THE IMPLEMENTATION OF CIRCULAR ECONOMY PRACTICES IN THE PACIFIC NORTHWEST BUILT ENVIRONMENT, ENABLERS AND BARRIERS

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Abstract

The Implementation of Circular Economy Practices in the Pacific Northwest Built Environment, Enablers and Barriers

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Construction is a highly resource-consuming industry. Over the last few years, various events have created disruptions and acceleration in the delivery of construction projects that have magnified how intensive is the use of raw materials and finished goods for construction. Further, this intensity translates into also producing a massive amount of waste annually. The construction industry is now looking for innovative solutions to mitigate the negative environmental impact caused by the whole industry. New models proposed by other industries have been adapted and introduced into construction, including the concept of Circular Economy. Circular Economy is an economic model that has emerged in recent years and its main goal is to keep the materials at their highest value in a closed loop.

This thesis relies on an extensive literature review that allowed to identify 12 Circular Economy practices and was followed up with a survey and interviews among a selected number of construction professionals. Fifteen industry representatives were inquired about these practices, their experience with implementing them as well as the enablers and barriers to each of them, and the stakeholders that drive the decision of implementing these practices on their projects. This research serves as an exploratory study and aims understanding what circular economy practices have a high potential to be implemented in the PNW and outline a framework to boost their implementation.

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CHAPTER 1 - INTRODUCTION

1.1 OVERVIEW

The global economy has historically been driven by a 'take-make-use-dispose' system known as "linear economy". However, this growth mechanism is not sustainable due to the limited amount of resources available on our planet. A new economic model called Circular Economy has been introduced in recent years to mitigate this issue.

Circular Economy (CE) is an economic model widely implemented in various sectors such as textile, technological, industrial, and lately, construction. Unlike the linear economy, its main characteristic is that a product at the end of its life cycle can be recycled or reused as a base for creating a new product with additional value. Instead of being disposed of, the materials are kept in a loop to reduce the waste to a minimum.

The construction industry is also known for massively consuming natural resources and producing considerable amounts of waste annually all around the world. For example, in Brazil, the waste generated by the construction industry represents 60% of the total volume disposed of in landfills (Benachio, Freitas, & Tavares, 2020). This percentage is around 30-40% in China and in the United States the amount of waste created reaches up to 67% (Lopez Ruiz, Roca Ramon, & Gasso Domingo, 2020). One of the main questions in the construction sector is what practices could be implemented to minimize the adverse environmental impact generated by the whole industry, which includes the materials' manufacture, the waste generated during the construction phase, and the massive waste generated during the end-of-life of a building.

1.2 BACKGROUND

The construction industry is one of the most resource-consuming. In the past it was responsible for the consumption of 40% of the natural resources every year though in recent years this number has dropped to around 30% (Hossain, Thomas, Antwi-Afari, & Amor, 2020). Nevertheless, materials consumption has started to increase again because of growth in the industry and the need for emergent products that require additional resources to support the industry's alignment with sustainability practices.

In 2013 the Ellen MacArthur Foundation (EMF) proposed a group of principles that could be applied in different industries - including construction: (a) Design out of waste and pollution, (b) keep products and materials in use, and (c) regenerate natural systems (EMF, 2013).

In 2019, based on the contributions made by the EMF, research was conducted to identify the barriers and drivers to the circular economy in the built environment (Hart, Adams, & Giesekam, 2019). In this research the enablers and barriers were classified into 4 different groups: cultural, regulatory, financial, and sectorial. He concluded that the principal obstacles to a circular built environment are the cultural and financial issues, especially those related to the current supply chain and the lack of development of markets that support circular models.

Guerra and Leite (2021) conducted a study to determine the United States stakeholders' awareness of the Circular Economy and the major challenges and enablers. In this research, they identified a group of circular strategies that can be applied to the built environment, and they sorted these strategies into two different groups: The circular strategies that can be implemented during the design phase and the strategies that can be implemented during the end-of-life of a building. It is important to mention that, even today, circular economy is considered a state-of-the-art topic in the United States, therefore most of the literature used by Guerra and Leite during their research came from countries in Asia and Europe. After conducting a group of interviews with participants from all over the United States, researchers concluded that the most significant challenges are related to the project budget and upfront costs and the lack of formal education in topics such as sustainability and circularity. However, one of the recommendations provided was to replicate the study performed in smaller geographical regions because the perception of the interviewees about the enablers and barriers will change depending on the region where the research is conducted.

In 2021, new research was conducted to identify the barriers and enablers to a circular building during the design phase (Cruz, Grau, & Bilec, 2021). Researchers interviewed different designers across the United States and classified their answers into 7 different groups: Regulatory, economic, technological, cultural, educational, technical, and environmental. This research discussed the role of the stakeholders and their influence in the implementation of CE practices. This study concluded by proposing that wider research should be conducted that includes the perspective of policymakers, owners, contractors, and manufacturers.

The literature review led us to identify this thesis topic, which will analyze the level of implementation in the Pacific Northwest of a group of 12 circular economy practices that can be applied during the design phase, construction phase, and end-of-life of a building.

1.3 RESEARCH METHODOLOGY

This research aims to discuss a group of construction practices aligned with the ideas that Circular Economy is proposing - and its level of implementation in the Pacific Northwest built environment. A list of 12 practices that has the potential to be implemented during the different phases of a project (design, construction, and end-of-life) is the primary focus and these will be discussed and studied. This study also includes the identification of the enablers and barriers to the implementation of these practices and the discussion about the principal stakeholders that drive this decision.

The research was composed of 7 different steps. The first 3 steps involved topic identification, literature review, and the identification of the gaps in the topic. In the later 4^{th} step in-person, and videocall interviews were conducted. A total of forty invitations to participate were sent to Owners, Designers, Prime Contractors, and Subcontractors and twenty-nine responses were received. Finally, fifteen interviews were conducted with the participants that showed the greatest interest and knowledge in the topic.

1.4 SUMMARY

This thesis includes a literature review chapter – Chapter 2 - which serves to understand the Circular Economy's general background - such as the origin of this model, the pillars that govern this, and the relationship between CE and the built environment. Chapter 2 also provides a description of the practices that were studied and discussed during the interviews.

Chapter 3 describes the research methodology and explains the steps that were followed to conduct this research – including the interviews. Chapter 4 describes the process of collecting data and the initial analysis. Chapter 5 provides a detailed analysis and discussion of the interview findings. In this chapter, the interview responses were discussed in detail and each of the 12 CE practices were studied separately.

Some of the limitations of this research were related to the data collection and target audience. Given that this is a novel topic in the United States, not all respondents felt confident discussing it. For this reason, the number of interviews conducted was significantly reduced and this research must be considered an exploratory study. It is important to acknowledge that most of the respondents and interviewees were prime contractors even though the target audience consisted of a mix of owners, designers, prime contractors, and subcontractors. This factor could create bias in the final results.

CHAPTER 2 - LITERATURE REVIEW

2.1 CIRCULAR ECONOMY

The global economy has been driven by a take-make-use-dispose system known as "linear economy." This system has lasted for many years due to the abundance of cheap natural resources (ARUP, 2018). However, this growth mechanism is not sustainable anymore because of the limited resources on our planet (Donald, Chiang Lin, & Chen, 2015). It is under this scenario that a new economic model called Circular Economy has been introduced in the last years.

There are different definitions of Circular Economy (CE). One of the most widespread and accepted is provided by the Ellen Mc Arthur Foundation: "Circular Economy is a regenerative system that aims to keep materials in a closed-loop at their highest value" (EMF, 2013). Circular Economy can be seen as a business model that aims to create a more equitable society and a more sustainable development by breaking the relationship between economic growth and resource consumption (Guisellini, Cialani, & Ulgiati, 2016).

One of the main points that differentiate CE from the linear economy is that materials should be designed out-of-waste and treated as an important resource that needs to be preserved instead of being disposed of after its use. Figure 1 shows two different tracks. The one on the left shows the "biological materials" cycle and the one on the right shows the "technical materials" loop.

