database.

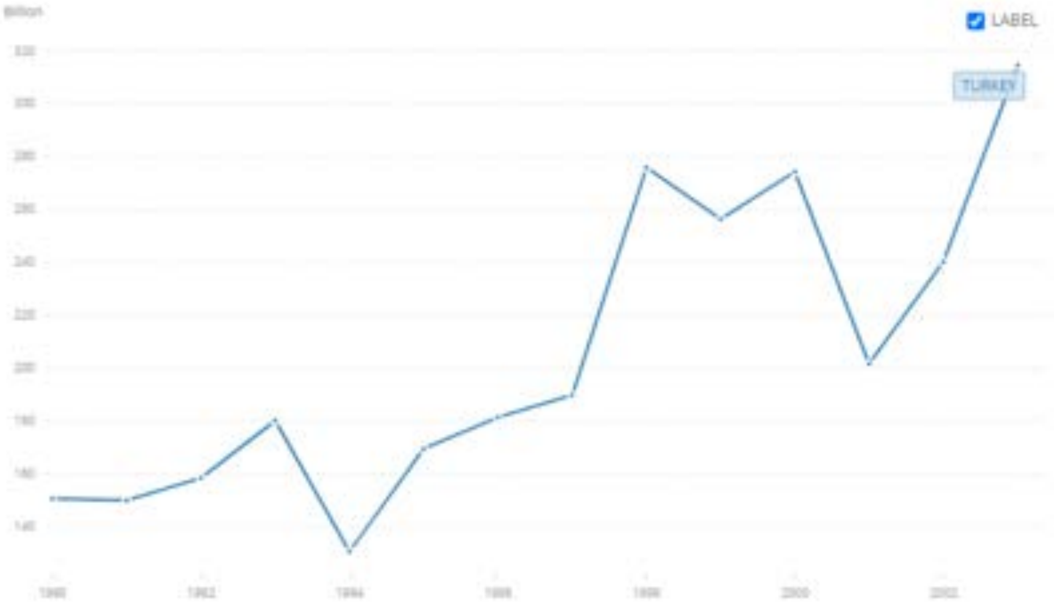


Figure 2.4 Graph showing GPA value of Turkey between 1990 and 2002 (World Bank, 2022)

Purchase et. al (2022) talks about a 2019 study by the Auckland City Council showing the benefits of recycling. In the study, a cost-benefit-analysis was made to separate demolition waste from landfill to be used on new constructions. There were two offered options; first having modest deconstruction, focusing on partial recovery and recycling and second option with intensive deconstruction focusing on the top two levels of hierarchy. After the analysis and comparison of the two options, cost benefits of both options were proven to be significant with results of $6.97 m and $14.46 m respectively. The benefits of both options were caused by newly created job opportunities for the deconstruction process, decreasing economic impact by reusing materials and also reduction of GHG.

Also in another examined study by Tam (2008), utilization of concrete waste produced after demolition as aggregates instead of dumping to wastelands, was proven to be beneficial to the economy with a net benefit of $30,916,000 per year.

With recycling the concrete waste, resource depletion and energy use were also lessened proving both ecological and economical sustainability can be found in construction projects.

Temporary emergency structures are crucial to generate a fast and effective disaster relief program. Thus, the structures that are planned to be built must be reliable for the long term, and they must be designed to be built in short periods of time for quick responses to emergency needs while not burdening the economic situation of a nation more than needed. This requires pre-planning for disasters and fast, systematic design phases of the structures.

The material choices must be done primarily from local resources, the designs should provide security and comfort for the people to restart the economy faster, passive systems may be accounted for to decrease the need for energy use and the structures may be designed for deconstruction or reuse after serving their emergency purposes to divide the cost into different life cycles.

2.4 Sustainability, Circular Economy and Construction

With high use of resources in the construction industry without thinking of the limits of raw materials and resources, a shift from linear economy to circular economy (CE) has become necessary for the efficient use of resources and to conserve resources. CE will help the construction industry to be more sustainable (Hossain, M. U., Ng, S. T., Antwi-Afari, P., & Amor, B., 2020).Authors state that the main challenge of CE is considering the end-of-life of materials and elements during the design phase of a project.

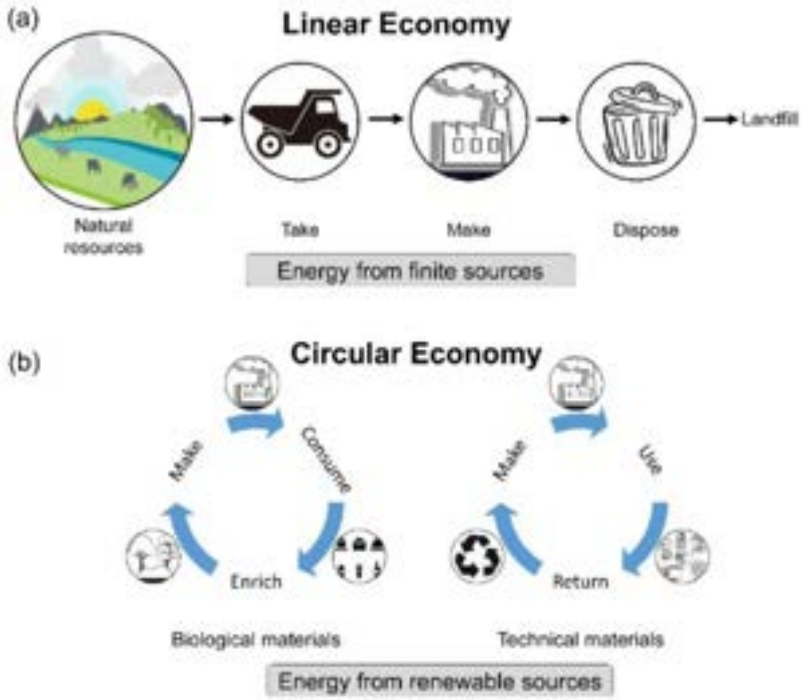


Figure 2.5 Linear Economy and Circular Economy models (Purchase et al. 2022)

CE, requires for raw materials to be recovered and recycled to be utilized in future processes instead of disposing them, contrary to linear economy (Purchase et al. 2022). Concept of CE comes from the reduce-reuse-recycle (3R) principle. Later on, this principle turned into a 4R framework with the inclusion of recovery operation as well (Anastasiades, Blom, Buyle, Audenaert, 2020). This framework supports a closed-loop system as defended by Tran (2017) saying that instead of waste staying as a residual product, it should be seen as a continuous resource in the system.

The CE process is also related to the “cradle to cradle” approach which is explained by Tingley and Davison (2012) as an approach which considers not recycling as the dominant option for a building’s end of life scenario but refunctioning and reusing of elements as the primary strategies.

Implications to adopt CE for C&D waste are given as; (i) integration of all related parties involved in a construction project and increasing the use of sustainable materials, (ii) recycling and reusing construction waste, and (iii) preventing excessive waste production (Hossain, Ng, Antwi-Afari, Amor, 2020). 4R also brings in economic benefits with slowing down the need for extraction of raw materials with reusing, recycling and recovery stages. (Purchase, Al Zulayq, O'Brien, Kowalewski, Berenjian, Tarighaleslami, Seifan, 2022).

Research done in Malaysia in 2006 analyzed the benefits and costs of a construction with minimized waste. It was found that minimization of C&D waste is beneficial to the economy with a profit of 2.5%. The study pointed out the multiple direct benefits including savings in cost due to reusing, recycling, selling materials, reduced transport costs and also reduced landfill charge costs (Osmani, 2011). Another research done on C&D waste of Bangladesh, Dhaka in 2016, showed that instead of sending the generated 1.28 million tons of C&D waste to landfill or unauthorized places, $45 million could have been contributed to the national economy if the wastes were to be recycled. This could also help in reducing the emissions (Islam, Nazifa, Yuniarto, Uddin, Salmiati, Shadid, 2019).

It is stated that the main challenge in adopting CE, is to consider the end-of-life of materials and elements during the design phase of a project (Hossain, Ng, Antwi-Afari, Amor). Mahpour (2018) highlighted three important hurdles in adopting CE in the design phase; (i) agency and ownership issues of end-of-life of materials; (ii) lack of integration of reuse and waste management in a sustainable way, and (iii) uncertainty in C&D waste management. Hence why modifications in the configuration between building elements and construction system is necessary to create a potential for the reuse of construction materials and elements (Ajayabi, Chen and Zhou, 2019).

2.5 Design of Temporary Structures According to Designated Function and Emergency

UNDRO (1982) declares that a faster process of permanent housing construction is more convenient than temporary housings however, due to the time needed to build adequate number of permanent housings for families to live after a disaster which can take years, temporary housing projects continue to be supported and used after each major disaster (Johnson, 2007).

2.5.1 The Required Performance From A Design & User Comfort

Grosso and Thiebat (2015) state that temporary structures have to follow sustainable design rules like flexibility, budget constrictions and speed of execution while responding to required thermal comfort, user comfort, acoustic needs and other function requirements. However especially for temporary housings and shelter after a disaster, the living situations in those designated camps and areas are in such a way that many families are crowded into small tents, and the used tents aren’t suitable for climate conditions most of the time being cold in the winter and also creating a lack of privacy in general due to crowd (Harada, 2000). Hence with the difficulties of collective centers or tent camps and with the required time needed for a permanent reconstruction or re-stabilizing the community, the use of temporary housing solutions become necessary (Johnson, 2006).

The designs of the structures are done in an insensitive and inappropriate way for the way people usually live (Johnson, 2006). The differences between requirements aren’t considered as exemplified by Johnson (2007) saying that basic wooden structures with shared areas and outdoor bathroom may be acceptable in some disaster areas while those may not be tolerable in another disaster situation and insulation, hot water and privacy may be needed. Author also states that a temporary housing has to provide safety for survivors from outside elements including fire as well as providing a minimum level of sanitation at the least and comfort level provided to the people must be at an acceptable level, matching local living standards (Johnson, 2007).

Huang and Long (2015) describes the conditions victims were in after the Wenchuan earthquake through a questionnaire survey with the victims after they had settled into their permanent houses from their temporary settlements. The questionnaire showed that the more unbearable situation for the victims was the summer indoor thermal environment due to the bad indoor thermal environment depending on the housing situation. Authors state that the positions of the housings and rooms are connected to thermal comfort. From this research, some conclusions were made; window design must be paid attention to if there is a high building density, the required insulations must be done and the relationship between the enclosing wall and the building on the edge of the settlement must be considered.

If temporary housing is in a city, victims can use the existing services and facilities with the assumption that the buildings of those facilities have not been extremely damaged. However, in Turkey and Japan the majority of the temporary housing was located outside of the cities. This is why next to temporary housing, after a disaster it may be necessary to provide extra services for education, healthycare, transportation, religious activities etc. Thus schools, clinics, shops, religious buildings, post offices and the like will be needed as well (Johnson, 2007).

2.5.2 Site Features and Further Risks

Selection of sites for temporary structures and temporary housings, are crucial part of the recovery process after a disaster and the site’s control, security, socio-demographic structure of the dwellers must be considered in order to decrease risks to minimum and as to not create new social and environmental issues (Arslan, Cosgun, 2008). Authors also state that while doing this, the economic and cultural background of the region that was affected by the disaster must be taken into consideration. Ferhat Özçep et al. (2003) has also declared that for post-disaster site planning, micro-zoning is crucial.

Johnson, Lizarralde and Johnson (2004) mentions that choosing a site outside the city limits for temporary housing means increasing the number of areas needing municipal services while causing the displacement of people to suburban areas. However temporary housings are usually located as such that the sites become inconvenient and transportation becomes problematic (Johnson, 2006). The issues and potentials of both suburban and in-city temporary housing sites are researched by Arslan and Cosgun (2008). Authors give examples from case studies;

- Sıralık temporary housing built close to the Sıralık Village outside of city borders, is declared to be not suitable for long term use due to the lack of temporary infrastructure. This causes the requirement of passive measures and the location also may cause a problem for the social integration of the village and the city.

The infrastructure of the Fevzi Çakmak temporary housing site had potential to be integrated into the new permanent buildings. The site had no transportation problems either and it was used for 3 years.

- Gümüşpınar temporary housing site had many service buildings and social infrastructure built and other permanent settlements close to this site. Dwellers could be integrated both physically and socially if a permanent housing were to be built.

Johnson (2006) talks about hazards and vulnerability for temporary housings, mentioning the possibility of causing more disasters if correct measures and mitigation strategies aren't taken and emphasizes the consideration of "vulnerability". Hewit (1997) calls vulnerability "human ecology of endangerment" to emphasize due to social geography, land uses and community's power structures, such communities also become exposed to danger. He defines six forms of vulnerability; (i) Exposure to dangerous threats and environments, (ii) Weaknesses: Buildings and people seeing harm due to weaknesses, (iii) lack of protection of people from hazards and dangerous situations, (iv) Disadvantage: lack of resources in danger response and affecting risks, (v) Lack of resilience: having or creating no capacity to avoid, withstand or recover from disaster, (vi) powerlessness: being incapable of creating safe conditions.

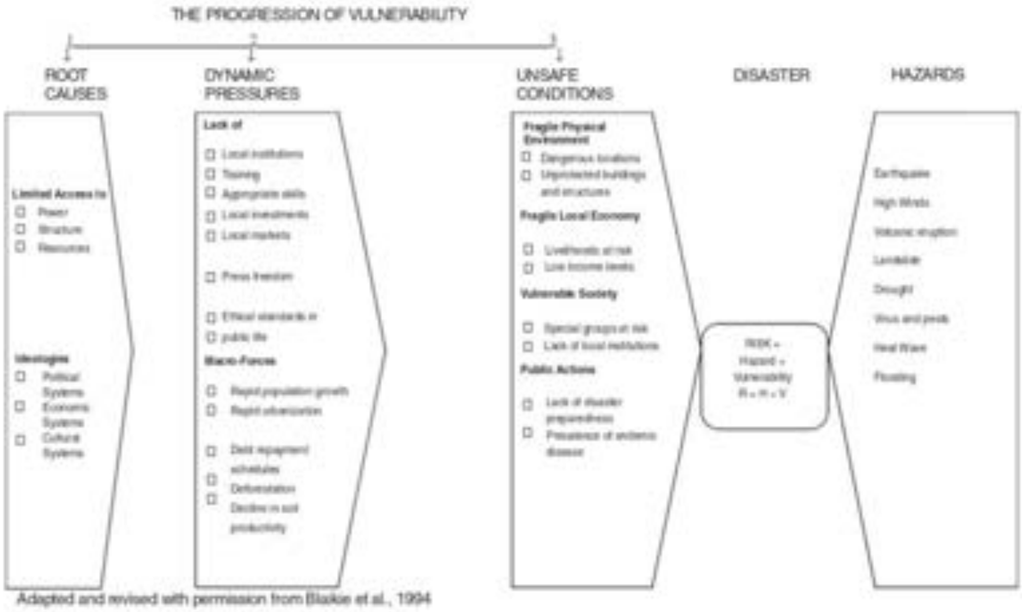


Figure 2.6 The Progression of Vulnerability, Thomas, Soliman (2003)

Site selection for emergency temporary structures are important to prevent further risks and should involve the consideration of hazards. Liu, Ruan and Shi (2011) exemplifies this with technique details such as “slopes steeper than 25° are considered to have a high risk of geohazards, whereas those that dip at less than 5° are regarded as stable and secure.” Soil conditions also are crucial for a stable foundation of the projects to prevent further risks (One Click LCA® software, 2018). And appropriate structural solutions must be provided such as opting for a lighter structural solution for softer soil conditions. Lack of consideration for further risks causes damage to the settlements and to the people. In 2008, due to wrong choice of location, landslides and floods damaged emergency housing while causing 50 fatalities that were all earthquake survivors.

Figure 2.7 Photograph of a temporary site for emergency houses built on riverbanks and on a hill affected by landslides. (Liu et al, 2009)

2.6 Design According to End of Life Scenarios

After temporary housing has served its initial purpose, it does net need to become a burden but can instead be a valuable resource of low-cost housing in a place where housing is in short supply (Johnson, 2006). As Johnson states, temporary housing becomes permanent and perceived as blight on the city. Reconstruction is focused on permanency and sustainability and tackles longer-term problems such as adequacy of housing, infrastructure, utilities and the economy.