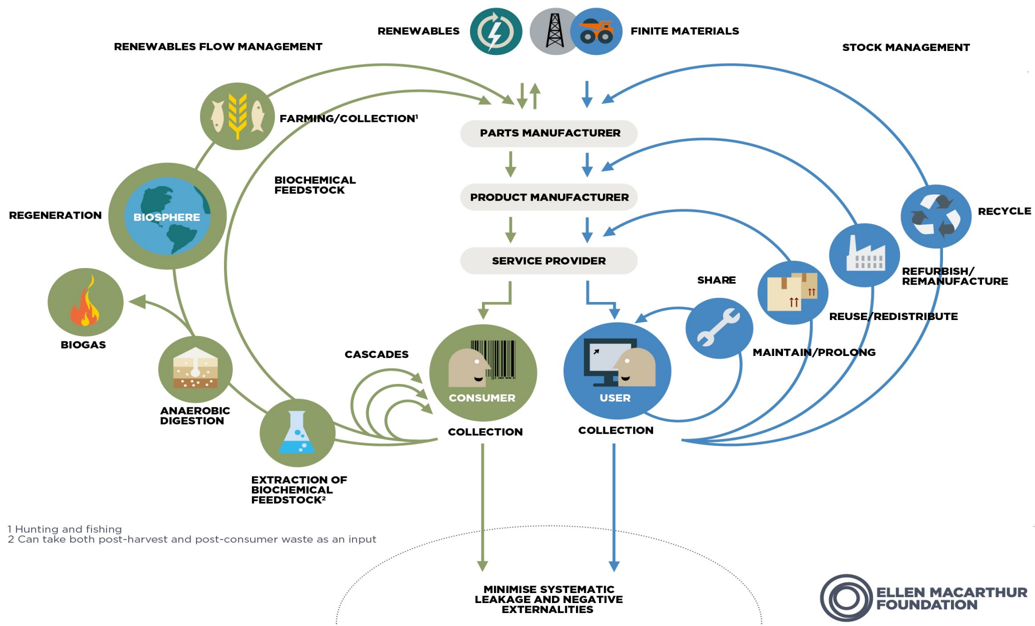

Figure 1: Circular Economy butterfly diagram (EMF, 2013)

An example of biological material can be a timber beam that initially was used as a structural element, later as a non-structural element, and at the end of its life was used as a raw material for the generation of biogas. In this case, the wood and its subproducts that were not contaminated with any toxins were returned to the environment at the end of its life.

Metals and plastics, by contrast, are good examples of technical materials. These materials must be kept in use as much as possible due to their finite nature and their inability to return to the environment without causing a negative impact. These types of products should be designed and built to be durable, modifiable, and to be reused as much as possible (Cheshire, 2016).

Kirchherr, Reike, & Hekkert (2017) performed an analysis of 114 Circular Economy definitions and concluded that CE outlines a system that is based on a business model that changes the "end-of-life" of a material by reusing, recycling, and recovering of this material in the consumption process. This leads to an improvement in environmental, economic, and social aspects to benefit current and future generations.

Figure 2 shows the potential positive impacts of CE in the dimensions (environmental, economic, and social) of sustainable development.

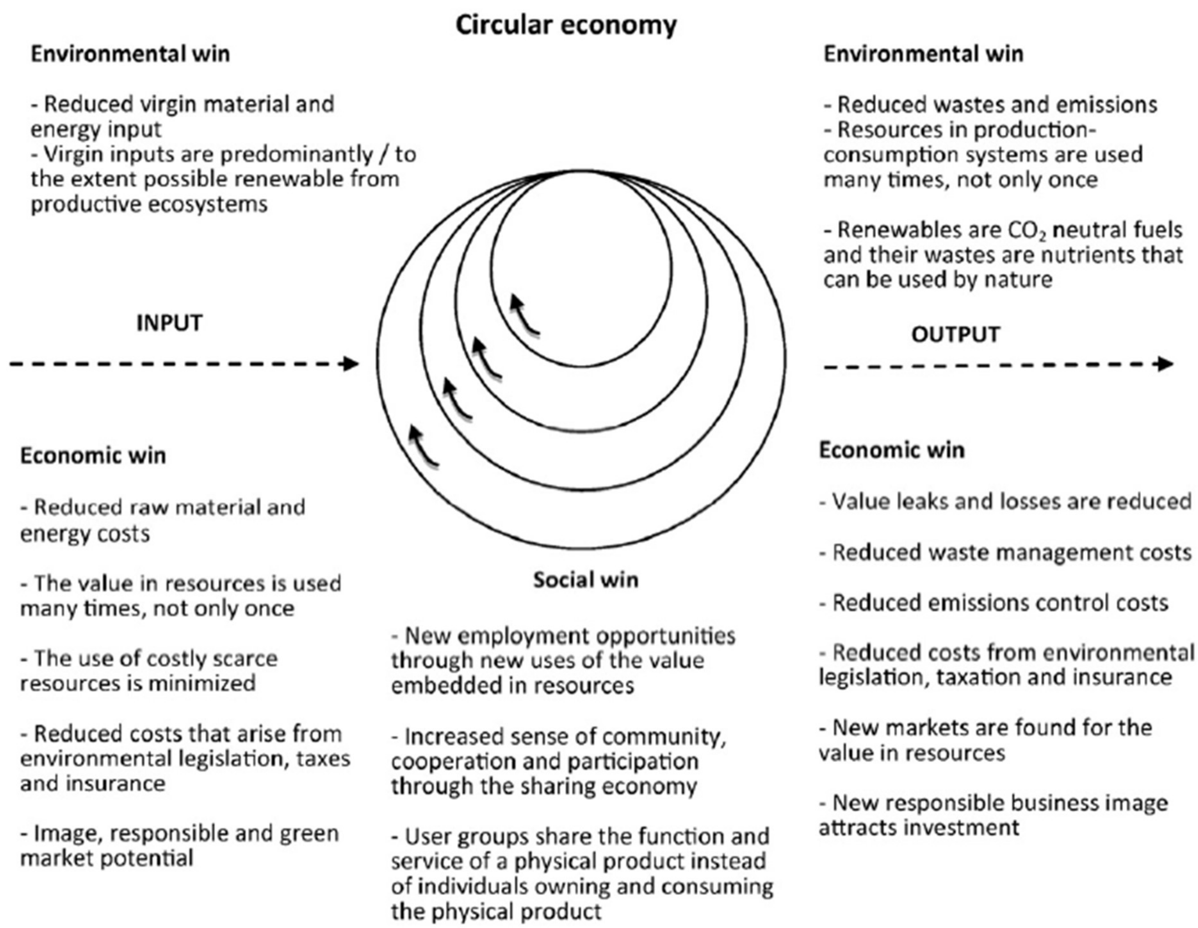

Figure 2: Win-win-win potential of Circular Economy (Korhonen, Honkasalo & Seppala, 2018)

It is important to note that the adaptation of this new economic model brings with it the creation of new business models and industries that strive to keep the value of the materials and products, and to look to provide services instead of products (Cheshire, 2016).

2.2 ORIGINS OF CIRCULAR ECONOMY

It is difficult to pinpoint when the concept of Circular Economy appeared for the first time, however, we can mention professors William McDonough, Michael Braungart, and the architect Walter Stahel as some of the most remarkable contributors to this new model. Stahel was very supportive of the circular economy concept. He wrote a paper called "The Product Life Factor" in 1982. In this, he proposed an economy based on a spiral loop system in order to reduce the energy consumption and the negative environmental impact without affecting the normal economic development of a society (Stahel, 2006).

Figure 3 shows the "self-replenishing system" proposed by Stahel (2006) which includes some characteristics that are considered the principles of the Circular Economy today.

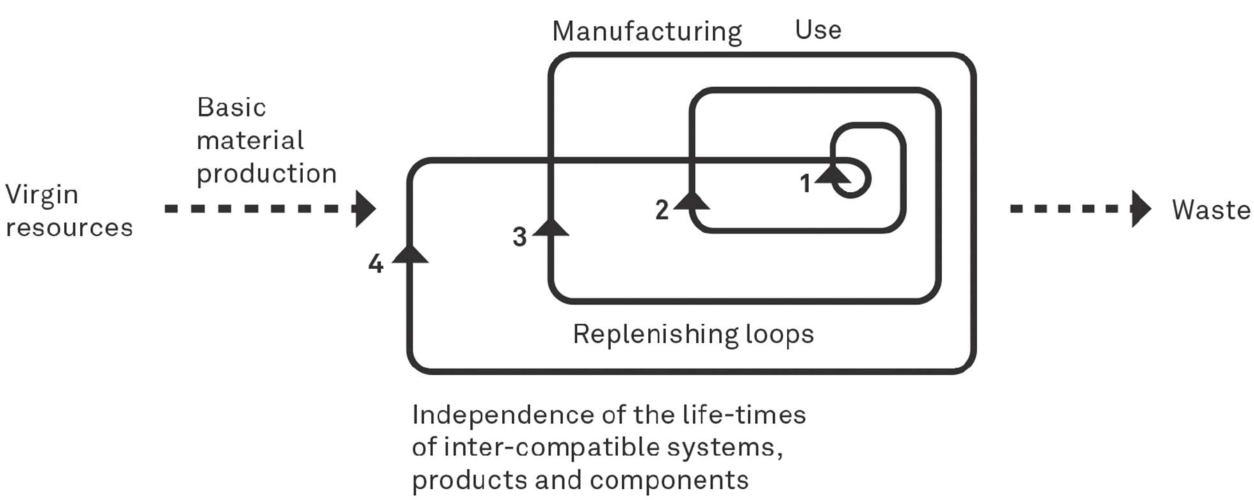

Figure 3: The self-replenishing system (product-life extension) (Stahel, 2006)

The first loop refers to reusing materials/components/products, the second loop represents the repair process, the third represents remanufacture, and the fourth is associated with products and materials recycling.

During the 70's the thesis of the Club of Rome called "limits to growth" provided a general view of the problems that many ancient cultures faced due to negligent management of natural resources and its final consequences (Meadows, Meadows, Randers, & Behrens, 1972).

In the early 90's the concept of Circular Economy was introduced in Germany. It was used to address problems related to raw materials and the adequate use of natural resources to have a sustainable economic growth. In China during the late 90's the concept of CE was introduced along with the term "harmonious society". Both of these emphasized on the development of waste-based closed loops and waste recycling (Winans & Deng, 2017).

Even though this concept is widely applied in Asia and Europe today, there is still a gap between the Circular Economy principles and pillars and the built environments. In North America we see CE as a tool that strives to reduce, reuse, and recycle materials as product of the construction industry but, as we will see ahead in this research, this concept embraces a wider spectrum of ideas and practices.

2.3 CRADLE TO CRADLE THINKING (C2C)

Many of the ideas and concepts related to Circular Economy are closely related to the cradle-to-cradle design backdrop developed and explained by William McDonough and Michael Braungart in their book "Cradle to Cradle: Remaking the way we make things". In this book both authors point out the global problems associated with environmental-friendly solutions and indicate what environmental-aimed practices are not applicable considering our current industries' situation. The cradle-to-cradle philosophy emphasizes the importance of going beyond the circularity concept and strives to get a spiral of continuous improvement (McDonough & Braungart, 2002).

The cradle-to-cradle thinking proposes that instead of focusing on how we can create less damage to the environment, we should focus on how we can be good to it. To set this goal we should think of the environmental system as a whole instead of as a group of small components (the ones that could be affected). For example, when we talk about a new material or product, the design idea should consider the entire lifecycle of this product and how this could affect the environment in any of its phases. The authors also proposed the idea that the natural systems must strive to avoid the unnecessary consumption of materials, products, or services (McDonough & Braungart, 2002). Figure 4 graphically shows the cradle-to-cradle concept that aims to dismiss the eco-efficient approach and replace it with the eco-effective one.

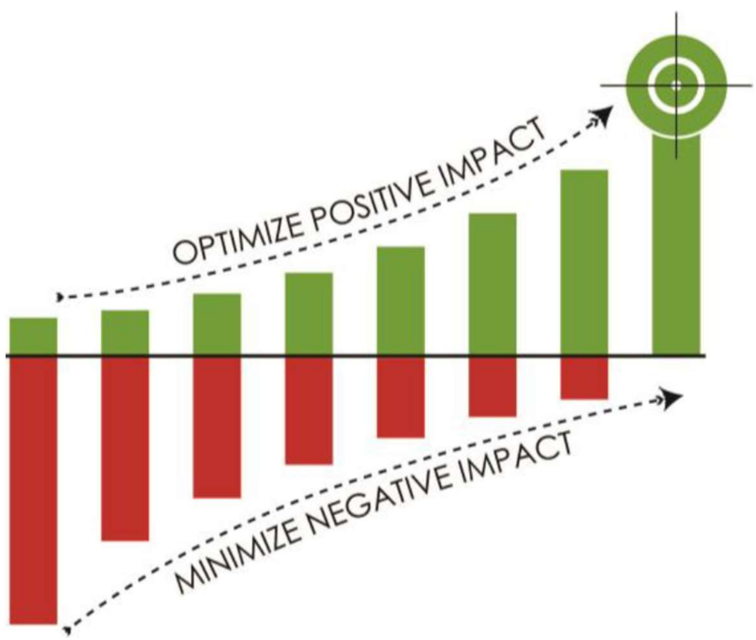

Figure 4: Eco-effective approach vs eco-efficient approach (Toxopeus, Koeijer &Meij, 2015)

It is interesting to see how we can extrapolate these concepts and their philosophy into the construction industry. Many different contractors and fabricators now consider the impact that their products and construction procedures have on the environment and new materials have emerged as improvement proposals. In this framework, materials such as mass timber appear to be a favorable option because it aligns with the main cradle-to-cradle philosophy. Another example is the fabrication and use of 100% water-based paints. This reduces the environmental impact produced by the typical chemicals in paint and creates a safer environment for the workers who are now less exposed to fumes. This new material benefits the environment (waste will be less contaminant when this material needs to be replaced) and improves the life quality of the people who will be close to the paint because they will now not be at risk of breathing any toxic gasses.

2.4 CIRCULAR ECONOMY'S PILLARS AND PRINCIPLES

Circular economy aims to keep materials in a closed-loop at their highest value. According to ARUP (2018), CE is founded on the following pillars:

- Design out of waste and pollution
- Keeping products and materials in use
- Regeneration of natural systems

These pillars are based on a group of principles called "The 11 R Principles" (Cimen, 2021). The principles will be shown in Table 1:

Table 1: The 11 R principles (Cimen, 2021)

Practice	Definition
Replace	Selection of emergent materials with better sustainability characteristics in order to replace the existing ones
Recover	Materials gathered from their initial purpose to be reused or incinerated to obtain energy
Recycle	Materials' processing in order to obtain a new material with different characteristics
Repurpose	Materials reused for a different purpose than was created initially
Remanufacture	Reuse of discarded parts to fabricate a product with the same function
Refurbish	Restoration or update of a product to improve their characteristics
Repair	Fixing a product in order to extend their lifespan
Reuse	Reutilization of a product that was already disposed of by another user or industry
Reduce	Improvement of a process' efficiency to use fewer resources during the fabrication of a product
Rethink	A reconsideration of materials or products usage
Refuse	Avoid products usage in order to diminish its consumption

Figure 5 portrays these principles and their interrelation with the different dimensions of the built environment, the project phases, and the subjects associated with them.