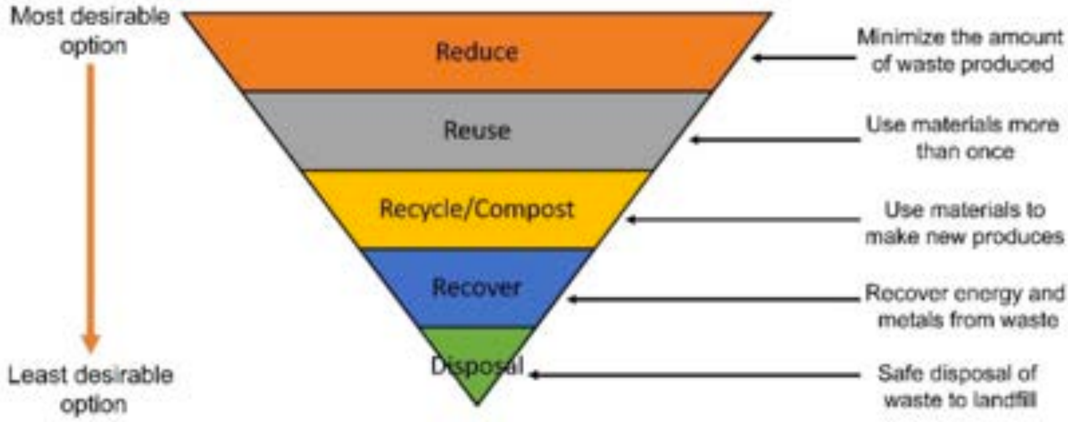


Figure 2.8 Global waste management hierarchy, (Rajendran K., Lin R., Wall D.M., Murphy J.D.)

This globally-used hierarchy begins with the most desirable waste minimization technique; to reduce waste at the source. This simply entails the reduction of excess waste, whether its material packaging or more efficient uses for materials on building sites. The responsibility of the problem falls on companies who create these products or designs buildings or other infrastructure. The second option in the hierarchy is to reuse products/materials once they reach the end of their lifespan. Again, this involves various inputs from different organizations and businesses, whether its designing for deconstruction on a building site or manufacturing materials which have a long lifespan. The next option is to recycle or compost the materials. Recycling involves finding use for materials which cannot be reused, generally achieved by altering the form of materials to make them desirable for use in other applications or materials. Composting is just recycling that occurs in organic matter, where the materials breakdown and become nutrient rich soil which has many applications. The fourth option is to recover which involves the processing of the waste, in some manner, to produce a valuable outcome. This can include combusting municipal solid waste for energy or recovering precious metals from electronics. The final option, disposal, is the least attractive option on the hierarchy. This is where waste that has no current value is disposed of in a safe manner (Purchase et al. 2022).

Recycling is actually the down-cycling of a material to a lower grade use. Concrete can be “recycled”, but only as low value aggregate, wood debris can be ground up for wood fiber or mulch, but thereby loses its most valuable properties. (design for deconstruction, EPA). The importance of considering the possible impacts of every phase of a structure increases when the designed structures are planned to be temporary structures with a much shorter use period at around 5 to 10 years than regular buildings that are usually planned to have 80 years of service time (Grosso & Thiebat, 2015).

While waste management at the end of the life cycle of a structure should be considered, the ideal approach is to aim to have no waste to manage at the end (Keys, Baldwin, Austin, 2000), through life cycle assessment (LCA) studies and detailed planning. Since the end-of-life scenario of a temporary structure may vary and change according to different situations, it should be considered from the beginning of the design phase and a structure does not have to have only one scenario but instead, it can be a mixed structure that will have some of its elements recycled, some parts reused, and some parts demolished. In any case however, the feasibility of the scenarios depends on a detailed planning stage where requirements such as facilities, manpower, and resources are thought through to create effective solutions during emergencies.

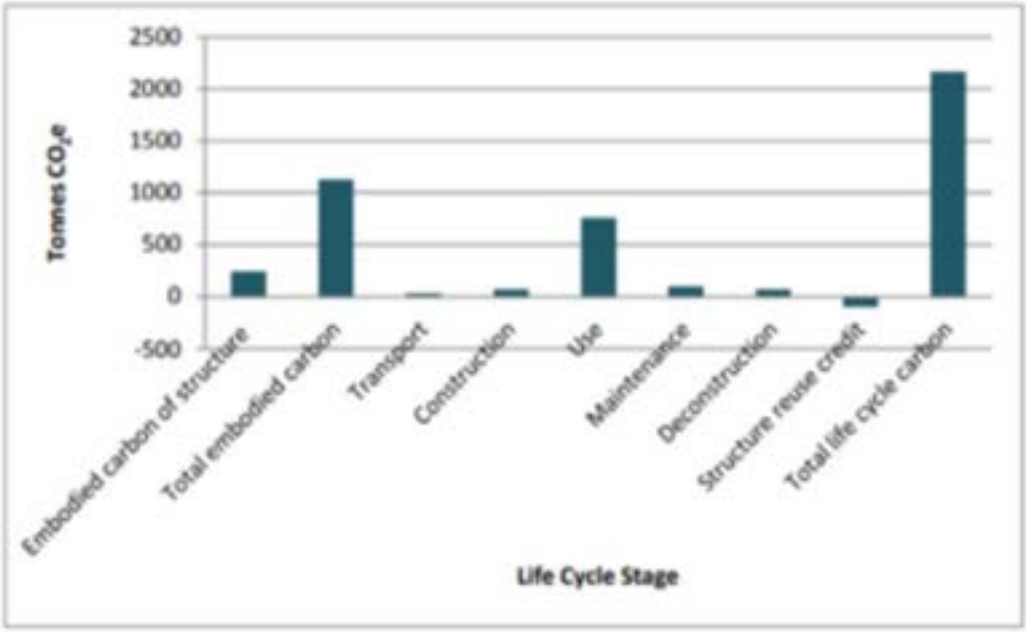


Figure 2.9 Graph showing CO2e emissions produced at each life cycle stage of a building (Tingley, 2012)

Webster and Costello (2005) also explain that there are better ways to deal with waste before landfill such as composting and using materials to generate energy. There are two points regarding the issues around temporary housing in the long term: first, temporary housing is always inhabited for longer than anticipated; and second, the units—or some materials from the units—can be reused for another purpose once vacated (Johnson, 2007).

2.6.1 Refunctioning and Reusing

Extending the useful life of an entire building is the highest form of salvage and reuse. (EPA). Johnson, Lizarralde and Johnson (2004) exemplify the predicted life of a structure expanding saying that survivors of past earthquakes in Turkey, Armenia and Colombia that had not been able to gain required income for new rental houses and afford a new roof, kept living in the temporary housings and even creating new ghetto settlements.

The permanence of temporary housing, or what we may call the ‘second life’ of temporary housing can actually be a sustainable practice, 1) economically, in terms of getting a longer life out of the upfront investments in temporary housing; 2) environmentally, by recycling buildings, building parts and rational use of land near the city; and 3) socially, by providing much needed low-cost housing to the market (Johnson, 2008).

Temporary housing reused as community buildings was an outcome found in only one temporary housing project in Turkey. However, it was very successfully done and remains a model for future planning. The temporary housing units were dismantled and reconstructed on other land as community buildings, such as a sports centres and schools (Figure 15). The housing units were row-house style, built with sandwich panels on a steel frame and each building contained eight units, totalling a 200m² building that could be configured a number of different ways. However, investments were needed to pay for the costs of transport and construction (Johnson, 2008).

The most ideal choice to handle a structure after its service time is refunctioning on-site since as can be seen from Figure 2.9, the impact of an element of the whole structure can be divided into several lifetimes when reused instead of demolishing the structure into landfill or recycling.

Figure 2.10 An eight-unit building that is part of the UMCOR temporary housing settlement (left); units reused as classrooms at a school (right) after being dismantled, moved across town and reassembled (Johnson, 2008).

Figure 2.11 View of the two units and the concrete foundations for the kitchen in 2000 (left) and inside view of kitchen built between to the two paper houses in 2004 (right). (Johnson, 2008)

For saving money and protecting the environment and conserving scarce resources, the affected region must consider the option of temporary houses to meet their short and long-term need during the reconstruction process. After the end of usage, temporary houses should be able to be re-used for the same or new function (Arslan, 2007).

Figure 2.12 Beci temporary housing site, general view (Arslan, 2007)

After the devastating earthquakes of 17 August 1999 and 12 September 1999, one of the temporary sites constructed after the earthquake in Duzce was the Beci Temporary Earthquake Housing site, which was located close to University of Abant Izzet Baysal.

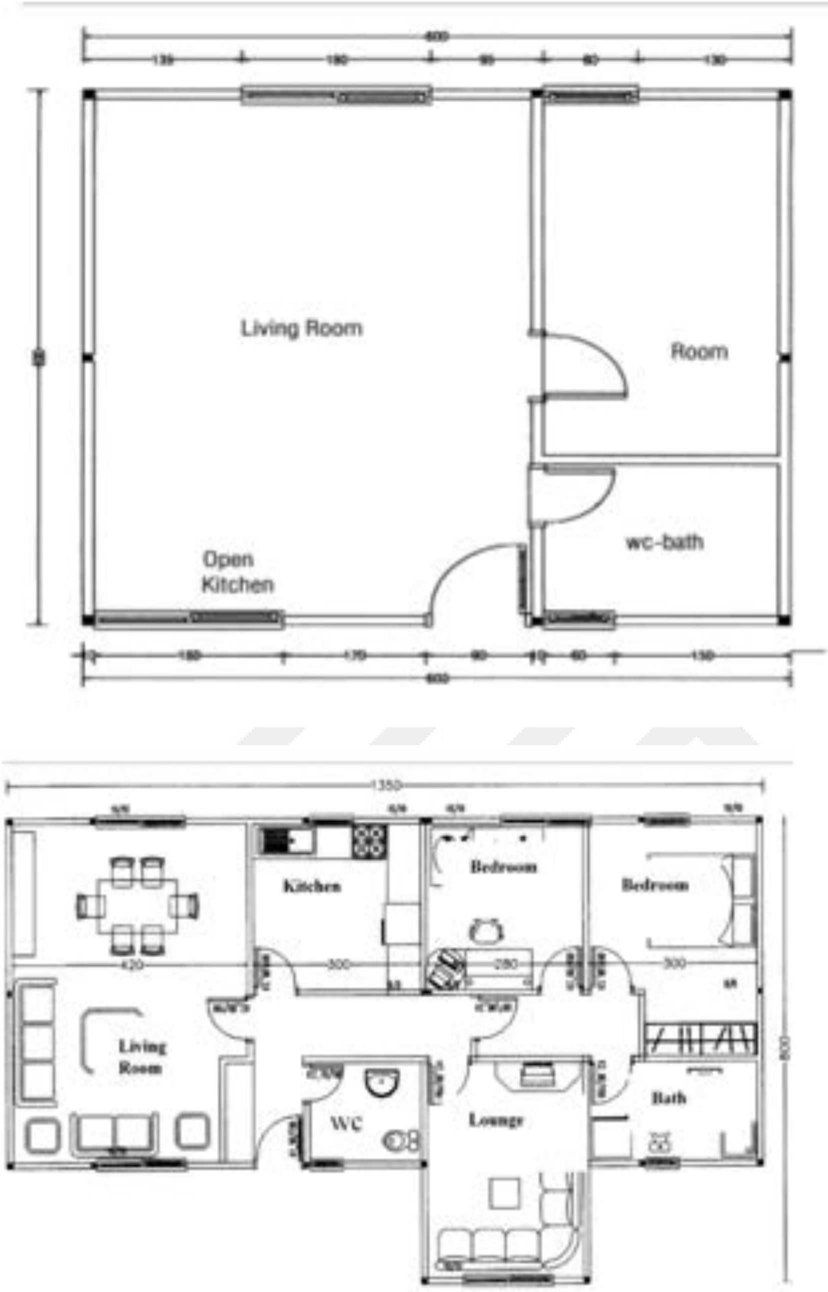


Figure 2.13 New permanent house formed from two temporary houses and some additional parts. (Arslan, 2007)

The possibility and feasibility of using the temporary houses and housing sites with the same (house) or different functions (mukhtar office, workmen dormitory, youth camp, etc.) must be considered before the disaster. İt is important to give a sustainable function to the houses and site (Arslan, 2007).

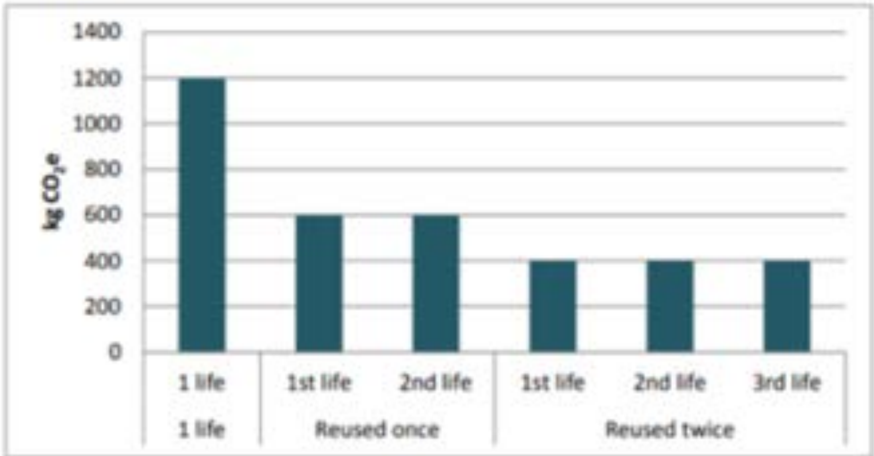


Figure 2.14 Graph showing CO2e emissions produced at each life cycle stage of a building (Tingley, 2012)

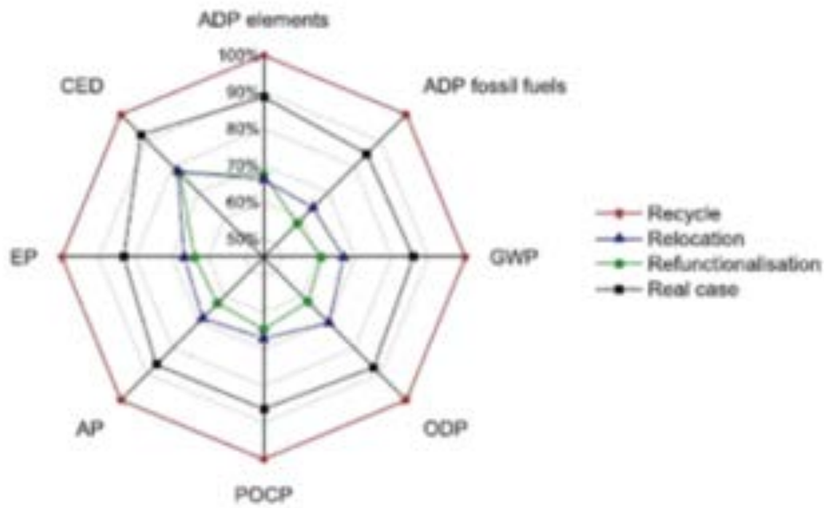


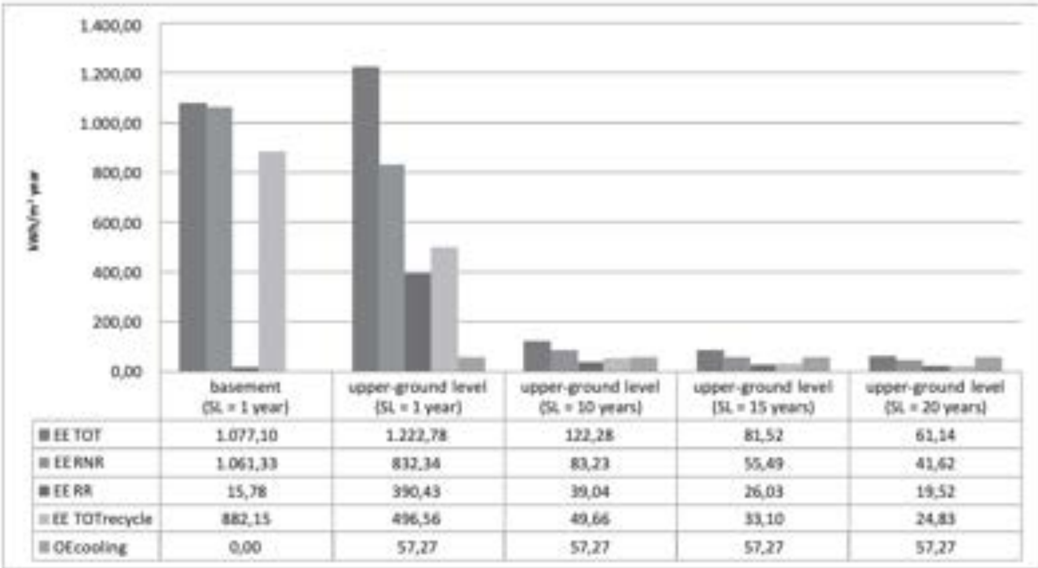
Figure 2.15 Results for the different EOL scenarios investigated for the pavilion (Arrigoni et al, 2018)

The graph is from a case study by A. Arrigoni and his friends (2018) on a temporary pavilion built for an international exhibition. The research is done for different end-of-life (EOL) scenarios including recycling, relocation, functionalization, and the real case of the pavilion.