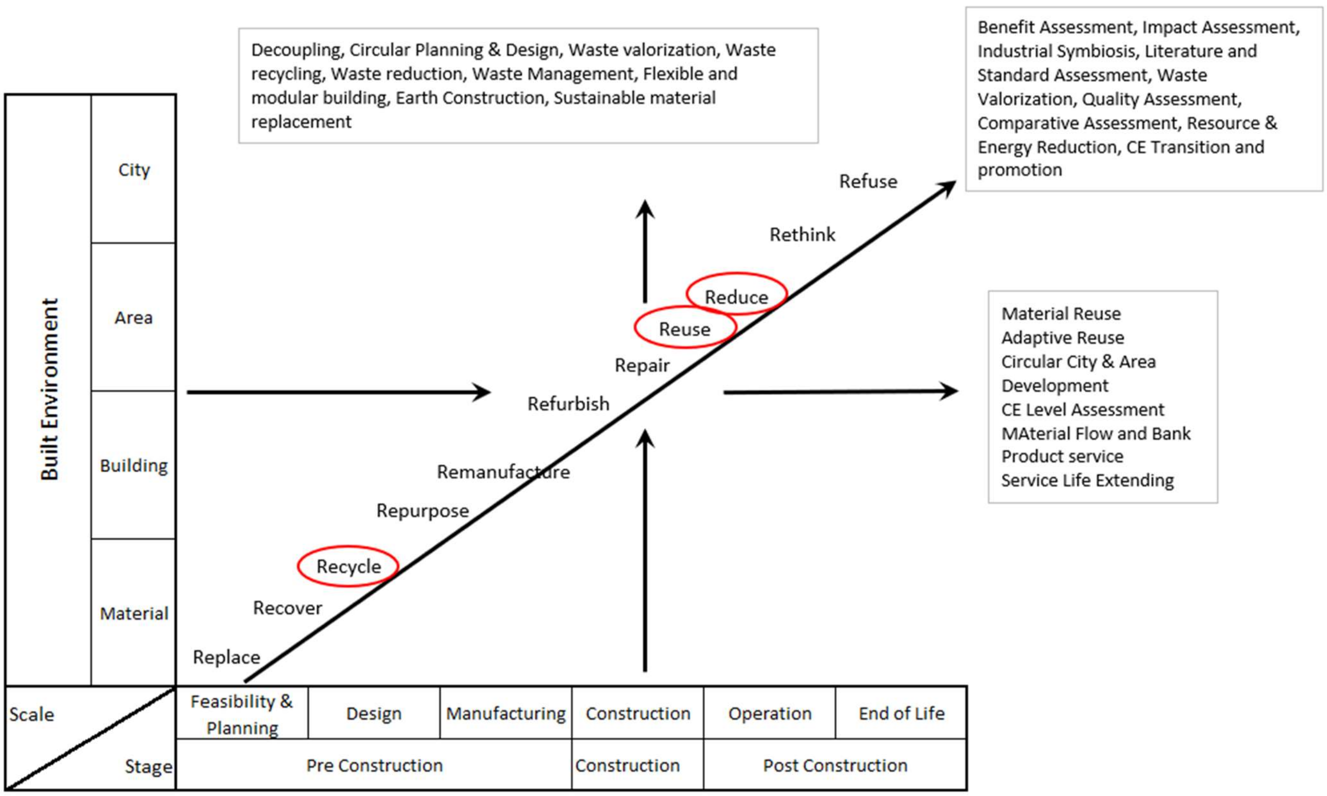

Figure 5: Circular Economy subject development. Adapted from (Cimen, 2021)

The most popular and studied of these 11R's are Reduce, Recycle, and Reuse. They will be explained in detail in the following paragraphs.

2.3.1 REDUCE

This principle attempts to minimize the initial input of energy, raw materials, and waste. It focuses its efforts on improving the production and consumption process. This is done through the implementation of technology, change in the product design, and more efficient use of materials. Even when reduction is a principle of eco-efficiency it does not avoid the degradation and destruction but it merely slows them down. This means that we cause damage in smaller proportions during a longer period of time (Cheshire, 2016).

2.3.2 REUSE

This principle states that any product that will not be disposed of as waste must be used again for the same purpose for which this was initially created (Guisellini et al., 2016). This principle is interesting when the positive environmental impact is considered because it represents a big reduction in resource usage, the energy required, and labor demand in comparison to the manufacture of a new product utilizing raw materials. Critics of this pillar might highlight that the original waste produced (and the chemicals, toxins, and contaminants associated with this) is only transferred to another place (McDonough & Braungart, 2002).

2.3.3 RECYCLE

According to the European Union this principle refers to "any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations" (Guisellini et al., 2016; pp.16).

This principle provides a good opportunity to utilize materials that still have a profitable value, as well as reduces the amount of waste that would need to be treated and disposed on the landfills, thus achieving a decrease in the environmental impact. A critical claim against this principle is that a society that can recycle all its waste will not have enough motivation to reduce the amount of waste generated initially.

2.5 CIRCULAR ECONOMY AND THE BUILT ENVIRONMENT

The built environment puts major pressure on the natural environment; therefore, this must transition to a circular economy (Pomponi & Moncaster, 2017). Buildings are unique entities with their own characteristics and complexities, where each of the materials used has its specific life cycle and all interact dynamically in space and time. Therefore, although buildings are made up of components that are manufactured products, when these products are assembled create an entity that no longer fits into the logic of manufacturing.

In the 1990s, buildings were responsible for 40% of the material and a third of the energy consumed globally. Two decades later, the construction sector is still the world's largest consumer of raw materials, and it accounts for 25-40% of global carbon dioxide emissions. (Pomponi & Moncaster, 2017).

According to Pomponi and Moncaster (2017), the concept of Circular Economy in the Built Environment has six different dimensions and they all need to be interrelated to meet the sustainability goals. Figure 6 portrays these six dimensions. The external arrows mean that all these dimensions should be seen as a whole and not individually and the internal lines showcase the importance of practical links between each dimension.

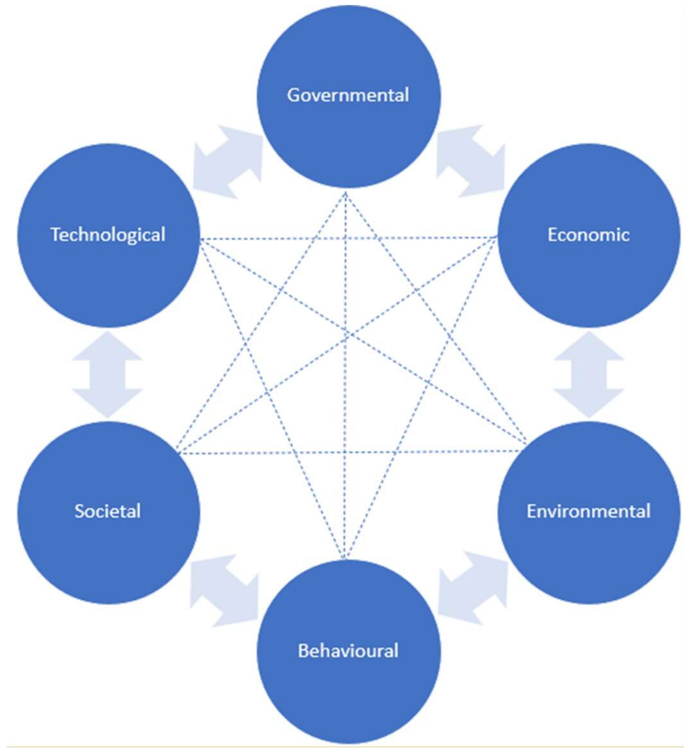

Figure 6: Circular Economy dimensions in the Built Environments (Pomponi & Moncaster, 2017)

2.5.1 CIRCULAR ECONOMY PRACTICES IN THE BUILT ENVIRONMENT

Now that the circular economy philosophy and principles have been analyzed and studied, it can be determined that all these concepts can be extrapolated to the construction and building industry and positively impact it.

In order to implement the idea of circularity, we must "begin with the end in mind." In this case it means that the buildings we design should be more adaptable and that their components and materials must have the potential to be reused at the end of their life. This will allow us to create buildings that will not cause a negative legacy in the community; instead they will generate a positive impact on the environment (Cheshire, 2016).

An example could be that we put more effort into ensuring that the buildings can be disassembled during the design process. This will create an opportunity for their components to be reused or recycled either by the same industry in another project or in a different location, or by another industry that will be able to get an additional value out of these. The goal is to reduce the consumption of raw materials while also creating new business models through the use of second-, third-, or fourth-hand materials.

Under the circular economy philosophy, all materials and components must be able to return to the biosphere without causing damage to the environment. In order to accomplish this, we need to know and understand the elements that are used during the production process of these materials. We must be aware of the cycle that these must follow. We must understand whether these can be reused, recycled, or disposed of. Knowing the compounding elements will allow us to improve the environment for the people who work with these materials and the final consumers like it was explained with the water-based painting case in Section 2.3.

Figure 7 shows an example of how the principles of circular economy could be implemented in a commercial building.

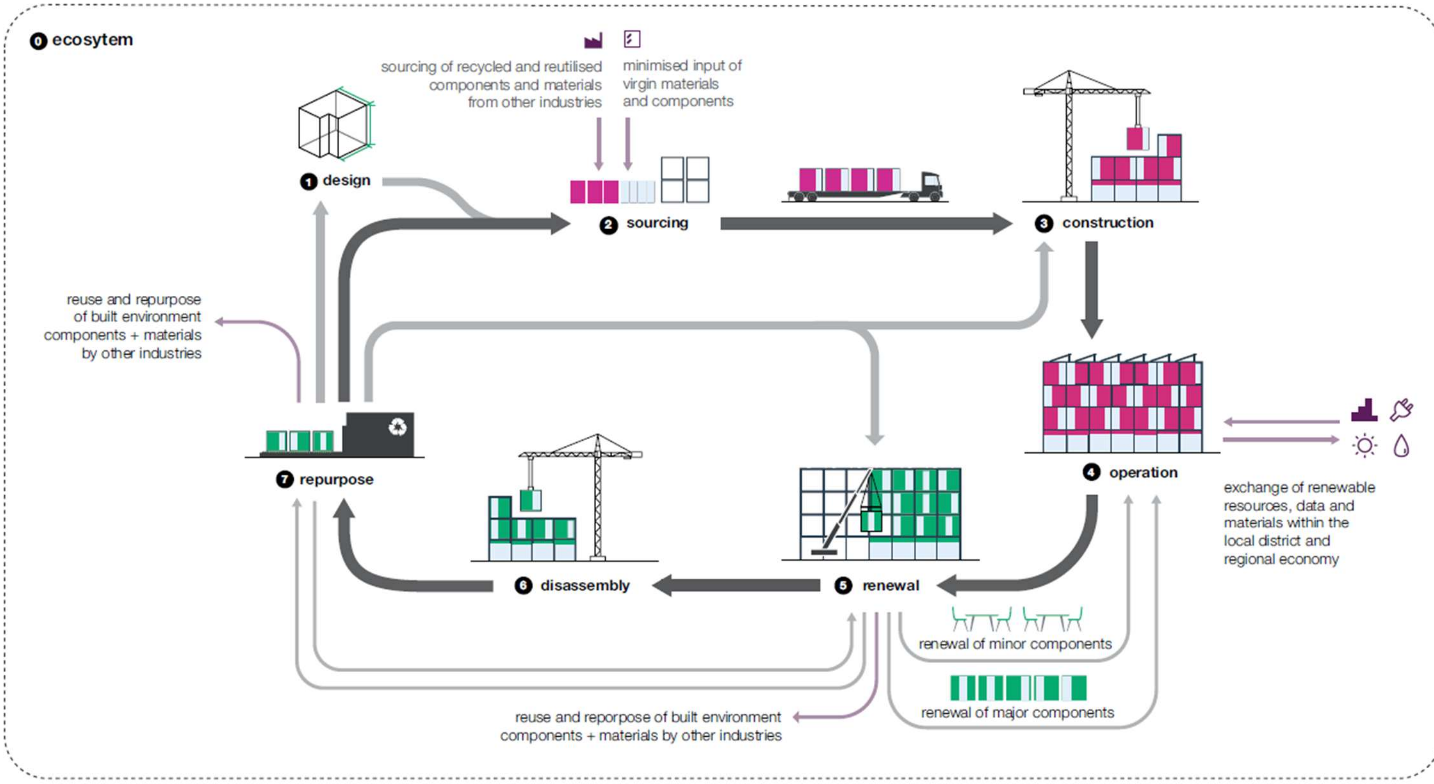

Figure 7: Application of CE principles to commercial construction (ARUP, 2016)

A list of Circular Economy practices was identified and the most popular were sorted considering the project' phase in which they can be applied. Table 2 shows the practices that will be studied.

Table 2: Circular Economy practices

PROJECT PHASE	PRACTICE DESCRIPTION
DESIGN PHASE	Selecting materials and products
	Design for modularity
	Design for adaptability and flexibility
	Design for standardization
	Design for disassembly
	Design for prefabrication
CONSTRUCTION PHASE	Built out of waste
	Building in layers
	Selective Demolition
END-OF-LIFE OR DEMOLITION	Deconstruction or disassembly
	Up-cycling (or closed-loop recycling)
	Down-cycling (or open-loop recycling)

Hereunder, we will provide additional information related to these practices to understand them better.

2.5.1.1 SELECTING MATERIALS AND PRODUCTS

Material and product selection is one of the most important steps during the design development process as well as for the implementation of circular economy practices. The main idea is to create a collaborative environment in which the owner, designer, and contractor work together towards the ideal material selection while considering factors such as local sources, material characteristics, building concept and quality, and environmental goals.

When talking about local sources we mean the act of using native materials from the area where the project is located. The goal is to reduce transportation and mining of materials from abroad, and in turn, to stimulate the local economy.

Material characteristics mean differentiating whether the material is biological or technical. Biological materials are those that could be returned to the environment without any type of treatment for sorting their components and which will be biodegraded naturally. Examples of this type of material are bamboo and timber. If these woods are not chemically treated, they can be returned to the biosphere without causing any negative environmental impact. Technical materials are the ones that are composed of different elements such as polymers and alloys. These types of materials cannot be separated easily (and in many cases it is impossible to separate them). It is, therefore, in many cases preferable to keep these materials in a loop. However, it requires designing them to be reused, remanufactured, or recycled. An example of technical materials can be found in the elements that go into the creation of something that is 3D printed because 3D printers have the possibility to mix different material types to obtain a final product with "improved" characteristics. Nevertheless, at the end of its life cycle, the materials from the 3D printed object cannot be separated into their individual components, so its final destination must be disposed of.

Building concept and quality can be influenced by the selection of reused or reclaimed materials and components. Many owners and designers consider second-hand materials as materials of lower quality, nevertheless, this idea should be eradicated. The building codes often do not even consider the reuse of materials as a viable option, so this possibility requires special attention during the design process. The purpose of building a "new" building is to ensure that its components will be disassembled at the end of their life cycle and that these components and materials can be reused or remanufactured.

Buildings and materials' lifespan is crucial for material selection. The structural elements of a building will have a longer lifespan than fixtures or fittings. In many cases this analysis is not performed leading to a significant waste generation in early phases of the building' lifecycle. For example, elements or components with a shorter lifespan could be designed with the use of biological materials so that these materials can be returned to the biosphere without complications once their lifecycle come to an end. Materials with a longer lifespan must be designed and fabricated to be resistant, disassembled, upgraded, or recycled (Cheshire, 2016).

2.5.1.2 DESIGN FOR MODULARITY

Off-site construction has become more popular in both academia and industry in the last years and modular construction, in particular, is one of the most efficient off-site construction methods (Kamali, 2016). The main characteristic of modularity is that different building components and elements are designed and fabricated off-site and individually. An example could be materials that are constructed at a fabric and then brought together and assembled to become a final product.

According to Kim (2020), modular construction can be classified by materials in steel-framed modular, wood-frame modular, and CLT-frame modular. It can also be classified by composite method in componentized modular, panelized modular, and volumetric modular. Componentized modular refers to a standardized component of a structure, such as an MEP system, while an example of panelized modular could be a wall or a roof system which might include elements such as insulation, drywall, electrical, or plumbing elements. Volumetric modular refers to a complete unit such as a room or bathroom which might include some external finishes and even façades.

Kamali (2016) demonstrated that modular construction could be applied to different building types: commercial, educational, and medical. Up to 85-90% of a building could be executed off-site leaving the remaining 10-15% to be built onsite. This includes activities such as foundations and utility hookups. The benefits of this construction approach are that it can improve the productivity rate, reduce the stoppages due to bad weather, reduce the waste generated in the project and, in the end, create a better-quality product. A critical point of this method is that the application is limited because of the experiences of the general contractors, the availability of vendors and suppliers, and the complexity of the projects.

2.5.1.3 DESIGN FOR ADAPTABILITY AND FLEXIBILITY

It is uncommon to find a building that has been occupied by its original tenant for a long period of time. Because of this, buildings continuously require renovation to fulfill the new tenants' requirements and preferences depending on the business type, the image that the tenants want to project, and even the technology that they use. We need to understand that it is different to design a building that will be flexible or a building that will have the possibility to be adapted to new and different uses.

We must determine the difference between a flexible building and an adaptable one. The first is a building that has been designed to allow an internal refurbishment to meet the requirements of a new tenant. An adaptable building is one that is designed to be suitable for new uses or patterns and can be modified (by adding or subtracting elements) to extend the buildings' lifecycle.

Many buildings have demonstrated to be adaptable more by accident than by their original design. For example, many old Georgian and Victorian houses have been adapted into offices, restaurants, or malls. Although these buildings had not the required characteristics, they were adapted to avoid their depreciation and, eventually, their demolition.

How can we design a building that will be adaptable? The answer is designing open buildings. Designers and owners cannot forecast the future, but factors like the building location, building concept, lifespan, market trends, and some unforeseen scenarios (risk analysis) can be considered.