In the graph, the least amount of impact would be done with functionalization which would require the least energy and resources. Most of the savings of energy were done by avoiding an erection of a subsequent structure in the future but instead using the existing one (Arrigoni et al, 2018). That way minimized amounts of resources would have been used.

Thormark [23] studied two cases: (i) the building which was built with a large proportion of reused materials and components; (ii) the building in which all materials and components had been new. The results showed that about 55% of energy could be saved with reused materials and components (Ramesh, Prakash, Shukla, 2010). Arslan and Cosgun (2008) divides "Reuse" plan of temporary housing and sites as; reuse and recycle with the same function by no additional part, reuse and recycle with the same function by additional part and reuse and recycle with different functions.

Permanent housing is not available for all sectors of society; renters cannot afford the increase in market rents after the disaster and do not qualify for the permanent housing subsidies usually aimed at homeowners—and therefore try to remain in temporary housing. New migrants come to the area and take up residence in the temporary housing because of the relative affordability of this housing (it is sometimes free). The availability of temporary housing allows the modernisation of family life— young families or elderly people reside in the temporary housing, giving them the opportunity to live apart from the rest of the family (Johnson, 2007).



	basement (SL = 1 year)	upper-ground level (SL = 1 year)	upper-ground level (SL = 10 years)	upper-ground level (SL = 15 years)	upper-ground level (SL = 20 years)
EE TOT	1.077,10	1.222,78	122,28	81,52	61,14
EE RNR	1.061,33	832,34	83,23	55,49	41,62
EE RR	15,78	390,43	39,04	26,03	19,52
EE TOTrecycle	882,15	496,56	49,66	33,10	24,83
OEcooling	0,00	57,27	57,27	57,27	57,27

Figure 2.16 Embodied Energy and Operational Energy of the case study building over installation and four service life scenarios and the related annual energy intensity (kWh/m2 -year).

Although the embodied energy of building components remains significantly high per unit of surface area in relation to the timelimited predicted use of the building (1 year), it can be drastically reduced depending on the extended number of years of their expected service life outside the boundary conditions of this project. (Grosso, Thiebat, 2015)

2.6.2 Relocation

Relocating temporary buildings to new sites is a convenient solution when the site's infrastructure is found to be inadequate, the rented site is not owned by the government or when the used site was planned and readied only for the use of temporary housings (Arslan, Cosgun, 2008). A case study of an exhibition temporary pavilion, EXPO Milano 2015 Brazilian Pavilion designed by Studio Arthur Casas and Atelier Marko Brajovic, shows that when the site is no longer available and new buyers aren't found, relocation can be the next best choice (Arrigoni et al, 2018). In the case study, the relocation of 2000 Expo Christ Pavilion to a protestant monastery of Volkenroda is mentioned with the refunctionalization of the structures built for 2012 Olympic games in London, converted into a residential district. However in the case of EXPO Milano 2015 Brazilian Pavilion, refunctionalization was not possible as the expo site had to be left empty. In the end, the pavilion was partially relocated. And even with partial relocation, the effects of emissions from the transportation to a distant site was seen. The impact of transportation is also stated as a big contributor to the embodied carbon of buildings by Akbarnezhad and Xiao (2017). And in transportation and relocation, quantity and size of the materials as well as the transportation distance are crucial to be considered in terms of emissions.

Figure 2.17 UMCOR

This was doable because the UMCOR project was designed to be dismantled and to be reused easily. However the additional costs of reuse was also apparent due to transportation, dismantling and reassembling processes. In Düzce, moving 8 units (200 m2) to be used as a sports center had a cost of $8000 including the required labor, installation of electricity and water and new elements like a new roof. Johnson therefore states that for reuse and relocation to be feasible, the costs have to be considered and a market willing to pay has to be found.

2.6.3 Recycling

Recycling of material is the act of rendering a material of a building re-usable and that can be remade after the building is disassembled (Arslan, 2007). The recycled material of a building is defined as a material which can be remade and re-used as a building material after the building is disassembled. It is called "recycled" when the building product is partly or totally manufactured from the disassembled materials.

Table 4. Definition of recycling methods

Number	Recycled method	Definition	Example
1	Product recycle	Method of reusing without processing	Reuse a glass bottle after washing
2	Material recycle	Method of recycling materials after processing	Recycling a glass bottle as glass
3	Feedstock recycle	Method of recycling feedstock after processing	Recycling a glass bottle for aggregate of concrete

Figure 2.18 Definition of recycling methods (Arslan, 2005)

In a table, Arslan (2005) separated recycling methods into 3; product recycle, material recycle and feedstock recycle. Product recycle is defined as " reusing without processing", material recycle is defined as "recycling materials after processing" and feedstock recycle is defined as "recycling feedstock after processing".

Using recycled materials has a positive impact on the environment through reducing emissions. According to a study, while recycled steel structures for the use of fewer than 2 years have an important role in decreasing the amount of released greenhouse gasses, for durations more than 5 years, thermal performance is seen to be the most effective factor (T. Seike, T. Isobe, Hosaka, 2019).

Increasing the potential for the construction waste and elements to be recycled and reused also means prolonging the life of landfill sites since waste going there will also be decreased. CO2 emissions contributed by the construction through its life cycle will also be lessened with recycling due to reducing transportation requirements as well. (Purchase et al. 2022). For effective recycling, the structure must go through as little traditional demolition as possible and chemicals like adhesives must be avoided to enable the salvaging of the parts easier without chemical reactions and harmful conditions. (Arrigoni et al, 2018). Also recycling is more viable when a market for recycled materials is available since a prejudice against recycled materials exists among the construction sector and clients. This can be seen in research done by B. Paker and N. Taş indicating the percentage of designers in Turkey willing to use recycled materials, with the high majority with %75 not preferring second-hand or recycled materials and %21,7 being indecisive. The reason for this negative perception for using recycled materials as Grotowski (2006, p.490) states is "often exacerbated by prejudice and lack of clear information and clear guidance". The reusing of materials, especially structural ones may be seen as "not safe" (Tingley, 2012, p.25). But while some materials may be unsafe to reuse or recycle, especially ones with chemical coatings and adhesives, some materials like old timber have better stiffness than newer ones (Tingley, 2012).

Carbon emissions that will be produced with the recycling process also have to be considered while choosing a scenario. However Akbarnezhad and Xiao (2017) mention that the emissions caused by the recycling process can be reduced and that the level of carbon emissions depend on the recycling process itself and the materials.

2.6.4 Deconstruction & Dismantling

While using green materials is important sustainability, designing a structure with good management of all its life cycle stages is seen as more effective in terms of overall impact ratios and this is now starting to be recognized by certification programs as well (Arrigoni et al, 2018).

Material and element reuse are seen as one of the most effective end-of-life strategies (Akbarnezhad, Xiao, 2017) in terms of managing C&D and and a full life cycle management. Akbarnezhad and Xiao (2017) states that this strategy helps reduce embodied carbon and energy of a structure, has the potential to reduce costs of future constructions and helps preserve resources and materials. Demolition process is seen as the process that's the most effective on the reuse and recycling of temporary structures (Arslan, Cosgun, 2008). If a careful design is done, most of the used elements in a building can be reused for other new applications after the end of service life of that building (Akbarnezhad, Xiao, 2017) . This dismantling of buildings to maximize potential to recycle and reuse of elements and materials, equals “deconstruction” (Cosgun, Arslan, 2011). This process requires for the buildings to be dismantled with the use of minimized energy and the least amount of material loss as it can be (Arslan, Cosgun, 2008). Also with deconstruction and making building components easier and faster to remove, it is easier to adapt or change the building to meet evolving functions over its lifetime (EPA). Deconstruction can also be called “construction in reverse”, disassembly of buildings to recover its elements and materials to reuse elsewhere (Cosgun, Arslan, 2011).

The circular economy approach through DfD, and preventing over-use of materials is crucial. This can be seen with the US Geological Survey where states that 60% of materials flow in the US economy were by the construction industry. Construction sector also uses a great amount of timber which impacts forests, copper and steel which share a big responsibility for mining and refining impacts, and also use of polyvinyl chloride (PVC) causing pollution and negative impact on health (EPA).

Deconstruction can either replace traditional demolition as a whole or a partial deconstruction can be used prior to traditional demolition (Cosgun, Arslan, 2011). Authors also explain that there are two main types of deconstruction; (i) non-structural deconstruction such as soft stripping of walls, removal of non-load bearing elements, fixtures and such, and also (ii) structural deconstruction referring to the dismantling of the building frame, roof system and its load bearing walls.To minimize the use of energy needed and loss of infrastructural materials and elements during deconstruction process and to increase the potential of reuse and recycling of the site and its infrastructures, designs should be done in a way that minimum intervention would be required to the land after use (Arslan, 2007).

Implementing reuse of materials and elements through deconstruction, also calls for the need for additional operations and changes in component designs. Some elements may require additional connection details such as steel connections to enable disassembly and also reuse of materials will require transportation between facilities and storage of elements which would add to the carbon emissions (Akbarnezhad, Xiao, 2017).

2.6.5 Design for Deconstruction

Reusing C&D waste with design for deconstruction (DfD) helps close the loop of resource use and life cycle through decreasing the need to mine for new virgin resources. This way DfD enables a circular economy model for the resources to be economically reused and recovered contrasting with the linear model of extraction, use and landfilling (EPA). DfD practice also next to this, helps with the prevention of waste generation and demand for new material through allowing easier modifications, maintenance, construction and disassembly (Olson, 2010).

In the Figure 2.19, Durmisevic (2018) exemplifies connection details that are designed for disassembly and detailing the order of disassembly of each element. Some of the connection details may be more dependent on each other which would require a strict order of disassembly while others may be more independent from each other.

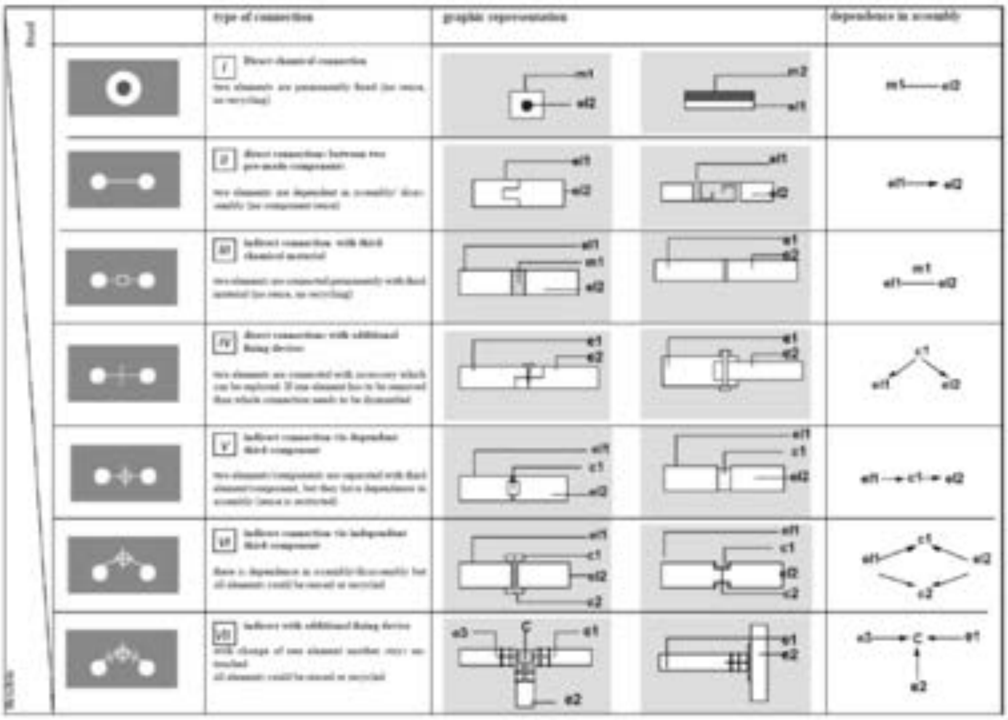


Figure 2.19 Connection Types (Durmisevic, 2018)

The Lego Architecture in this research is a design approach to DfD, and refers to a kind of design inspired by the logic of Lego bricks, which usually has a significant modular feature in the shape of components. At the same time, Lego Architecture also has the characteristics of portability and speed in construction, and presents the language of discrete design in the way of forming buildings. Based on these characteristics, Lego's architectural design methods are often used in temporary construction areas with small total investment and short construction period, such as temporary resettlement houses after disasters, simple workshops or plant greenhouses in rural areas (Chen, Wang, Chen, 2021).

In the example shown in Figure 2.20 below, the roof is removed to ground level for a more effective deconstruction, then separated into planes and sheathing. Snowplowing was used to remove shingles and sheathing was removed from joints with pry bars. Studs were removed from the sheathing with drive-by method, lumbers were de-nailed, and were readied for a new construction. Reclaimed wood was reused for the ceiling of Cal State University Visitors Center. (EPA)

Figure 2.20 Deconstruction of a building (EPA)

To achieve this it is necessary to have the basic an infrastructure of contractors skilled in deconstructing buildings, the cost of deconstruction and the recovered materials must be competitive with alternatives, and there must be a market for the recovered materials.(EPA)

Using fewer materials also simplifies deconstruction.DfD suggests that designers consider if possibly the same architectural effect or performance can be achieved by using fewer material types, or the same material in different ways (EPA).

Elias-Ozkan (2014) explains in their research that even though deconstruction is perceived to be more costly than demolition, with the return of the materials and the required time for both processes, deconstruction’s end result is more beneficial.

CHAPTER 3

MATERIALS AND METHOD

The strategy used in this study comprised three main stages. In the first stage, the importance of designing a project with design for deconstruction principles was proven using selected case studies and mathematical analysis of their deconstruction processes.

In the second stage, a systematic review has been conducted to identify and synthesize research evidence in order to make a generic source of information. Thisstage comprised of a comprehensive literature review and data collecting from research papers to create lists later to be used as a guide to create the resulting workflow example. This strategy ensures that all relevant, research-based evidence has been collected. For the systematic review of literature, relevant literature was fetched from the largest scientific database, known as Science Direct. To maintain relevance, the keywords included “construction and demolition”, “waste”, “construction”, “circular economy”, “framework”, “climate change”, “carbon emissions” and “design for deconstruction”.

The final stage of the study used the data collected, to create workflow proposals and exemplify the design stage process of a temporary structure.

3.1 Defining the Importance of Design for Deconstruction

Salvage rate is seen as important for any end-of-life scenario possible for a structure to separate toxic materials and keep the materials and elements in a high quality state to make them reusable as much as possible.

In order to showcase the importance of designing a structure with design-for-deconstruction principles for an efficient salvage rate, 27 case studies were researched on and their deconstruction success rates were collected. The case studies were grouped into 2 categories as (i)projects designed with DfD principles, and (ii) projects designed without DfD principles. This grouping was done in order to see the result difference that can occur for a deconstruction project, in the presence of DfD versus to lack of DfD in projects. For projects designed with DfD principles, a total of 11 cases were studied on and for projects that were designed without DfD principles, 16 cases were selected to be studied on.

The case study selection was done according to their relevance as in if deconstruction was the purpose of the project. Projects that were traditionally demolished and got its waste seperated afterwards to be recycled were not included in the data research. The selected case studies also had to have certain data given about them by the original researchers regarding their salvage rates, reuse rates and/or recycle rates. Projects that did not have both reuse rate and salvage rate at the same time, were also excluded from the data collection as they were not valuable to the purpose of the study. Some selected studies included direct rates in percentages, while some had information regarding the salvaged materials' volumes, weights or not all percentages were given but enough information was given to be used to calculate all necessary rates to be included in the data research. After the data for all 27 case studies were collected, they were turned into 2 seperate charts as they were grouped initially; (i)projects designed with DfD principles, and (ii) projects designed without DfD principles. The data on each chart were used later on to calculate each group's average reuse and salvage rates. After this, a new chart was made to showcase each group’s average reuse and salvage rates on one table, and calculate the differences between each rate in order to see the difference DfD can make in the result of a deconstruction.