The idea behind Open Buildings is to create a building that will last beyond the intended use since it can be adapted to other functions. Why do we want adaptable buildings? The built environment is in constant change and transformation and is therefore a product of a never-ending design process (Cheshire, 2016). Brand (1994) wrote in his book "How Buildings Learn: What Happens to Buildings after they're Built" that designers must consider how buildings can be used in the future in order to reduce the probability of designing a building that can only serve one purpose. He also explained that architects, apart from being artists of space, could become artists of the time, allowing the buildings to change in the time.

2.5.1.4 DESIGN FOR STANDARDIZATION

Design for standardization refers to the use of determined components, products and elements for the construction. It proposes the idea that it might be easier for the contractors to assemble and disassemble any structure built from standard components mainly because the labor would be repetitive (International Standard ISO 20887, 2020). Design for standardization also supports the implementation of the practice design for adaptability and flexibility in addition to the re-use of building components.

Standard elements could be referred to as standard dimensions. For example, a standard height, length, and size of some timber elements, insulation panels, or masonry elements. Also we might use the term standard connections to refer connecting parts that can easily be separated without causing damage to the original components. It could, for instance, be steel or timber connections.

Modularity is a wider and more complex dimension. Standard modules can easily be assembled or disassembled according to the owner's needs and requirements. In this case, standard grid dimensions, heights, lengths, and component characteristics come together to create an adaptable living area or working environment (International Standard ISO 20887, 2020).

2.5.1.5 DESIGN FOR DISASSEMBLY

As it is written in the name: Disassembly refers to the decoupling process of different elements or components that conform a building. This could, for example, be the non-structural elements such as flooring, finishes, and even the building's cladding. This process is focused on the material separation and can be developed at any stage of the life cycle of a building.

Design for disassembly is the practice of planning the future deconstruction of a building and the reuse of its components and materials (Cruz & Grau, 2020). This practice is based on the recovery of most of the building components without damaging them. This is done in order to reuse, remanufacture, or recycle these components. Buildings must be designed in a way where it is considered in advance what should be done with their elements at the end of their lifespan – they must be designed in a way that enables the disassembly process.

Some of the most popular principles utilized to achieve this goal are the following (Cheshire, 2016):

- Utilize mechanical connections instead of chemical ones just like coatings, resins, or adhesives

- To provide the building with an easy access to the designed connections. Embedded connections are not recommendable because they will require at least a partial destruction of any building component
- Design the building considering all their elements separated or, in other words, in layers (structure, finishes, cladding)
- Standardization of components, dimensions, and materials quality
- The final set of as-built drawings must also consider a demolition plan to provide information about the disassembly process that must be followed
- Building's fixings must be durable enough to remain operative in order to facilitate the removal of the elements when required

The value of a component will be determined by its condition at the moment when it is disassembled. The value is made up by considering the effort that is required to refurbish it and the quality that this element will have when used again.

Design for disassembly would be one of the best practices to implement in the built environment in order to pursue a circular economy philosophy. Though, the practice is not that easy to incorporate because it will require additional labor during the deconstruction process. Often is the time invested more worthy than the outcome of this practice, and it might be difficult to justify the additional labor used. A lot of research is conducted to find innovative jointing methods that make the re-utilization process easier and more profitable in the future.

We must also consider the barriers associated with this practice. An example is the immature development of salvaged materials market, the lack of quality of the materials recovered as well as the lack of a building code that supports and regulates the reuse of the materials recovered.

2.5.1.6 DESIGN FOR PREFABRICATION

Off-site construction has become more popular all around the world. The United States is no exception. Prefabrication is the practice that involves the fabrication of building elements in a warehouse or another location and the subsequent transportation of these elements to be assembled on the construction site (Global Infrastructure Hub, 2022).

The following list is of the most relevant advantages offered by prefabrication:

- Waste reduction
- Lower interferences generated due to bad weather
- Improvements in the quality of the final product
- Higher productivity rates and shorter schedules
- Reduction of the environmental impact (air, water, noise)

This practice cannot be applied to all projects, but it requires special project characteristics to be effective. One of these characteristics is the project's level of replicability or redundancy. The building or project must have many similar elements or standard components. An example of this type of building could be hotels, hospitals, and apartment units.

The continuous implementation of technology into construction such as the use of BIM, virtual design and construction (VDC), augmented reality (AR), and virtual reality (VR) are boosting the cooperation among owners, designers, and contractors, which in turn, is boosting the implementation of prefabrication. However, the lack of experienced vendors, suppliers and contractors, in addition with the level of uniqueness of the project are among the main factors that can mitigate the implementation of prefabrication.

2.5.1.7 BUILT OUT OF WASTE

The decisions made at the early design phases of a project have a significant impact on the volume of waste generated during the construction phase and at the end of its lifespan. We must understand that the waste generated for a material is related to not only its final disposal but also to the extraction method utilized, the manufacturing process, and the maintenance required to keep its value.

When we talk about Circular Economy in the Built Environment, we might think that the materials must only come from the construction industry. This is a misconception. The idea widespread by the Circular Economy philosophy is that the Built Environment should have the ability to use the "waste" that is generated for another industry as a source. This practice can be boosted if owners, designers, and contractors agree to ensure that the recovered materials will fulfill the building quality requirements and comply with the current building code.

We might refer to the concept explained by Lean Construction which states that waste is any task that does not create any additional value (Kim, 2020). According to Kim (2020), waste can be reduced in construction by migrating from on-site construction to off-site construction. This migration allows the construction team to control better the production process, quality assurance, and productivity rates. With off-site construction, most of the on-site activities would be related to the assembling process of the prefabricated products.

Technology provides us with tools that can be applied to reduce the waste generated on-site. BIM is one of the most popular tools used today. It allows for a better coordination process between designers, contractors, suppliers, and subcontractors. BIM tools such as clash detection would allow the different teams to identify areas and elements that might collide with each other while saving time and money and boosting the process of waste reduction.

One of the last options available to reduce generated construction waste is using standard modular components (modularity) because its innate nature makes the installation process more manageable.

2.5.1.8 BUILDING IN LAYERS

Circular Economy principles might be challenging to apply to a building due to its innate complexity and the variety of pieces and components' lifespans that conform to them. However, the concept of Building in Layers helps designers to solve this issue. This practice allows designers to approach each of these elements and components of the building from a different standpoint.

Building in Layers is based on the concept of building different components separately, considering factors such as material lifespan, design requirements, material characteristics, and quality requirements. This type of construction separates the building elements based on their lifespan. The structure of a building can, for instance, be designed to have a lifespan of at least 20 years while furniture is designed to have a more frequent rotation. Another example is using electrical wires or water pipes embedded inside concrete walls or other durable finishes. The placement of these elements beneath the wall is inconvenient because the lifespan of the pipes is shorter than that of the concrete wall. Therefore, the wall will eventually be damaged to replace the pipes.

Brand (1994) explains in his book "How to Buildings Learn" that a building can be separated into six different components. These are shown in Figure 8:

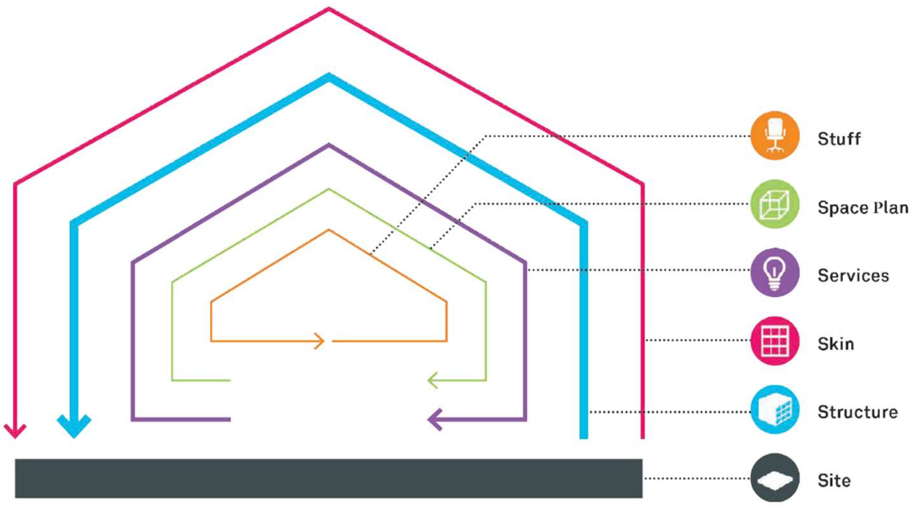

Figure 8:Six different components of a building (Dams, Maskell, & Shea, 2021)

The structure, façade, services, walls, ceilings, and furniture must be separated (Brand, 1994). Building in Layers benefits other phases of a building too. For instance, the components with a shorter lifespan or elements requiring permanent maintenance should be more accessible to facilitate it during the operation phase. An example of this can be the building's boilers which must be maintained to ensure the users of the building's comfort.