3.1.1 Case Studies

27 case studies were selected in 2 groups as (i)projects designed with DfD principles, and (ii) projects designed without DfD principles. Each case study had to include necessary data either directly giving salvage and reuse rates or required information to enable the necessary calculations.

The selected case studies for (i)projects designed with DfD principles;

1) 93 year-old Kominka Reuse
2) Everett Grand
3) Discovery Center
4) People’s Pavillion
5) Expo Milano 2015 Brazillian Pavillion
6) Villa Anneberg 1st Life
7) Villa Anneberg 2nd Life
8) Ski Slope
9) Office Building
10) Modular Show House
11) PassivHaus

From the selected case studies, Villa Anneberg had deconstruction scenarios for 2 different life stages of the structure. 1st scenario was based on the original structure meanwhile 2nd scenario was based on the new structure that would be built after the 1st original structure’s end-of-life and deconstruction, using the salvaged material. So even though 6 and 7 are named after the same structure, in the end they are different structures with different designs and potentials.

Ski Slope, Office Building, Modular Show House and Passiv Haus did not include information regarding their reuse rates seperate from their salvage rates however because the salvage rates alone were also seen as valuable to the study, they were included in the data collection.

The selected case studies for (i)projects designed with DfD principles;

1) Whole House
2) Milford Fire Station
3) Riverdale Village Apartments
4) Marion County Senator Block
5) Stowe Village
6) Bagley Down Apartments
7) Erickson's Diversified Corporate Headquarters
8) Four Times Square
9) Ridgehaven Green Office Building
10) Whole Food Market Corporate Headquarters Building
11) Seeley & Kellogg Houses
12) The Lisbon Expo 98 Macao Pavillion
13) Ft. McClellan Military Barracks Scenario 1
14) Ft. McClellan Military Barracks Scenario 2
15) Ft. McClellan Military Barracks Scenario 3
16) Traditional House BRE

Some studies regarding the selected researches included success rates for reuse, recycle and salvage, while some studies were solely focused on salvage rates. Studies that only gave information regarding salvage rates were not included in the calculation of reuse and recycle success rates but were included in the overall salvage rate average calculation. Ft McClellan Military Barracks was included as 3 seperate scenario calculations due to all 3 scenario focusing on different deconstruction rates and methods and their projected rates and calculations were used in the collected data charts. The same project also included a 4th scenario done by the original researchers, however it was a scenario of traditional demolition and deconstruction was not involved thus that scenario was excluded from the data charts.

3.1.2 Calculations of Reuse, Recycle and Salvage rates

From the collected date of each case study, firstly their missing required rates were calculated using given information by past researchers. The required calculations to have all necessary data goes as follows;

- Everett Grand's reusability rate was not given but the used materials' and the reusable materials' volumes were given, and the reuse rate calculation was done by ratioing the volume of reusable materials to total used materials for the structure
- Milford Fire Station's recycle and reuse rates were not given. Total waste, disposed and diverted materials were given in tons. Recycled materials' costs and their tons were also given. Using these, reused materials were first calculated in tons, then salvaged materials, reuse rate and recycle rates were all calculated using given numbers.
- Riverdale Village Apartments consisted of 2 seperate buildings, but their data were given as 1 project. Diverted subtotal, landfill subtotal were given in tons but the diverted materials were also given in percentage. Reusable and donatable materials were listed in tons, so their total was calculated and then turned into percentage according to the total waste material. Recyclable materials were also listed in tons, and their rate was also calculated using the subtotal of waste material.
- Marion County Senator Block's total waste, disposed materials and diverted materials were given in tons while the latter was also given in percentage. The recycled and reused materials were also given with their weights seperately and their rates were calculated using given information.

- Stowe Village's total waste and disposed materials were given in tons, while diverted materials were given in tons and in percentage. Recycled and reused materials were given in tons individually as well, and their rates were calculated.
- Bagley Down Apartments' total waste, disposed and diverted rates were given in tons. From here, recycled and reused materials percentages were calculated.
- Erickson's Diversified Corporate Headquarters' recycled and reused material rates were calculated, using the given total waste, disposed, diverted, recycled and reused material weights.
- Four Times Square project's total waste, disposed, diverted, recycled and reused material information were only given in tons so they were also turned into rates using given data.
- Ridgehaven Green Office Building's total waste, disposed, recycled and reused information were only given in tons, and from here, necessary rate calculations were done using given info.
- Ft. Mcclellan Military Barracks scenario numbers were given only in Ibs as total material, reusable salvage, recyclable, hazardous material and landfill. From here the reusable, recyclable and total salvage materials were calculated for each 3 scenario chosen.

After calculating and gathering all necessary data regarding the chosen case studies, they were turned into tables and each tables average rates were calculated later to be used for comparison between projects designed with DfD principles and projects designed without DfD principles.

The following nomenclature and equations were used to calculate the reuse, recycle and ralvage rates of the case studies:

Nomenclature used is given below:

Projects designed with DfD in mind = PD_w

Projects designed without DfD in mind = PD_o

PD_w examples; W1, W2, W3

PD_o examples; O1, O2, O3

Not given = NG

W1; reuse success = X_1, recycle success = Y_1, salvage success = Z_1

W2; reuse success = X_2, recycle success = Y_2, salvage success = Z_2

W3; reuse success = NG , recycle success = NG, salvage success = Z_3

O1; reuse success = A_1, recycle success = B_1, salvage success = C_1

O2; reuse success = A_2, recycle success = B_2, salvage success = C_2

O3; reuse success = NG , recycle success = B_3, salvage success = C_3

Equations used to calculate the 3 indicators were as follows:

For projects designed with DfD in mind:

PD_w successful reuse average = $(X_1 + X_2) / 2 = U_w$ ....(Eq.1)

PD_w successful recycle average = $(Y_1 + Y_2) / 2 = R_w$ ....(Eq.2)

PD_w successful salvage average = $(Z_1 + Z_2 + Z_3) / 3 = S_w$ ....(Eq.3)

For projects designed without DfD in mind

PD_o successful reuse average = $(A_1 + A_2) / 2 = U_o$ ....(Eq.4)

PD_o successful recycle average = $(B_1 + B_2 + B_3) / 3 = R_o$ ....(Eq.5)

PD_o successful salvage average = $(C_1 + C_2 +C_3) / 3 = S_o$ ....(Eq.6)

After the initial calculations done to see the average reuse and salvage potential rates of 2 groups of case studies created, these calculations were put in a table to make a comparison between 2 groups and then to calculate their rate differences to see how much the larger value, differs from the lower value, and then to compare these 2 calculated values for both reuse average differences and salvage average differences, to see where DfD principles affect the most in the deconstruction results of a project.

In order to see the differences between Uw and Uo , and also the differences between Sw and So and see how much higher the larger value is in percentages, the nomenclature and necessary equations would be;

U_d = Reuse rate difference
S_d = Salvage rate difference

If $U_w > U_o$ then $U_d = (U_w \times 100) / U_o$
If $S_w > S_o$ then $S_d = (S_w \times 100) / S_o$

Using this calculation method, the data were turned into a table and the result was used to compare and contrast the impacts of DfD's existence and absence on deconstruction projects and to highlight the potential it creates.

3.2 Creating Data For The Proposed Workflow

This section of the study consist of 2 steps; (i)Guide the designer into choosing the best end-goal, and (ii)How to reach that goal. First step is to guide the designers towards the best outcome or the better alternate results one can have with DfD. This is done through collecting data for possible end-of-life scenarios and ranking them using Deft Ladder and given recommendations by past researchers. 2 charts were created and data of the two were cross-checked. With this, it was aimed that designers don't miss a possibility for the structure's end-of-life scenario while planning.

In the 2nd part of this section, we tackle takle the question of "how" by creating a workflow proposal that aims to be a non-strict step by step guide that aims to make sure a matter that is directly or indirectly connected to the structure's deconstruction process at the end of its life, is not forgotten and the result fits the initially planned scenario without meeting any unplanned obstacle. As the workflow proposal is to be created using recommended matters to be considered during the design stage, these matters were collected through literature review and case study reviews.

Through this study for this step of the guide, each matter mentioned to have the potential to affect the deconstruction process by past researchers were collected, and were grouped into 4 different charts named as the matters were given in those researches and case studies; (i)deconstruction principles and recommendations, (ii)factors that affect deconstruction, (iii)material recommendations for DfD, and (iv)case study conclusions – negative and postive factors.

First three charts were created with data collected through literature review of 17 research papers regarding deconstruction and DfD. Fourth chart; case study conclusions – negative and positive factors, was created through 27 case studies of projects that have went through deconstruction process or were planned to be deconstructed. Each chart was named with a letter and each column, matter reflected on the chart was numbered. This was done to be able to refer to the matter easier. Through cross-reference checking the created four charts, a collective chart was created referencing each previously created chart using the aforementioned labeling system. This cross-referencing to create the finalized "Design for Deconstruction Recommendations" chart, to make sure each given recommendation or caution is backed up by at least 2 different studies and/or researchers to validate the matter's frequency in deconstruction projects and its relevance. The given recommendations were seen to be necessary to be grouped into "pre-design stage" and "design-stage" matters to consider to allow the created workflow to focus on design stage while defining the information and issues that has to be solved to not cause issue with the design later on. The collected data were seperated into 3 headlines; (i)legal and governmental issues, (ii)location attributes, and (iii)structure information. Other recommendations outside of the "pre-design-stage", were used as references to the steps included in the workflow chart, while the "pre-design-stage" chart was used as a core of the design stage, to connect the matters to the design stage, to further show the designers where those pre-design matters can cause issues or slow down the design process if not tackled beforehand and correctly.

The created charts serve these purposes;

- Defining less considered factors in a design and construction stage that can affect a deconstruction stage of a structure
- Defining the DfD principles and recommendations to further guide designers
- Connecting material choices with deconstruction potential of a design
- Ranking the end-of-life scenarios in terms of feasibility under DfD principles
- “Material recommendations” is a chart that can also be a chart designers can refer to during design stage
- Defining the possible outcomes of DfD
- Defining the stages and matters to be considered during pre-design and design stage

3.3 Creating A Workflow Proposal

Two workflows were created using the informational and mathematical data and results created using deductive reasoning. First workflow created is defined to be a general workflow that can apply to any structure’s design phase and it is to emphasize the importance of each steps to be taken and considered.

Second workflow was created to showcase what different steps may be added to a structure’s design depending on the scenario of it. The scenario is defined as totality of multiple decisions made for the structure as; (i)function, (ii)structural material, (iii)foundation type, (iv)chosen end-of-life scenario, and (v)any additional design choices to ease or complicate the design, construction and/or deconstruction process.

The chosen scenario for the 2nd workflow are as follows;

- Function: School complex
- Foundation: Precast-concrete
- Structural material: dry-stacked concrete blocks
- Chosen end-of-life scenario: Some buildings will go through full disassembly, rest will be turned into permanent buildings

After the scenario is defined, importance of connection details for a full disassembly was deducted using literature review and a connection detail research was done for the chosen materials and scenario. The connection detail study was done first by sketching and then turning the sketches into 3D sketch models using Rhinoceros software. The created connection details were then made into a chart using Microsoft Excel, to showcase the possibilities a designer can come accross to enable them to make the most feasible decision.

At the last stage, the required additional steps were added to the generalized workflow to create an alternate one, showcasing the possible additional steps to be added to a design, construction and deconstruction of a structure changing depending on the scenario of the structure.

CHAPTER 4

RESULTS AND DISCUSSION

Through case study researches on deconstruction projects or deconstruction simulations performed on projects that were designed to be deconstructed and also projects that were not designed to be deconstructed, the impact of DfD on material salvage rate thus waste management potential was emphasized through calculations given by past researchers.

With this, a guide to designing for deconstruction to make the process smoother for designers to reach the DfD goals of the project was found necessary. This was done with collecting informational data from literature review and other case studies concerning the subject detailing and exemplifying design phases, impacts, DfD stages, deconstruction processes, result affecting factors, recommendations, sustainability, impacts, details and solutions. The guide was turned into a workflow proposal with varying alternatives according to potential scenarios.

Incorporating LCA and revision checks frequently in the workflow was found necessary to keep budget and the possible impact of the structure in check, while meeting the initial design for deconstruction goals.

The requirements of a project and the various resources that can be used for that project should be determined and the benefits should be compared to make the design feasible in terms of cost, impact, amount and type of waste generation, end of life scenario, LCA, and user comfort. These information should be gathered during pre-design stage to ease the design stage and prevent future issues in the result to scenario compability. The pre-design stage proposal including collecting data on resources, facilities, legalities, permits, market potentials material sources was also created before the workflow.

4.1 Defining the Impact of DfD On Deconstruction Process

In order to define the impact of designing for deconstruction on the deconstruction results and potential salvage and waste management rates, a total of 24 deconstruction project case studies were selected to collect data from. Some of the selected case studies were deconstruction projects that have been performed, while some are based on calculations and simulations done on built projects, creating data on its reuse, recycle and salvage potentials. One of the selected case study had 4 deconstruction simulation scenarios with 4 different results, due to one of the scenario not including deconstruction but was focused on traditional demolition, that scenario's results were not used in the data charts and results created which are focused on deconstruction projects. One other project selected had 2 scenarios, first one depicting the re-usable timber after the 1st life ends, and 2nd scenario is for the 2nd design that was built using the 1st structure's salvaged timber, again depicting its salvage rate however while the 1st building is built, 2nd design has not been built as the 1st structure's life has not come to an end yet.

2 charts were created using the collected data giving the projects' reuse, recycle and salvage rates; (i)projects designs with DfD principles, and (ii)projects that were not designed with DfD principles. The "projects designed with DfD principles" chart consists of 10 case studies, with one of them repeating in name because of its 2nd life scenario created with the 1st structure's salvaged materials.

Table 4.1 Projects designed with DfD in mind

Projects designed with Dfd in mind	Reuse	Recycle	Salvage
93 year-old Kominka Reuse	78.00%	22.00%	100.00%
Everett Grand	94.50%	NG	NG
Discovery Centre	99.83%	0.11%	99.94%
People's Pavillion	100.00%	0.00%	100.00%
Expo Milano 2015 Brazillian Pavillion	22.00%	78.00%	100.00%
Villa Anneberg 1st Life	82.70%	17.30%	100.00%
Villa Anneberg 2nd Life	86.40%	13.60%	100.00%
Ski Slope	NG	NG	58.00%
Office Building	NG	NG	64.00%
Modular Show House	NG	NG	60.00%
PassivHaus	NG	NG	58.00%
Average	80.49%		83.99%

People's Pavillion was built to be completely deconstructable without harming any of its materials with "borrowed" materials and elements. After the use of the pavillion, it was deconstructed to return the elements and materials to where they were borrowed form except for its facade, that was created from recycled plastic, was dismantled to be distributed amongst the citizens as keepsake. This project is shown to be a prime example of full potential that can be created through DfD, as structures can be built to be fully dismantled, leaving no waste behind and without using excessive resources. While this project alone could be used as a reason to emphasize the importance of DfD, we continue with other case studies for a more extensive research.

Ski Slope, Office Building, Modular Show House and PassivHaus case studies are for built projects but their salvage potential data were calculated by BRE Trust using a methodology with assessment scores of connections, accessibilities, materials, reuse and recycling potential, optimisation of deconstruction and fixtures. From these case studies, the "reuse and recycling potential" data were used to describe their salvage potential, however the reuse and recycling rates were not seperated due to lack of information by the researchers and was instead given as "salvage rate" only on the chart.

Expo Milano 2015 Brazillian Pavillion is a project that was built to be dismantled and this goal gives us a 100% salvage rate after its deconstruction. However, while some parts of the pavillions were planned to be relocated and/or reused which would give a much higher reuse rate than the resulting 22%, due to lack of planning, lack of buyer researches before dismantling and time constraints, the dismantled parts had to be sent to be recycled instead of meeting their initial goals of reuse.

Everett Grand and Villa Anneberg were rated on their timber structural material salvage/reuse potentials as timber structures. Everett Grand's soleplates, slab and tiles were assessed to be non-reusable by the researchers while its roof trusses, gables, exterior walls, floors and roof structure were assessed to be fully re-usable meaning 16.56 cubic metres out of 17.52 cubic metres of wood could be re-used.

Reusable timber rate calculation for Everett Grand;

17.52 cubic metres = total wood used

16.56 cubic metres = wood with reuse potential after salvaged

(16.56 x 100) / 17.52 = 94.50, 94.50% of the wood used for Everett Grand was calculated to be re-usable after deconstruction.

Villa Anneberg's roof boardings, roof battens and baseplates were assessed to be recyclable, while its roof trusses, gables, exterior walls and 75-80% of its intermediate floor were assesed to be reusable. With this assessment, 11.580 kg of the used 14.000 kg wood on the structure, was calculated to be reusable. Meanwhile for its 2nd life, 14.200 kg wood was planned to be used for its construction and 12.272 kg of it was seen potentially re-usable after a future deconstruction process.

Reusable timber rate calculation for Villa Anneberg's 1st life;

14.000 kg = total wood used

11.580 kg = wood with reuse potential after salvaged

(11.580 x 100) / 14.000 = 82.7% of the used wood was calculated to be re-usable for the structure's 1st planned end-of-life.

14.000 – 11.580 = 2420 kg potential waste.

Reusable timber rate calculation for Villa Anneberg's 2nd life;

14.200 kg = total wood used

12.272 kg = potentially re-usable wood after future deconstruction

(12.272 x 100) / 14.200 = 86.4% of the wood was foreseen to be re-usable for the structure's 2nd planned end-of-life.

14.200 – 12.272 = 1928 potential waste.

Discovery Centre that was built as a demonstration project, was deconstructed to result with a waste diversion rate of 99.94%. Its potential reusable material rate was calculated to be 99.83% with 32.084 kg of material while 0.11% of its materials of 36 kg was calculated to be recyclable which were materials such as metal flashings and EPS. Only 0.06% was given to be wasted after the deconstruction demonstration.

93 year-old Kominka Reuse project is the oldest structure used as a case study for deconstruction. A Japanese Kominka was dismantled for its parts to be re-used for a museum building. As Japanese structures were built for its parts to be dismantled and renewed with traditional joint systems (King County), enabling the structures to endure many years, Kominka was also accepted as a structure to be built with DfD principles.Through this deconstruction process, 100% of its elements were salvaged while 22% was reported to be recyled and 78% was re-used for the new museum building.

To calculate average salvage rate of projects designed with DfD principles (Sw), 10 data was used as 1 of the case studies did not have information regarding its salvage rate.

S_w = (100% + 99.94% + 100% + 100% + 100% + 100% + 58% + 64% + 60% + 58%) / 10 = 83.99%

Meanwhile to calculate the average reuse rate of projects designed with DfD principles (Uw), 7 data were used as 4 of the case studies had not given separate information regarding the reuse and recycle rates.

U_w = (78% + 94.5% + 99.83% + 100% + 22% + 82.7% + 86.4%) / 7 = 80.49%

The chart of "projects designed without DfD principles" consists of 16 case studies and while all 16 of the projects have information for their salvage rates, only 1 of the projects's reuse rate wasn't given.

Table 4.2 Projects designed without DfD in mind

Projects designed without Dfd in mind	**Reuse**	**Recycle**	**Salvage**
Whole House	9.00%	70.00%	79.00%
Milford Fire Station, Milford, Massachusetts	5.88%	77.02%	82.90%
Riverdale Village Apartments	22.80%	53.06%	76.00%
Marion County Senator Block	3.33%	79.11%	82.44%
Stowe Village	10.00%	40.00%	50.00%
Bagley Down Apartments	55.66%	17.49%	72.80%
Erickson's Diversified Corporate Headquarters	10.38%	58.15%	68.50%
Four Times Square, New York	0.47%	58.47%	58.94%
Ridgehaven Green Office Building	28.90%	21.88%	50.80%
Whole Food Market Corporate Headquarters Building	24.38%	16.90%	41.28%
Seeley & Kellogg Houses	3.00%	89.10%	92.10%
The Lisbon Expo 98 Macao Pavilion	10.00%	4.00%	14.00%
Ft. McClellan Military Barracks Scenario 1	41.00%	0.70%	41.70%
Ft. McClellan Military Barracks Scenario 2	40.00%	0.70%	40.70%
Ft. McClellan Military Barracks Scenario 3	33.70%	0.70%	34.40%
Traditional House BRE	NG	NG	49.00%
Average	19.90%		58.41%

Whole House was deconstructed and the salvaged materials were rated according to their reusability and recyclability. The total structure was given to have a waste divertion rate of 79% with 9% of its materials resulting to be reusable after deconstruction. 1% of the salvaged materials was rated 10 that could be reused as it is, 1% was rated at 9 as materials that could be reused with similar functions and qualities meanwhile 7% was rated at 8, meaning the materials can be reused with different functions or at different qualities. The remaining 70% of the salvaged materials was rated at 5 to 7 as recyclable and rest were seen as better to be disposed.

The Milford Fire Station gave a resulting material and salvage of 687 tons. 118 tons of it was disposed meanwhile 569 tons was diverted which is 82.9% of the structure's materials. Asphalt paving, concrete and metal pieces were given with recycling cost which was used to make the assumption that those materials were recycled while wood, cardboard and slate showed no recycling cost and were assumped to be reused and not recycled. Asphalt paving was 329 tons, concrete was 192 tons and metal was given at 7.7 tons which means the recycled materials weighed a total of 528.7 tons equating to 77.02% of the structure's materials. The remaining 5.88% was seen to be potentially reused consisting of 20 tons of wood, 2.4 tons of cardboard and 18 tons of slate.

Riverdale Village Apartments consisted of 2 buildings to have been deconstructed. It was given that 96.5 tons of its ending materials was diverted, resulting with 30.7 tons of landfill. With ending result being calculated to be 127.2 tons, it means the total diverted/salvaged materials' rate would be 75.86%. The apartments' reusable materials were reported to consist of framing lumbers, bricks, hardwood floorings, stair units, windows, doors, toilets, sinks, tubs, shelves and kitchen cabinets weighing a total of 29.1 tons, giving 22.8% rate of materials. Meanwhile the remaining calculated 53.06% of materials were reported to be recyclable consisting of rubbles, metals and asphalt shingles weighing at 67.4 tons.

Marion County Senator Block was reported to have a total ending result of 16.649 tons with 2923 of it being disposed and 13.726 tons of material ending up diverted, meaning 82.44% of total materials was salvaged. From the salvaged materials, 13.006 tons was reported to have been recycled equating to 79.11% of materials, and 720 tons have been reused equating to 3.33% of the resulting materials.

Stowe Village's total resulting material weight was reported to be at 265.6 tons, with 132.8 tons being disposed and 132.8 tons being diverted equating to 50% of the resulting waste. From the diverted materials, 10% of the total materials was recycled, weighing 26.6 tons and remaining 40% was reused equating to 106.2 tons of material.

Bagley Down Apartments had given a total waste of 154.5 ton with 42 tons of it being disposed and 112.5 ton being diverted equating to 72.8% of the waste. 26.5 ton of the waste was reported to have been recycled, which with calculations equates to 17.49% of the total waste and remaining 55.56% was reused weighing 86 tons of material.

Erickson's Diversified Corporate Headquarters had resulted with a total waste of 270.6 ton, 85.3 ton was disposed and 185.4 ton was diverted meaning 68.5% of the resulting waste was salvaged. From the salvaged materials, 157.4 ton was recycled equating to 58.15% of the total waste and remaining 28.1 ton was reused, equating to 10.38% of the total waste.

Four Times Square by researchers was reported to have had a total waste of 27.027 tons, and 11.097 tons of it was disposed while 15.930 tons was salvaged equating to 58.94% of the total waste. Recycled materials weighed 15.805 tons equating to 58.47% of the total waste and only 125 tons was reused, equating to only 0.47% of the total waste.

Ridgehaven Green Office Building was reported to have had 366 tons of resulting waste and 180 tons of it was disposed while 186 tons was diverted equating to 50.8%

of the total waste. From the salvaged materials, 80.1 ton was recycled equating to 21.88% of the total waste and remaining 28.9% was reused.

Whole Foods Market Corporate Headquarters Building had a total waste of 55 tons, 31.8 ton was disposed and remaining 23.3 ton was diverted meaning 41.28% of total waste was salvaged. 9.3 ton of the waste was reported to be recycled equating to 16.9% of the total waste materials and 13.9 ton was reused equating to 24.38% of the total waste.

Seeley & Kellogg Houses were reported with united numbers so their data were also used as 1 project. The total waste weight of the deconstruction project was reported to be at 887.4 tons with 70.3 ton of it being disposed and 92.1% being diverted. Reuse rate was given at 3% and recycle rate was given at 89.1%. The Lisbon Expo 98 Macao Pavillion was reported to have a salvage rate of 14%, with 4% being recycled and 10% ending up being reused.

Ft Mecclellan Military Barracks project consists of scenarios of different types of deconstruction/demolition styles and their projected end results of salvage, reuse and recycle. The total weight is always at 142.748 Ibs, recyclable waste is projected to be 1032 Ibs always and hazardous materials are always weigh 141 Ibs. For the 1st scenario, reusable salvage was projected to be 41% of the waste weighing 59.089 Ibs, and landfill weighing 82.486 Ibs. On the 2nd scenario, reusable salvage was given to weigh 57.291 and was calculated to equate to 40% of the waste. Meanwhile on the 3rd scenario, the reusable salvage rate drops more to 33.7% of the waste weighing 48.134 Ibs annd landfill would be at 93.441 Ibs.

Traditional House BRE's total salvage potential was given to be at 49%. Its reusable materials were given as fibre cement, 30-40% of its timber battens, timber truss, metal connecting plates and 20-30% of timber studs. Meanwhile its recyclable materials were reported to be 60-70% of its timber battens, roof joists, timber truss, metal connecting plates, 70-80% of the timber studs, rest of the timber and plasterboards.

To calculate average salvage rate of projects designed without DfD principles (So), 16 case study data were used.

S_o = 58.41%

Meanwhile to calculate the average reuse rate of projects designed without DfD principles (Uo), 15 data were used as 1 of the case studies had no information regarding its reuse rate.

U_o = 19.9%

After calculating salvage average and reuse average rates of projects designed with DfD principles and projects designed without DfD principles seperately, we see that both for reuse average and salvage average, projects that were designed with DfD principles are much higher than projects that were not designed with DfD principles.

Table 4.3 Salvage and reuse rate ratio differences

	Salvage Rate Average	Ratio	Reuse Rate Average	Ratio
Projects designed with Dfd in mind	83.99%	1.44	80.49%	4.04
Projects designed without Dfd in mind	58.41%	1	19.90%	1

S_w = 83.99%

U_w = 80.49%

S_o = 58.41%

U_o = 19.90%

$U_w > U_o$, $S_w > S_o$

However, while we see the impact of DfD on the results of deconstruction case studies, one can also argue that projects designed without DfD principles can also be deconstructed with high salvage rates, as it is visible even in some case studies included in the data such as Seeley & Kellogg Houses or Milford Fire Station. With this, in order to emphasize the real difference DfD makes, we look at the difference between averages in Table 4.3, and calculate how much the averages of projects designed with DfD principles are higher than the averages of projects designed without DfD in terms of percentage.

$(U_w \times 100) / U_o = 404\%$

$(S_w \times 100) / S_o = 143.7\%$

From this calculation, we see that Uw higher than Uo by 404% and Sw is higher than So by 143.7%. The difference between these rates show us the important result DfD can impact for deconstruction projects, which is the reusability of salvaged materials, distinguishing reuse potential rate from salvage rate since Sw is 1.4 times of So but Uw can quadruple Uo. As more reuse potential means higher quality salvage, and projects with DfD principles are now shown to yield more reusable salvaged materials, it can also mean even recycled materials may turn into higher quality products if they're salvaged from projects that were designed with DfD principles.

4.2 Determining Factors Affecting a Deconstruction Process

In order to guide the designers into what matters should be taken into consideration when designing for deconstruction and choosing the most feasible detailed designs and materials, a list of given factors from past researches has been made. Information from 14 research papers has been compiled to create a list of 21 necessary considerations.

Table 4.4 Factors that affect deconstruction

Factors That Affect Deconstruction						
Suitability of materials for recycling	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)					
Availability of recycling facilities locally	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)					
Reusability of a component	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)					
Design service life of a component	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)	Densley Tingley, D. (2013)	Chini, A. R., and Balachandran, S., (2002)	Guy, B., & Ciarimboli, N. (2008)	Morgan, C., & Stevenson, F. (2005)	Webster, M. D., & Costello, D. T. (2005, November)
Existance of disassemble-able connections	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)	Guy, B., & Ciarimboli, N. (2008)	Webster, M. D., & Costello, D. T. (2005, November)			
Availability of necessary equipments	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)	Chini, A. R., & Bruening, S. (2003)	Addis, B. (2006, February)			
Structural attributes	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)					
Required handling procedures	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)	Akinade, O. O. et. al. (2017)	Guy, B., & Ciarimboli, N. (2008)	Guy, B., Shell, S., & Esherick, H. (2006)		
Geography and location	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)					
Availability of industrial recycling/prefabrication plants or stora	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)					
Condition of components	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)					
Adequate training of workers	Chini, A. R., & Bruening, S. (2003)	Morgan, C., & Stevenson, F. (2005)	Dorsthorst, B., & Kowalczyk, T. (2002, April)			
Necessary time	Chini, A. R., & Bruening, S. (2003)	Morgan, C., & Stevenson, F. (2005)	Guy, B., & Ciarimboli, N. (2008)			
Existence of hazardous materials	Chini, A. R., & Bruening, S. (2003)	Guy et. al, 2006				
Market and consumer opportunities	Chini, A. R., & Bruening, S. (2003)					
Client wishes	Chini, A. R., & Bruening, S. (2003)					
Number of building elements	Chini, A. R., & Balachandran, S. (2002)	Crowther, P. (2005)	Webster, M. D., & Costello, D. T. (2005, November)			
Design flexibility	Morgan, C., & Stevenson, F. (2005)	Crowther, P. (2005)	Guy, B., Shell, S., & Esherick, H. (2006)			
Simplicity/standardization of the building	Webster, M. D., & Costello, D. T. (2005, November)	Chini, A. R., & Balachandran, S. (2002)	Crowther, P. (2005)	Webster, M. D., & Costello, D. T. (2005, November)	Chini, A. R., and Balachandran, S., (2002)	Guy, B., & Ciarimboli, N. (2008)
Simplicity of elements	Webster, M. D., & Costello, D. T. (2005, November)	Crowther, 2005				
Prejudice against salvaged and recycled materials	Chini, A. R., & Bruening, S. (2003)					

The listed issues are: suitability of materials for recycling, availability of recycling facilities locally, reusability of a component, design service life of a component, existence of disassemble-able connections, availability of necessary equipments, structural attributes, required handling procedures, geography and location, availability of industrial recycling/prefabrication plants or storage yards, condition of components, adequate training of workers, necessary time, existence of hazardous materials, market and consumer opportunities, client wishes, number of building elements, design flexibility, simplicity/standardization of the building, simplicity of elements and prejudice against salvaged and recycled materials.

In order to see the potential reasons of some projects that were designed with DfD principals, not giving the aimed salvage rates, 8 case studies were selected and the factors affecting the results were pinpointed.

Table 4.5 Factors that affect the overall efficiency positively and negatively

Name	Country	Salvage Rate	Recycle Rate	Reuse Rate	Factors that affected the overall efficiency positively	Factors that affected the overall efficiency negatively	Reference
Whole House Reuse	New Zealand	~78%	~70%	8%	No conventional demolition	Not enough support for deconstruction from existing economic system	Zaman, A., Arnott, J., McIntyre, K., & Hannon, J. (2018)
					Materials for reuse were appropriately stored	Lack of	
					Piece by piece dismantling		
Family House	Netherlands	91%		91%	Check was done on the degree of treatment needed for salvaged components to be reused	Workers did not work neatly	Erkelens, P. A. (2003)
						No supervision	
						Many components were fixed and not demountable	
Seeley House		88%				It was built in 1988	Boyd, S., Stevenson, C., & Augenbroe, J. J. (2012)
Ft. McClellan Military Barracks	U.S.	~42% (100% manual case)	~41.4%	~0.72%	Four scenarios were tried for efficiency analysis	100% manual deconstruction requires more time and work force	[illegible] Guy, B., & Lindner, A. S. (2006)
					Metal parts were removed by hand before deconstruction		
					Salvaged wood was transported to close areas so expenses do not exceed that of virgin materials		
Wood Framed House	U.S.	~13.21				Deteriorating condition due to water intrusion	Diyamandoglu, V., & Fortuna, L. M. (2015)
Expo Milano 2015 Brazilian Pavilion	Italy	100%	78%	22%	Sustainability was important during design	Refunctionalization was not an option because plot was supposed to be left as it was found	Arrigoni, A., Zucchinelli, M., Collatina, D., & Dotelli, G. (2018)
					The use of disassemblable prefabricated modules was favoured	1% of materials were sourced from further than 1000km, contributing highly on impact of structure	
					Flooring was dry assembled in order to facilitate disassembly	Due to the needed speed of construction, faster solutions were chosen	
					Dry connections were used to allow recovery	Even though 84% of the structure was planned to be reused, due to lack of time, only 22% was reused and rest was recycled	
					Building materials were sourced from a 350 km radius, reducing impact of transport to site	No buyers were found so relocation of the whole structure was not possible	
					Renewable energy was used		
					Adhesives were not used		
					Recyclable, certified materials were used		

The salvage rate of each project was calculated and found factors were listed in a chart. Using this it was concluded that while designing for deconstruction increases the potential salvage rate, some factors that are usually overseen such as economic system, government support, material market, worker education, possible damages during use and lack of time planning were identified.