It is advantageous if elements can be disassembled separately and without affecting or damaging adjacent elements during the deconstruction. This characteristic is essential if the plan is to reuse the components or materials.

2.5.1.9 SELECTIVE DEMOLITION

Selective demolition consists of a group of activities that aim to separate and sort different building elements and materials such as bricks, metals, doors, timber, pipes. and provide them with a new life. One of the main purposes of this practice is to increase the value of the building's components through the redirection of materials which instead of ending up in a landfill will generate additional value for the owner.

The selective demolition process offers the following advantages in comparison to the traditional method (Pantini & Rigamonti, 2020):

- Reduces the amount of waste deposited in landfills, which in turn helps the land preservation
- Revalorize construction materials that could have been considered waste, thus reducing the consumption of raw materials
- Generates a positive environmental impact through the reduction of waste and the need for raw materials
- It has the potential to reduce the demolition costs due to a lower landfill charge and the possibility of selling the materials recovered

The demolition process faces some difficulties as well. An example is the fact that most of the existing buildings have not been designed to be dismantled into different components. For instance, materials composed of different layers or elements such as coatings or finishes are impossible to be separated considering the technology required and the associated costs.

This practice is also ruled by the possibility of re-using the recovered building components, the development of a market for second-hand materials, and their competitiveness in terms of price, quality, and reliability. The last aspect that must be considered is the lack of building codes, regulations, or mandates to regulate and boost the use of the materials recovered.

There are both pros and cons associated with selective demolition. Opponents point out that this practice requires additional time, more physical space, and more skilled laborers, which generates additional costs to the project. A thorough assessment should be performed to understand the project goals not only in terms of money but also in terms of environmental matters. All in all, selective demolition is much better for the environment than traditional demolition. Pantini & Rigamonti (2020) demonstrated that selective demolition produces a significant improvement in the environment in terms of energy reduction, fossil resource depletion, and mineral resource consumption. An economic analysis is likewise essential because the positive impact could be diminished if the materials are not adequately managed, the transportation distances are excessively long, or there is not a strong market supporting this practice.

2.5.1.10 DISASSEMBLY OR DECONSTRUCTION

Disassembly is related to the disconnection of non-essential and individual parts that conform a building (non-structural elements, internal finishes, carpets and flooring, wall panels). Deconstruction refers to removing the structural elements of a building - and the subsequent relocation of the different parts. Deconstruction differ from disassembly in that it refers to the disconnection of the structural elements or sections of a building to rebuild a new building without the need for any additional adaptation. While disassembly is related to the recovery of some building components to make them reusable (Grady, Minunno, Chong, & Morrison, 2021).

2.5.1.11 UP-CYCLING

The up-cycling concept refers to remanufacturing or repurposing a material that was initially considered waste into a product of the same quality or better. An example of the upcycling process would be re-utilizing a steel beam for the same purpose in a different project. This practice states that a positive environmental impact can be generated in 2 ways: reducing energy consumption (especially during the refurbishment process) and avoiding the material's disposal. (Oyenuga & Bhamidimarri, 2017).

Upcycling allows contractors and designers to remember the 3R's principles explained in Section 2.3 (Reduce, Reuse, and Recycle), in which the reuse principle refers to that materials should be used again and again to fulfill the purpose these were created for.

2.5.1.12 DOWN-CYCLING

The down-cycling system considers the processing of an original product in order to obtain a different product with a lower value (Guerra & Leite, 2021). An example of down-cycling is the use of crushed concrete as an aggregate to fabricate lower-quality concrete.

2.6 BARRIERS AND DRIVERS OF IMPLEMENTATION OF CIRCULAR ECONOMY PRACTICES

There are different barriers associated with the implementation of Circular Economy practices. Amongst these, the most popular are the ones related to project costs and schedule, lack of regulations to support the implementation of these practices, lack of markets to commercialize materials, and lack of awareness of the concepts related to circular economy.

Table 3 shows the results obtained by Guerra and Leite (2021) during their research that was developed in 2021. The research explains the main barriers and enablers identified according to a group of designers, contractors, and suppliers all around the United States. Even though these results were not conducive due to the limited number of developed interviews, they still provide us with a general framework that allows us to perform a similar analysis.

Table 3: Circular Economy barriers and drivers (Guerra & Leite,2021)

Barriers	**Drivers**
- Budget and upfront cost	- Education and cultural change
- Shedule and project timeline	- Data availability
- Lack of awareness and change resistance	- Policies and market-based incentives
- Current construction business model	- Popularization of new voluntary stewardship programs
- Lack of regulations and implementation guidelines	

Another study provides us with data related to the barriers and enablers of circular building design (Cruz et al., 2021). This study developed a more profound description and analysis than Guerra and Leite, and the results are shown in Table 4. Even though the description of the barriers and enablers is more detailed in this new research, it is only based on the designers' opinions. This research ultimately neglects the perspective of general contractors, owners, and suppliers who play an important role in the construction sector. Likewise, the new research does not analyze the enablers or drivers, but the authors provide solutions based on their experience.

Table 4: Barriers and drivers to Circular Building Design (Cruz et al., 2021)

Barriers	**Drivers**
- Cost and schedule constraints	- Establishment of policies of zero waste to boost reuse over recycling
- Lack of regulations that support CE practices	- Establishment of goals related to reusable or salvaged components
- Lack of support of the construction players	- Improve the level of education in topics related to Circular Economy
- Lack of awareness about CE principles and concepts	- Allocation of federal funds for initiatives focudes on CE
- Lack of standardization and transportability of building elements	- Raising public awareness of CE through public campaigns
- Conflicting goals between the project and CE philosophy	- Development of technology to support materials' tracking
- Lack of integration of the building components	- Creation of tax deduction policies for CE design strategies

Most of the enablers proposed by Cruz et al. (2021) are related to public policies to boost the implementation of Circular Economy. The profound analysis developed on the barriers will be used to group the answers obtained during the interview process. This exercise will help us to better understand the construction stakeholders’ perspectives from different points of view.

CHAPTER 3 - RESEARCH METHODOLOGY

3.1 RESEARCH OBJECTIVE

The objective of this research is to address the following questions:

- What are the most common Circular Economy practices implemented in Construction?
- What are the enablers and barriers for the implementation of Circular Economy practices in the construction industry?
- Who is the main driver leading the implementation of Circular Economy practices in the construction industry?

3.2 RESEARCH PROCESS

A research process comprised of eight steps was performed to answer the questions mentioned above. The first phase addressed the topic identification. Given that the environmental impact caused by the construction industry is a discussed topic nowadays, the practices proposed by circular economy appear as an efficient approach to reduce this negative impact.

A literature review was performed during the second phase of the process. This included the analysis of different sources such as books, papers, webpages, and articles. This part is used to gain knowledge about the circular economy, its pillars, objectives, practices, enablers, and barriers.

The third phase focused on detecting all potential gaps. Most of the literature about CE comes from Europe and Asia, so this step included adapting CE principles to the United States and local construction market. Factors such as the cultural, geographical, and economic differences were taken into consideration. This gap identification created the foundation that was later used to develop the questions that will be approached in the following chapters.

The research design was finalized during the fourth phase of this research. Based on the available information and the local construction market, survey and interviews appeared as the best alternatives for collecting data. Prospective participants were identified through the contact information obtained from the Associated General Contractors of America (AGC) and the University of Washington Construction Industry Advisory Council (CIAC). A total of 15 individuals were recruited. Each of these individuals answered a short survey and was interviewed by March 2022.

The main goal of the interviews was to discuss a list of 12 Circular Economy practices with a group of construction stakeholders to determine the level of implementation of these practices in their projects, the enablers and barriers, and the identification of the stakeholder that drives the implementation of these practices.

An approval from the Institutional Review Board (IRB) at the University of Washington was required before conducting any interviews. Because this thesis involved the use of interviews that poses little to no risk to any potential research population, the research qualified for an "exempt status".