In order to further the analysis of factors affecting a deconstruction process, a chart was made to pinpoint the certain issues that arose and some factors that affected the project's process and outcome positively. For this, a total of 5 projects were selected. All selected projects were made sure to be designed with DfD considerations.

The considered issues in the selection process were as follows;

- All projects must be designed with DfD principles partially or fully
- Different structural materials must be used
- Projects must have different functions and/or reasons to be built
- Design for deconstruction consideration must be kept in mind for different scenarios; easier material replacement, second-life planning, reusing of the structure or its elements, temporary and/or emergency functions

The selected projects are; (i)The Future Arena, Brazil, (ii)Chartwell School, U.S., (iii)Circle House, Denmark, (iv)Ski Slope, UK, (v) Hualin Temporary Elementary School, China.

In order to collect the problems and advantages of each project, research papers were found for literature review and reported issues were listed.

Table 4.6 Negative and positive factors of case studies

Name	Country	Positive Factors	Negative Factors
The Future Arena	Brazil	Second life was planned	Project was cancelled due to governmental issues
		Ramps, rainscreen cladding, structural steel were to form shells of four schools	
		arena was designed simultaneously with schools	
Chartwell School	U.S.	Services as visible, easy to access and maintain	Due to seismic zone codes, some elements were needed to be nailed.
		Alternate window assemblies were proposed to allow for the removal of windows without disturbing the cladding	Nailed connections will be a hinderance due to required labor and possible damage
		Simple Floor Plan	Proposed double-bend clips for exterior sidings were not used due to required fire rating
		Concrete pavers were used for reusability	
		Wood was reclaimed from wine aging tanks for exterior siding	
		Structural elements were labeled with grades and properties	
		Set of durable drawings were provided to provide efficient disassembly in the future	
		Bigger structural wood frame for easier deconstruction	
Circle House	Denmark	Same 6 concrete elements were used in the designs	
		90% of materials can be reused without losing value	
		Cradle to cradle approach was adopted	
		No adhesives	
		Mechanical joints are used	
		Recycled materials are used	
		Users can change components as they wish due to easy disassembly	
Ski Slope	UK	Standardized construction	Not all materials are suitable for reuse or recycle
		Step by step sequence	No clear brief is given for deconstruction
		"As built" construction details were given	Designing for deconstruction was not a commitment
		Steel framework was delivered in sections and bolted on site to enable reuse	Mineral wool, extruded polystyrene insulation, insulated panel backing, composite metal roof and rubber floorings are difficult to recycle/recover
		Mechanical fixings were used to aid deconstruction	
		Green roof was laid on metal deck for easy removal	
		Full access for maintenance	
		Deconstruction score is 66%	
Hualin Temporary Elementary School	China	Paper tubes and timber joints were used	Inexperienced volunteers caused the delay in construction
		Inexpensive and available materials were used	Un-clear communication between architects and volunteers caused problems and extra costs
		Limited variations of elements for fast construction	The structure was only planned for 3 years and maintenance was not thought over, paper tubes started to mold even though it could have been prevented with simple techniques
		Local sources were used for fast transportation	
		Changeable parts enabled for longer life time than planned	

Here, the positive factors given were used as "recommendations" and some of the negative factors were used to create "recommendations" to counter them. For instance; for "no clear brief is given for deconstruction" with Ski Slope case study, it was transformed to preparing for deconstruction steps such as "give briefing" and "create as-built drawings". For Chartwell School, "due to seismic zone codes, some elements were needed to be nailed" factor was given and it was transformed into "check with codes & regulations" during design stage in order to not meet with last minute changes like in the case study and have our design forced to have a different end-result than initially planned.

4.3 Defining The Deconstruction Principles and Recommendations

A thorough literature review was done in order to collect given recommendations for design for deconstruction and deconstruction processes. A total of 16 papers were used as references to create a table listing the principles and recommendations.

Table 4.7 Deconstruction principles and recommendations

Make sure the right tools are provided	Chini, A. R., & Bruening, S. (2003)	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)			
Provide adequate training to the whole crew	Chini, A. R., & Bruening, S. (2003)	Morgan, C., & Stevenson, F. (2005)	Dorsthorst, B., & Kowalczyk, T. (2002, April)	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)	
Consider material handling	Chini, A. R., & Bruening, S. (2003)	Akinade, O. O. et. al. (2017)	Guy, B., & Clarimboli, N. (2008)	Guy, B., Shell, S., & Esherick, H. (2006)	
Plan ahead to provide adequate time	Chini, A. R., & Bruening, S. (2003)	Morgan, C., & Stevenson, F. (2005)	ICE		
Make an assessment of hazardous materials	Chini, A. R., & Bruening, S. (2003)	Guy, B., Shell, S., & Esherick, H. (2006)			
Carry an inventory checklist	Chini, A. R., & Bruening, S. (2003)				
A building must be re-situated only if it cannot remain on its current site	Chini, A. R., & Bruening, S. (2003)				
Check opportunities for market and potential consumers for recycled or salvaged materials and elements	Chini, A. R., & Bruening, S. (2003)				
Use bolts/nuts joints instead of chemical adhesives and welding	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)	Guy, B., Shell, S., & Esherick, H. (2006)	Addis, W., & Schouten, J. (2004)	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)	
Avoid secondary finishes	Crowther, P. (2005)	Guy, B., & Clarimboli, N. (2008)			
Specify durable materials	Densley Tingley, D. (2013)				
Avoid composite materials	Crowther, P. (2005)	Webster, M. D., & Costello, D. T. (2005, November)	Webster, M. D., & Costello, D. T. (2005, November)	Crowther, 2005	
Have a limited number of building elements	Chini, A. R., & Balachandran, S. (2002)	Crowther, P. (2005)	Webster, M. D., & Costello, D. T. (2005, November)	Webster, M. D., & Costello, D. T. (2005, November)	Guy, B., Shell, S., & Esherick, H. (2006)
Design off-site for deconstruction	Guy, B., & Clarimboli, N. (2008)	Jaillon, L., Poon, C. S., & Chiang, Y. H. (2009)			
Do flexible designs to enable efficient reuse	Morgan, C., & Stevenson, F. (2005)	Crowther, P. (2005)	Guy, B., Shell, S., & Esherick, H. (2006)		
Use modular construction	Crowther, P. (2005)	Guy, B., Shell, S., & Esherick, H. (2006)			
Use layering approach	Habraken, N. J. (2000)	Webster, M. D., & Costello, D. T. (2005, November)			
Standardize your design	Webster, M. D., & Costello, D. T. (2005, November)	Crowther, P. (2005)	Chini, A. R., & Balachandran, S. (2002)	Webster, M. D., & Costello, D. T. (2005, November)	
Prefer retractable foundation	Meadows, D. (2011)				
Avoid in-situ casted concrete	Densley Tingley, D. (2013)				
Prefer reusable green elements	Webster, M. D., & Costello, D. T. (2005, November)				

Simplify your design	Webster, M. D., & Costello, D. T. (2005, November)	Guy, B., Shell, S., & Esherick, H. (2006)			
Avoid hazardous and toxic materials	Webster, M. D., & Costello, D. T. (2005, November)	Guy, B., Shell, S., & Esherick, H. (2006)			
Identify the storage areas for salvaged materials	ICE	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)			
Identify removal methods with associated recovery rates	ICE				
Have adequate amount of "as built" drawings	Addis, W., & Schouten, J. (2004)	Chini, A. R., & Balachandran, S. (2002)	Guy, B., & Ciarimboli, N. (2008)	Morgan, C., & Stevenson, F. (2005)	Webster, M. D., & Costello, D. T. (2005, November)
Prefer reusing to recycling	Morgan, C., & Stevenson, F. (2005)				
Count in the possible damage during assembly-disassembly processes	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)				
Simple consolidation of plumbing service points within a building helps reduce the length of lines, entanglement and conflict between elements	Guy, B., Shell, S., & Esherick, H. (2006)				
Long spans, post and beam construction reduces the number of structural elements	Guy, B., Shell, S., & Esherick, H. (2006)				
Long spans, post and beam construction allows structural stability when removing envelope elements	Guy, B., Shell, S., & Esherick, H. (2006)				
Access to connections and maintenance areas are important	Guy, B., Shell, S., & Esherick, H. (2006)				
Long-lived components should be separated from short-lived components to facilitate adaption and simplify deconstruction	Guy, B., Shell, S., & Esherick, H. (2006)				

Similar recommendations were written once while giving reference from all the selected research papers that were relaying the same matter.

4.4 Defining the Carbon Contributing Life-Cycles

After literature review, different life cycles were mentioned to be contributing to carbon emission of a structure. Because different sources were mentioning various stages, a collection of each mention was done and listed according to the order in each paper.

In order to have a comprehensive carbon-contributing-life-cycle categorization, 3 articles were used as reference.

Table 4.8 Carbon contributing life cycle categorization

Carbon Contributing Life Cycle Categorization		
Cradle to gate	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)	
Extraction of raw materials	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)	Tingley, D. D., & Davison, B. (2012)
Transportation	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)	Tingley, D. D., & Davison, B. (2012)
Manufacturing	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)	Tingley, D. D., & Davison, B. (2012)
Gate to site	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)	
Transportation	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)	Tingley, D. D., & Davison, B. (2012)
Site to cradle/grave	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)	
Materials input		Tingley, D. D., & Davison, B. (2012)
Construction	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)	Tingley, D. D., & Davison, B. (2012)
Operation/use of the building		Tingley, D. D., & Davison, B. (2012)
Maintenance/repairs	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)	Tingley, D. D., & Davison, B. (2012)
Deconstruction/demolition/recycling/landfill	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)	Tingley, D. D., & Davison, B. (2012)

Life cycles were separated into 3 stages; (i)cradle to gate, (ii)gate to site, and (iii)site to grave. While this classification was done by Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014), stages under these classifications include references from Tingley, D. D., & Davison, B. (2012) and Densley Tingley, D. (2013).

Cradle-to-gate stage includes; (i)extraction of raw materials, (ii)transportation, and (iii)manufacturing. Gate-to-site stage includes transportation. Site-to-cradle/grave stage includes; (i)materials input, (ii)construction, (iii)operation/use of the building, (iv)maintenance/repairs, and (v)deconstruction/demolition/recycling/landfill which are the chosen end-of-life scenario of the structure.

4.5 Collecting Recommendations for Materials

With the deconstruction process and required detail designs changing according to the preferred material, collection of recommendation for 4 main materials; concrete, timber, masonry and steel was found necessary in order to make material selection and detail design processes in DfD more feasible.

Four research papers were selected to stay as references for the created list of recommendations for each material. The recommendations were filtered according to their effect on deconstruction and dismantling processes. Any given recommendation from the research papers that were seen to be not affecting the process was dismissed.

Table 4.9 Recommendations for materials

Recommendations For Materials		
Timber		
Use screws, bolt and metal plates instead of nails to lessen wood damage	Webster, M. D., & Costello, D. T. (2005, November)	Densley Tingley, D. (2013)
Label members with species and grades	Webster, M. D., & Costello, D. T. (2005, November)	
Do not use adhesives	Webster, M. D., & Costello, D. T. (2005, November)	Guy, B., Shell, S., & Esherick, H. (2006)
Prefer panelized construction	Webster, M. D., & Costello, D. T. (2005, November)	
Keep services separate from structure	Webster, M. D., & Costello, D. T. (2005, November)	
Larger timber components are easier to salvage	Webster&Castello,2005	
Damp can render components unsuitable for reuse	Guy B. Et al, unknown date	
Older timber structures are easier to deconstruct as they have simpler techniques and standardized components	Webster, M. D., & Costello, D. T. (2005, November)	
Wood joists are deconstructable but need greater care to prevent damage	Webster, M. D., & Costello, D. T. (2005, November)	
Prefer panelized roofs	Guy, B., Shell, S., & Esherick, H. (2006)	
Masonry		
Lime mortars are easier to separate but their performance should be assessed	Densley Tingley, D. (2013)	
Do not use cement mortar as they are not cost-effective to seperate	Guy, B., Shell, S., & Esherick, H. (2006)	Densley Tingley, D. (2013)
Prefer mechanical fasteners	Densley Tingley, D. (2013)	
Use a systems that allows de-panelization	Guy, B., Shell, S., & Esherick, H. (2006)	
Steel		
Use bolted and clamped friction connections	Webster, M. D., & Costello, D. T. (2005, November)	
Use precast decks	Webster, M. D., & Costello, D. T. (2005, November)	
Use common shapes	Webster, M. D., & Costello, D. T. (2005, November)	
Avoid short filler pieces	Webster, M. D., & Costello, D. T. (2005, November)	
Use regular spacing	Webster, M. D., & Costello, D. T. (2005, November)	
Mark steel grades and shape designations on members	Webster, M. D., & Costello, D. T. (2005, November)	
Avoid conventional composite floor systems	Webster, M. D., & Costello, D. T. (2005, November)	
Seek alternatives to spray-on fire proofing	Webster, M. D., & Costello, D. T. (2005, November)	
Concrete		
Avoid cast-in-place members	Webster, M. D., & Costello, D. T. (2005, November)	Densley Tingley, D. (2013)
Label each component with information on concrete strength and member reinforcement	Webster, M. D., & Costello, D. T. (2005, November)	
Fasten precast members with removable mechanical fasteners	Webster, M. D., & Costello, D. T. (2005, November)	
Allow thermal movement of connections to avoid cracking	Webster, M. D., & Costello, D. T. (2005, November)	
Avoid blow-grade construction since foundation walls and deep footings are not salvagable	Webster, M. D., & Costello, D. T. (2005, November)	
Precast slabs-on-grade, precast foundation walls and shallow footings have a greater change of being salvaged	Webster, M. D., & Costello, D. T. (2005, November)	
Prefer alternatives to topping slabs for connecting precast planks	Webster, M. D., & Costello, D. T. (2005, November)	
Removable materials like plywood on sleepers may be used to provide a smooth sub-floor	Webster, M. D., & Costello, D. T. (2005, November)	
Post and beam and flat plate concrete systems allow for maximum flexibility in separating non-cementitious materials	Guy, B., Shell, S., & Esherick, H. (2006)	

4.6 Defining the Possible End-of-life Scenarios

A Deft ladder chart was compiled by using research paper by Addis, B. (2008) showing the priority stages of end-of-life scenario of a structure for waste management principles starting with highest level of waste prevention to the lowest level. The steps of the Deft Ladder starts with complete prevention of waste and ends with landfill, creating more waste as we go below the ladder.

The steps are listed in the following table.

Table 4.10 Deft ladder

Deft Ladder	Addis, B. (2008, February)
Prevention	
Object renovation	
Element reuse	
Material reuse	
Useful application	
Immobilization with useful appliction	
Immobilization	
Incineration with energy recovery	
Incineration	
Landfill	

Subsequently, the mentioned end-of-life scenario processes from past research papers were collected and put in order using the created Deft Ladder and a cross matching was done. For this chart, 4 research papers were used along with the Deft Ladder.

Main scenarios of the compiled chart are; (i)prevention, (ii)object renovation, (iii)reuse of material / elements, (iv) recycling of materials, (v)incineration with energy recovery, (vi)incineration, and (vii)landfill of materials.

Table 4.11 End-of-life scenarios

End-of-life Scenario Preferance Order		
Prevention	Addis, B. (2008, February)	
—Complete re-use		
Object Renovation	Addis, B. (2008, February)	
—Re-use of the structure with element upgrades		
Reuse of material / elements	Tingley, D. D., & Davison, B. (2012)	
—Removal of part of a building	Addis, B. (2008, February)	
—Removal of a component or an element for reconditioning	Addis, B. (2008, February)	
—Salvaging and storing elements for subsequent reconditioning	Addis, B. (2008, February)	
Recycling of materials	Tingley, D. D., & Davison, B. (2012)	
—Down-cycling/processing into construction materials	Addis, B. (2008, February)	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)
—On-site reprocessing	Addis, B. (2008, February)	
Incineration with energy recovery	Addis, B. (2008, February)	
—Using to generate energy	Webster, M. D., & Costello, D. T. (2005, November)	
Incineration	Addis, B. (2008, February)	
—Composting	Webster, M. D., & Costello, D. T. (2005, November)	
Landfill of materials	Webster, M. D., & Costello, D. T. (2005, November)	Tingley, D. D., & Davison, B. (2012)

“Prevention” is described as complete re-use of the structure without creating any waste. “Object renovation” is the re-use of the structure with element upgrades, creating minimum amount of wastes. “Reuse of material / elements” come across with three levels; removal of part of a building, removal of a component or an element for reconditioning, and salvaging and storing elements for subsequent reconditioning. Later we move to “recycling of materials” in the chart, which are less desirable than re-use stages. This step has two stages as; down-cycling/processing into construction materials, and on-site reprocessing. With these, the materials are assumed to be recycled into re-usable materials with up-cycling or down-cycling. We then move to “incineration with energy recovery” which is described as using the salvaged materials and wastes to generate energy. With this materials are not re-usable but it still gives some benefit back. Then we move to “incineration” which is described as composting. And lastly we end the end-of-life scenarios with “landfill of materials” which are basically materials that are nothing but waste. This step is not considered to have any recovery level, in fact landfill causes more harmful gases to be created.

4.7 Creating A Workflow Proposal For Temporary Structures Using DfD Principles

While creating a workflow proposal to achieve DfD, the focus remained on the design stage. However, due to the collected information that can directly affect a deconstruction process of a structure, the issues that should be considered and solved were defined seperately. This stage is divided into 3 categories as for determining the location, determining the design brief and determining legal and economic factors. These were not seen to have a required order. The determining of the location is recommended to be based on; (i) hazard potentials, (ii) infrastructure, (iii) required facilities, (iv) transportation, and (v) site distances for material transportation. Determining design brief includes five information; (i) required emergency function, (ii) required performance, (iii) required time for construction, (iv) required user-comfort level, and (v) required period-of-use. These matters were all seen to have the potential to affect material choices, detail and overall design and even end-of-life scenario of the structure. The recommendations under “determine the legal and economic factors” were collected from the problems met in case studies and the determined factors that affected a structure’s deconstruction process positively.

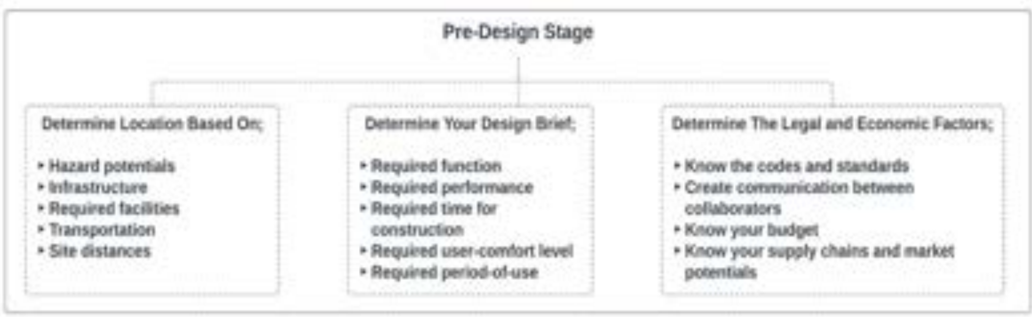


Figure 4.1 Factors to be determined pre-design stage

The collected recommendations, positive and negative factors seen in case studies as in Table 4.4, Table 4.5, Table 4.6, Table 4.7, and Table 4.9; were used to create a general guide by cross-checking the given information by different authors and studies, and by collecting them under related step and recommendations. These were then again categorized under design steps as; (i) plan end-of-life scenario, (ii) choose the right materials, (iii) design connection details, (iv) design the structure, (v) check with codes and regulations, (vi) make cost comparisons, (vii) prepare for consturction, (viii) prepare for deconstruction process, and (ix) prepare for aftermath of the salvaged materials. Repeated and similar recommendations were written as one with all related references. Some recommendations were written multiple times under different steps as they were seen to be related to multiple design stages.

The created steps and their the connected recommendations and sub-steps, were used directly for the workflow created. While some references are recommendations, some references are to divide a design step into different processes that flow together.

Table 4.12 Collected Recommendations Divided Into Design Steps

Plan end-of-life scenario						
__Know your market opportunities for salvaged and/or recycled materials	Arrigoni, A., Zucchinelli, M., Collatina, D., & Dotelli, G. (2018) - Expo Milano 2015 Brazilian Pavilion	Chini, A. R., & Bruening, S. (2003)	Riverdale Village Apartments			
__Know your local resources	Hualin Temporary Elementary School	Expo Milano 2015 Brazilian Pavilion				
__Know the Legalities and required permits	The Future Arena	Expo Milano 2015 Brazilian Pavilion				
Choose the right materials:						
__Prefer reusable green elements	Webster, M. D., & Costello, D. T. (2005, November)	Expo Milano 2015 Brazilian Pavilion	Hualin Temporary Elementary School	Circle House		
__Avoid hazardous and toxic materials	Webster, M. D., & Costello, D. T. (2005, November)	Guy, B., Shell, S., & Esherick, H. (2006)	Ski Slope			
__Use Local sources	Hualin Temporary Elementary School	Expo Milano 2015 Brazilian Pavilion				
__Avoid composite materials	Crowther, P. (2005)	Webster, M. D., & Costello, D. T. (2005, November)	Ski Slope			
Design connection details						
__Prioritize disassembly	Webster, M. D., & Costello, D. T. (2005, November)	Densley Tingley, D. (2013)	Morgan, C., & Stevenson, F. (2005)	Expo Milano 2015 Brazilian Pavilion		
__Prefer joint systems or locks instead of adhesives and welding	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)	Guy, B., Shell, S., & Esherick, H. (2006)	Addis, W., & Schouten, J. (2004)	Webster, M. D., & Costello, D. T. (2005, November)	Erkelens, P.A. (2003) - Family House	Arrigoni, A., Zucchinelli, M., Collatina, D., & Dotelli, G. (2018) - Expo Milano 2015 Brazilian Pavilion
__Make connections accessible	Chartwell School	Guy, B., Shell, S., & Esherick, H. (2006)	Ski Slope			
__Standardize the connection types	Webster, M. D., & Costello, D. T. (2005, November)	Chini, A. R., & Balachandran, S. (2002)	Crowther, P. (2005)	Guy, B., & Ciarimboli, N. (2008)	Ski Slope	Circle House
Design the structure:						
__Limit the number of building elements	Circle House	Ski Slope	Hualin Temporary Elementary School	Chini, A. R., & Balachandran, S. (2002)	Crowther, P. (2005)	Webster, M. D., & Costello, D. T. (2005, November)
__Do flexible designs to enable efficient reuse	Morgan, C., & Stevenson, F. (2005)	Crowther, P. (2005)	Guy, B., Shell, S., & Esherick, H. (2006)	Circle House	Chartwell School	
__Use modular construction	Expo Milano 2015 Brazilian Pavilion	Crowther, P. (2005)	Guy, B., Shell, S., & Esherick, H. (2006)			
__Standardize your design	Webster, M. D., & Costello, D. T. (2005, November)	Chini, A. R., & Balachandran, S. (2002)	Crowther, P. (2005)	Guy, B., & Ciarimboli, N. (2008)	Ski Slope	Circle House
__Use larger components	Webster&Costello 2005					
__Separate service and maintenance areas	Ski Slope	Webster, M. D., & Costello, D. T. (2005, November)	Guy, B., Shell, S., & Esherick, H. (2006)			
Check with codes and regulations	Chartwell School					
Make cost comparisons	Riverdale Village Apartments					
Prepare for construction:						
__List required tools	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)	Chini, A. R., & Bruening, S. (2003)	Addis, B. (2006, February)			
__Define the required adequate training for the workers	Hualin Temporary Elementary School	Chini, A. R., & Bruening, S. (2003)	Morgan, C., & Stevenson, F. (2005)	Dorsthorst, B., & Kowalczyk, T. (2002, April)	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)	
Supervise the process	Family House	Hualin Temporary Elementary School				
Prepare for deconstruction process:						
__Prepare as-built drawings	Ski Slope	Chartwell School	Hualin Temporary Elementary School	Addis, W., & Schouten, J. (2004)	Chini, A. R., & Balachandran, S. (2002)	Guy, B., & Ciarimboli, N. (2008)
__Identify removal methods	Ski Slope	ICE				
__Plan the required time for deconstruction	Chini, A. R., & Bruening, S. (2003)	Morgan, C., & Stevenson, F. (2005)	Guy, B., & Ciarimboli, N. (2008)	ICE	180O'Brien, E., Guy, B., & Lindner, A. S. (2006) - Ft. McClellan Military Barracks	Arrigoni, A., Zucchinelli, M., Collatina, D., & Dotelli, G. (2018) - Expo Milano 2015 Brazilian Pavilion
__Define the required training for workers	Hualin Temporary Elementary School	Chini, A. R., & Bruening, S. (2003)	Morgan, C., & Stevenson, F. (2005)	Dorsthorst, B., & Kowalczyk, T. (2002, April)	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)	
__List required tools	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)	Chini, A. R., & Bruening, S. (2003)	Addis, B. (2006, February)			
Prepare for aftermath of salvaged materials:						
__Identify storage areas for salvaged materials	Ft. McClellan Military Barracks	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)	ICE			
__Define market opportunities for salvaged materials	Arrigoni, A., Zucchinelli, M., Collatina, D., & Dotelli, G. (2018) - Expo Milano 2015 Brazilian Pavilion	Chini, A. R., & Bruening, S. (2003)	Riverdale Village Apartments	Whole House Reuse		
__Define material handling	Erkelens, P.A. (2003) - Family House	Chini, A. R., & Bruening, S. (2003)	Akinade, O. O. et al. (2017)	Guy, B., & Ciarimboli, N. (2008)	Guy, B., Shell, S., & Esherick, H. (2006)	Akbarnezhad, A., Ong, K. C. G., & Chandra, L. R. (2014)
__List hazardous materials	Chini, A. R., & Bruening, S. (2003)	Guy, B., Shell, S., & Esherick, H. (2006)				

The pre-determined pre-design stage was integrated into the workflow created, as the information gathered there, are also information required for the design steps. This way this step turns into an information pool to be used during the design stage's different steps, to avoid going back and forth as much as possible by helping the designers make more feasible decisions and to not meet with issues that could force the whole design to be changed thus wasting time and budget which are crucial for emergency situations.

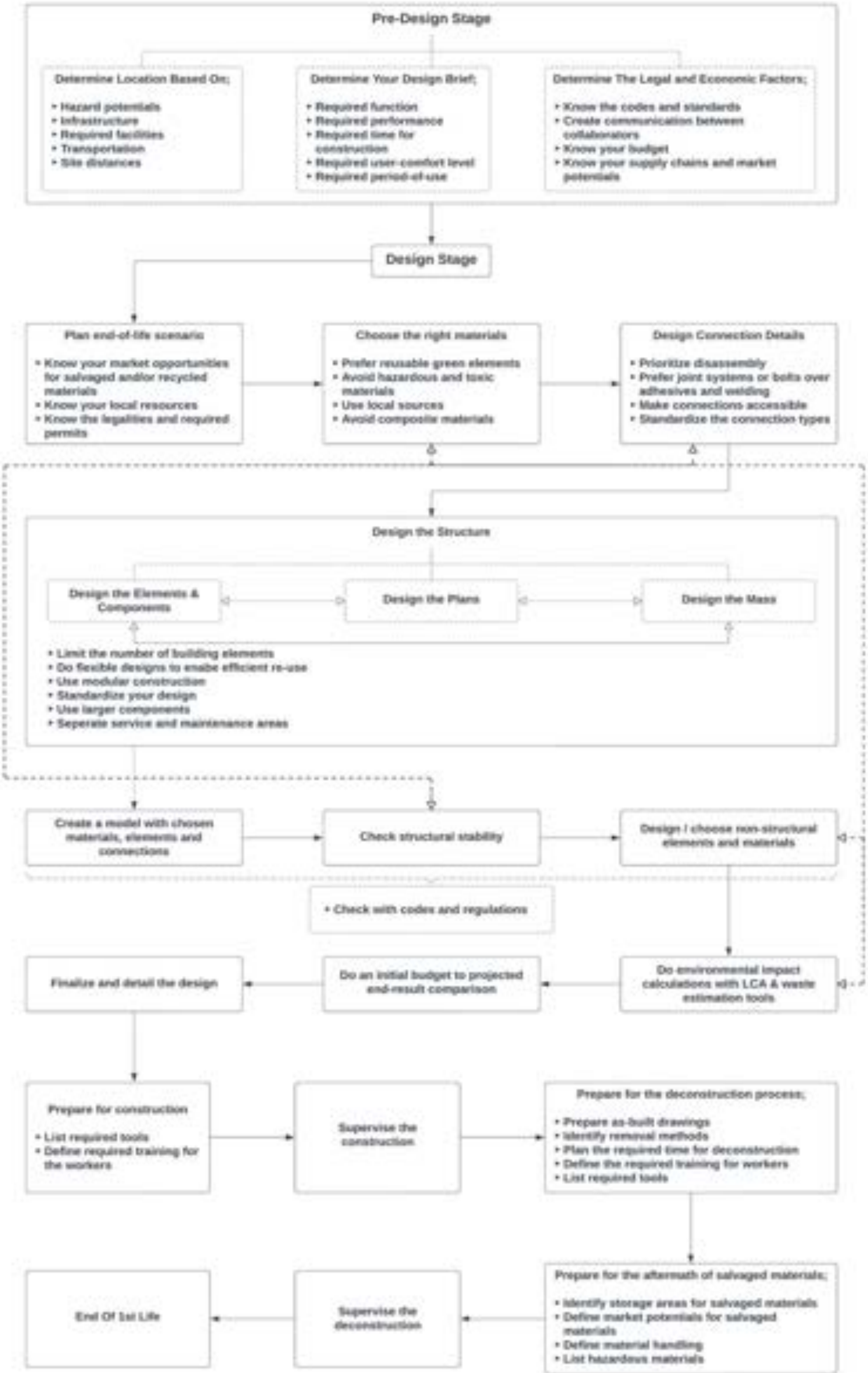


Figure 4.2 Proposed general workflow for a structure designed with DfD principles

The first created workflow is a general workflow that starts with the emergency situation, assuming everything is designed from scratch and ends with the finalization of 1st life of the structure thus the end of the emergency need. The design stage begins with planning the end-of-life scenario then moves to choosing the right materials and later to designing connection details. All three steps include related recommendations transferred directly from Table 4.12. After designing connection details, designing the structure begins. This step was divided into three sub-steps as; (i) design the elements & components, (ii) design the plans, and (iii) design the mass. These three sub-steps were not put in an order but instead the flow and possibility of going back-and-forth between all three were shown as mass, plan and component designs can be worked on simultaneously. With three sub-steps, designing the structure step has one collective recommendations again taken directly from the same table. After the design of the structure, a structural stability check was necessary along with an impact estimation for a sustainable design with a feasible end-result. For these calculations, a prototype model creation was required hence why creation of a model was added as a step before the calculation steps.

The results of these calculations can force the designer to go back in the workflow up untill choosing materials or connection details and make changes to have better results. After these, finalizing and detailing the design step was added which moves on to preparing for construction. Preperation steps; preparing for construction, preparing for deconstruction process and preparing for the aftermath of salvaged materials all include recommendations collected in Table 4.12. However, these recommendations work more as enforced sub-steps that were seen required for the designers to do for a smoother end-result and control over the design. Supervision steps were added for construction and deconstruction processes and the workflow was finalized with the end of 1st life of the structure.

While this generalized workflow can be a guide for various designs and situations, designers should also know the different required steps for different situations and scenarios. These differences can be caused due to the information gathered at pre-design stage such as time limitations, legal issues, or economic factors. Some examples for the information gathered in pre-design stage that can cause for designers to take different steps;

- The site given by the involved parties may be for limited time of use and re-use on site may not be possible
- Required facilities may not be at a feasible distance
- Time constraints may not allow for certain construction techniques, more complicated designs or designs that require manufacturing.
- 2nd hand material market may not be existent and buyer potential may be low for salvaged materials
- Required function and regulations may not allow for certain materials, designs, connections and more
- The location given by the government may be lacking required infrastructure for a permanent transformation of the structure for its 2nd life

Next to the possibility of how pre-design stage can affect the decisions made during design stage, again some decisions made during design stage can also affect the rest of the design stage steps. Planning the structure to be re-used or recycled, using materials with higher environmental impact, and choosing certain types of connections for instance can require additional steps in the workflow. As each design is unique to its scenario and can create different end-results for the workflow, to examplify the possible difference a scenario for the design was assumed and an alternative workflow was created.

The assumed design-brief for the alternative workflow;

- Function; one emergency shelter structure and one food storage structure
- Number of structures; two

- Use-period; 3 years

Additional information gathered at pre-design stage;

- Warehouses are nearby to store materials
- Site will be available after 1st use, given by the government to transform permanently
- 2nd hand market potential is higher for concrete and steel
- Construction time is limited

After the assumed pre-design stage, the design stage begins and from here, the assumed designer makes choices that are enforced by the pre-design information or the prior decisions made by the designer.

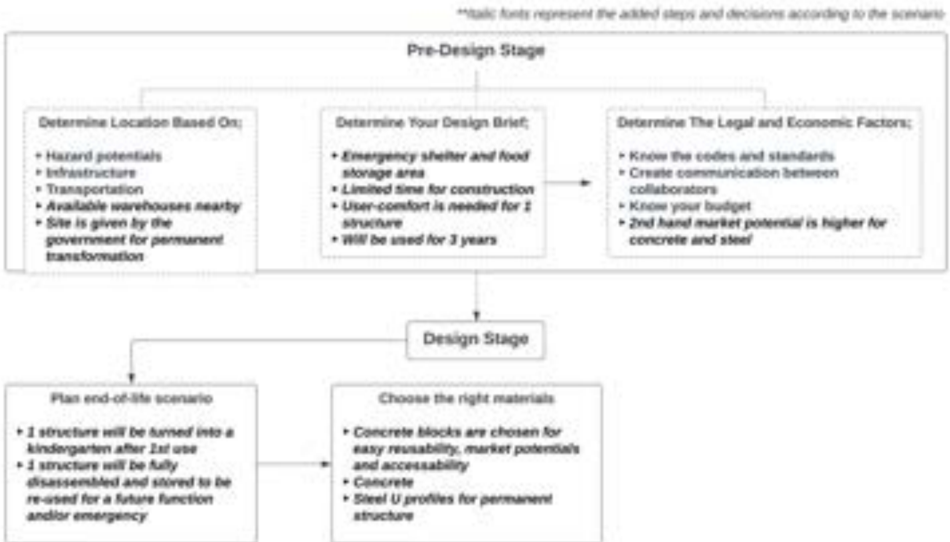
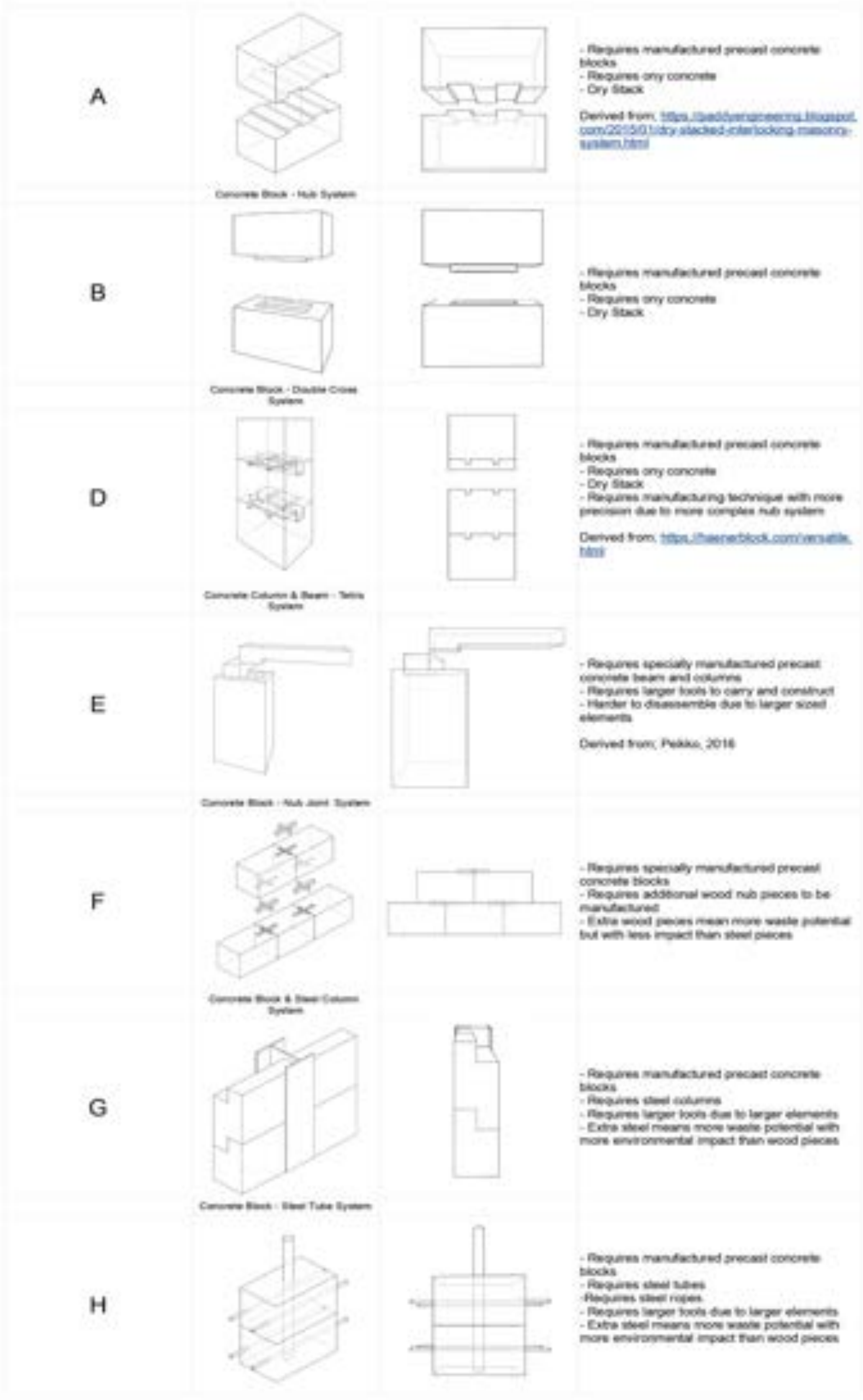


Figure 4.3 Alternative Workflow, Before Connection Design Step

In Figure 4.3, we see first decisions made by the designer by choosing end-of-life scenario and materials to be used. One of the structure was planned to be used as a kindergarten after the emergency situation, and the other structure was planned to be dismantled and stored to be re-used for a future emergency situation. Due to 2nd hand market being better for concrete and steel, designer chooses those two materials as main structural materials. In order to choose the most feasible, assumed designer did a connection type research for dry-stacked concrete blocks to be easily dismantled and re-usability as seen in Table 4.13. Here, an example of a possible connection type study is shown and each connection type has possible advantages and disadvantages. Some of these drawings of connection types in the chart were derived from past researches. From here, designers pick the most feasible connection type as the assumed designer picks two different connection types for the two separate structures planned.

The assumed designer picks Type-G for the more permanent structure that will be transformed into a kindergarten and Type-A for the food-storage structure that is planned to be dismantled and doesn't require the same level of performance as a shelter. The latter connection type also requires smaller tools and machinery to carry, so dismantling is presumed to be potentially easier than Type-G with steel columns and larger concrete-components. The lack of steel also means lower environmental impact, which is a better choice for materials with no planned 2nd life as of yet after being dismantled and stored.

After "design connection details" stage, designing of the structure begins with mass design, plan designs and its structural element designs. Here designer made the decision of standardizing openings, designing separate service areas to make the structure dismantled and transformed easier after 1st use, and decided to divide the required rooms with detachable wall panels later to be dismantled and to be re-used and to allow for the structure to have a more flexible design as recommended.



A	Concrete Block - Hub System		- Requires manufactured precast concrete blocks - Requires ony concrete - Dry Stack Derived from: https://paddyengineering.blogspot.com/2015/01/dry-stacked-interlocking-masonry-system.html
B	Concrete Block - Double Cross System		- Requires manufactured precast concrete blocks - Requires ony concrete - Dry Stack
D	Concrete Column & Beam - Tetris System		- Requires manufactured precast concrete blocks - Requires ony concrete - Dry Stack - Requires manufacturing technique with more precision due to more complex hub system Derived from: https://haenerblock.com/versatile.html
E	Concrete Block - Nub Joint System		- Requires specially manufactured precast concrete beam and columns - Requires larger tools to carry and construct - Harder to disassemble due to larger sized elements Derived from; Pekko, 2016
F	Concrete Block & Steel Column System		- Requires specially manufactured precast concrete blocks - Requires additional wood nub pieces to be manufactured - Extra wood pieces mean more waste potential but with less impact than steel pieces
G	Concrete Block - Steel Tube System		- Requires manufactured precast concrete blocks - Requires steel columns - Requires larger tools due to larger elements - Extra steel means more waste potential with more environmental impact than wood pieces
H			- Requires manufactured precast concrete blocks - Requires steel tubes -Requires steel ropes - Requires larger tools due to larger elements - Extra steel means more waste potential with more environmental impact than wood pieces

Table 4.13 Dry stacked concrete block connection detail design research

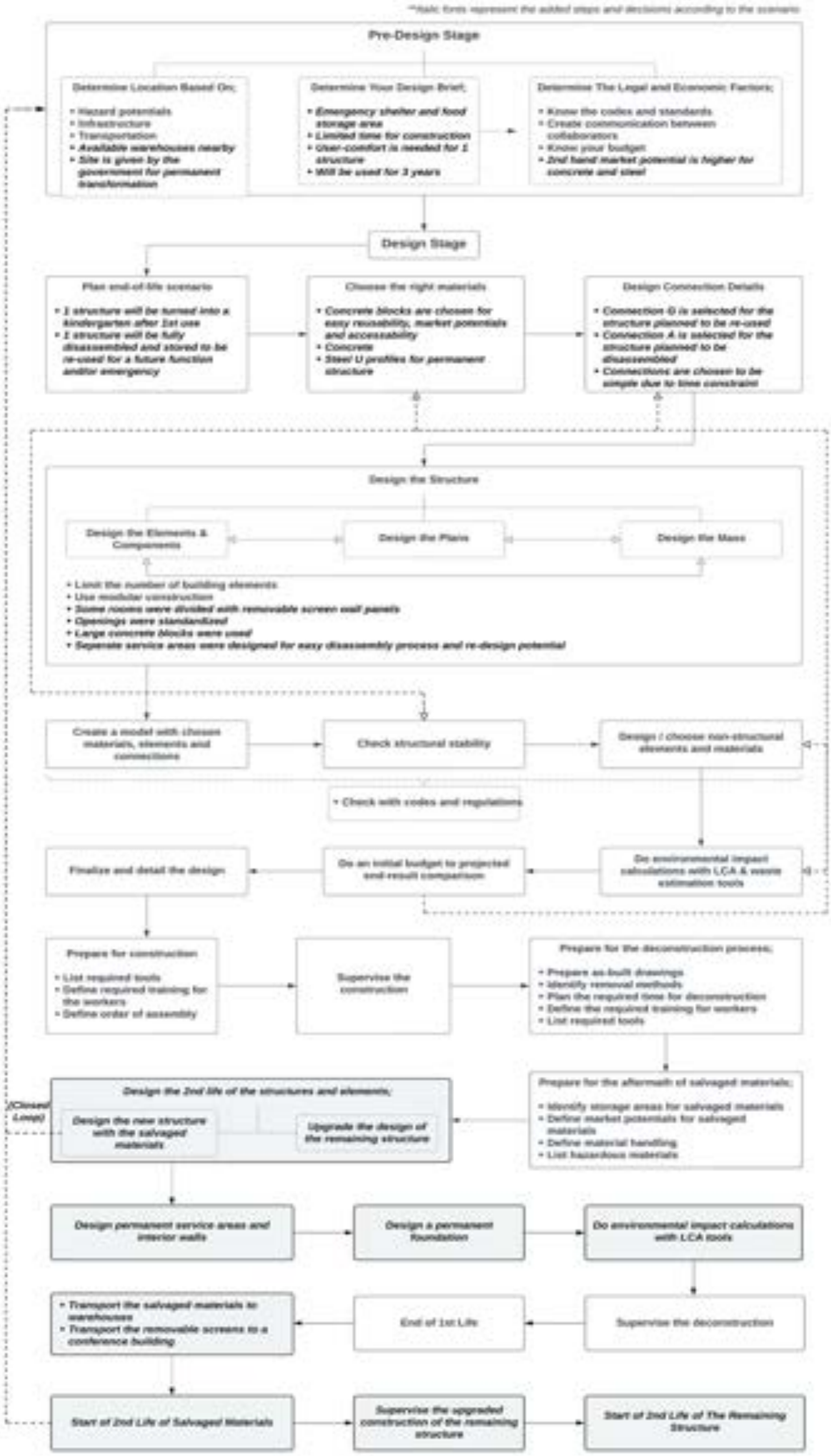


Figure 4.4 Specified workflow example for a structure designed with DfD principles

After the design of the structure, the proposed workflow went as it originally did with the general workflow untill the “design the 2nd life of the structures and elements” step which became a necessary step due to the designer choosing to re-purpose one built structure and to dismantle the other structure. For the re-purposed structure, more steps were added as; (i) Designing permanent service areas and interior walls, (ii) designing a permanent foundation, (iii) doing environmental impact calculations with LCA tools for the new design, (iv) transporting the removable screens to a conference building, (v) supervising the upgraded construction of the remaining structure, and (vi) start of the remaining structure. For the food-storage structure that would be dismantled and have its materials stored, additional steps added were; (i)transporting salvaged materials to warehouses, and (ii) start of the 2nd life of the salvaged materials. From here, due to the materials used in the structure being dismantled and stored to be re-used for a future emergency structure in the future, the workflow created a loop where the salvaged materials can be used as a material resource for the future emergency structure design which could potentially be a prior information gathered during pre-design stage and would affect the design of the structure.

CHAPTER 5

CONCLUSION

The goal of this study was for the study itself to act like as a guide for designers, with collected data and created workflows. By acting like a guide, it aims to make emergency relief system structures during dire situations to go smoother while also adding a perspective of end-of-life and deconstruction for a better sustainability and less carbon footprint. The subject of this thesis is formed through observation and research on how temporary structures have been handled internationally and locally to this day and seeing the lost potentials and harm caused to the nature from lack of planning in their constructions and end-of-life scenarios.

Study starts with a literature review based on emergency structures, temporary structures, sustainable designs and design for deconstruction. Through case studies and literature review, multiple informational data tables were created to give recommendations in design for designers and to pinpoint usually over-seen issues in design stages. As study focuses on designing emergency structures with deconstruction principles, the importance of DfD was tried to be emphasized through again literature review but also by making calculations using the mathematical data of salvage rates, recycle rates and reuse rates of chosen case studies. The most impactful side of DfD was shown to be the reuse rates of deconstructed structures as literature review informed us of the importance of prioritizing reusing before recycling, higher rates reached through DfD was seen as an importat matter to be highlighted. This way the difference of DfD was emphasized and re-confirmed for the readers.

Collected data and created tables were used to create a workflow proposal for emergency structure design phases to conclude the guide aim of this study with a step by step process. Later this workflow was applied to a specified scenario to exemplify possible differences and additional steps that can be added. While creating the alternate specified workflow, the scenario was chosen to include two different structures with different connection types but focusing on dry stacked concrete blocks still, while one of the structures structural system included steel columns as well. And one of the structures was planned to be dismantled and stored completely while the other one was planned to be re-used on site. This two-scenario brief was created to have shown two different workflow changes in one workflow.

The data used in this workflow include various recommendations for different materials, end-of-life scenarios and stages to be considered to create a feasible workflow proposal for the designers. These collected data and recommendations from case studies and literature review can be furthered with a wider research and detailing issues for temporary structures built for more various functions. Due to this, the created workflow using the collected data can also be furthered with a wider range of recommendations under steps and can be turned into different workflows for specific scenarios and functions by focusing on researches and cases studies based on structures with the selected functions.

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