The fifth, sixth and seventh phases of this research consisted of the participants' invitation & selection, survey data collection, and interview data analysis. Based on the information obtained in phase 4, the research team decided to reach out to a group of owners, designers, prime contractors, and subcontractors. These potential participants were contacted by email and asked about their availability and willingness to be part of the research (see Appendix A).

A pre-interview survey was sent to the participants who demonstrated the topic's most significant interest and knowledge. This survey was comprised of a group of questions that allowed us to understand the participants' background and experience, their level of involvement during the decision-making process, and their companies' role, size, and characteristics. Interviews were conducted with the participants that answered the pre-interview survey. The questions asked during these interviews are included in Appendix C. The interviews were recorded for later analysis. These served to identify similarities and differences in the participant's answers concerning the topic addressed. After the data analysis was concluded, these records were deleted to guarantee the participants' privacy.

The eighth and final phase of the research is comprised by discussion and conclusions. Conclusions were drafted based on the results that were obtained in phases sixth and seventh. The analyzed interviews provided enough information to identify similarities among the interviewees. The answers helped the research team differentiate the viewpoint of each of the parties that were involved in the research. Figure 9 shows all the phases developed during the research process.

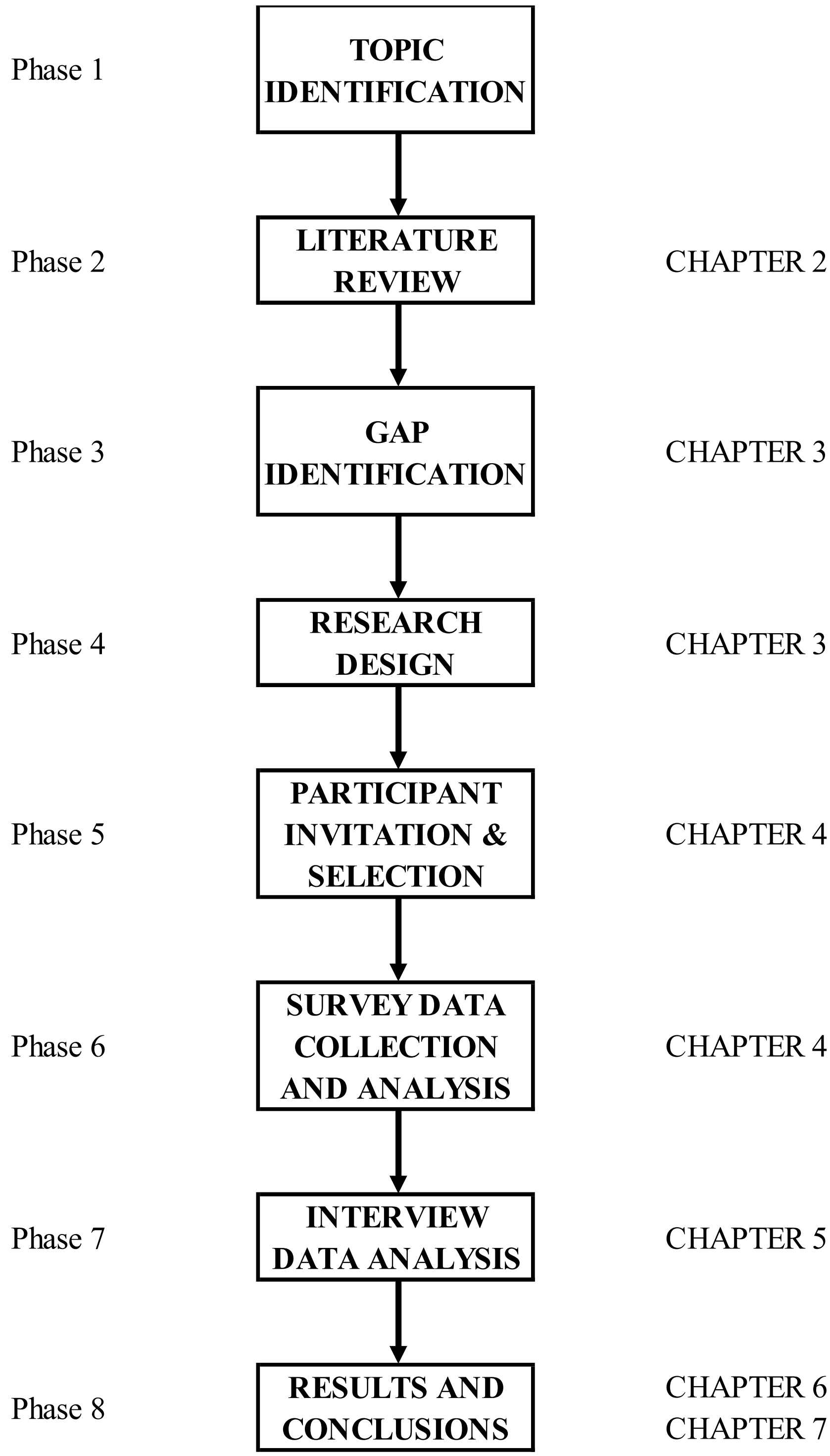

Figure 9: Research process

3.3 PARTICIPANT INVITATION AND SELECTION

A diverse group of owners, designers, prime contractors, and sub-contractors were invited to participate so that we could examine comments and insights from different perspectives and backgrounds. A copy of the participants' invitation is included in Appendix A. Some of the responses received included the contact information of additional people interested in participating in the research. Finally, surveys were sent and interviews were arranged with the participants who showed the greatest interest and knowledge in the topic.

3.4 DATA COLLECTION

The research questions were separated into three different groups. The first group of questions aimed to identify the interviewees' background and professional experience in the industry. These questions were formed to provide us with a better understanding of the interviewees' background, level of experience, and the role they occupy in their companies. The second group of questions aimed to obtain information about the interviewee's company. The answers to these questions provided us with information about the type and size of the participants' company, the type of project they have worked on, and their level of involvement during the decision-making process. The first and second groups of questions were part of the pre-interview survey and were delivered through an email to be returned in advance to the interview. Once these questions were answered, interviews were arranged. A copy of the first and second group of questions will be included in Appendix B.

The third group of questions was explored during the interviews and aimed to discuss different points. The first point was the level of implementation of [P-1 to P-12] in recent projects. The second point was to assess the possibility of implementing [P-1 to P-12] in future projects using a scale of 1 to 5, where 5 meant “most probable to apply”. The third point was to identify the enabler and barriers to [P-1 to P-12] implementation. The fourth point was to identify the stakeholders that drive the decision to implement [P-1 to P-12]. As previously mentioned, this group of questions was discussed during the interviews using the platform Zoom. The goal of the interviews was to understand the awareness of industry leaders about the application of circular economy practices in the construction sector in the Pacific Northwest. Additionally, interviews also investigated the identification of major barriers to the implementation of these practices and the enablers that could boost the transition to a circular economy in the construction industry.

CHAPTER 4 - SURVEY DATA COLLECTION AND ANALYSIS

4.1 PARTICIPANT INVITATION AND SELECTION

A total of forty (40) invitations were sent by email to different potential interviewees without differentiating the type or size of the companies or the interviewees' positions in their companies. The participants were introduced to the topic in the invitation and asked about their willingness to participate in this research (more detail in Appendix A). We gave the participants 10 days to answer. Afterward, an initial conversation was held with the ones who showed interest in participating in this research.

Twenty-nine responses were received (72.5%) out of the 40 invitations sent. Some of these responses included the contact information of the most suitable person in the respondent's company.

4.2 DATA COLLECTION

A pre-interview survey comprising the first and second groups of questions explained in Chapter 3 were sent to the prospective interviewees. The answer to these questions provided us with a better understanding of the background and professional experience of the participants. Once these groups of questions were answered, video calls were arranged based on the availability of the interviewees. The data described in this section is based on the responses from fifteen construction industry participants in the Pacific Northwest. This represents 37.5 percent of the total number of invitations sent (40). The summary of the responses collected in the pre-interview survey will be shown in Appendix D. The analysis of the responses obtained will be discussed hereafter in this chapter.

4.3 ANALYSIS OF PRE-INTERVIEW SURVEY RESULTS

4.3.1 INTERVIEWEES' LEVEL OF EDUCATION

The participants were asked about the highest level of education they completed. As appears in Figure 10, seven of the respondents completed a master's degree and the eight remaining respondents completed a bachelor's degree. Hence the level of education of the participants is from medium to high level.

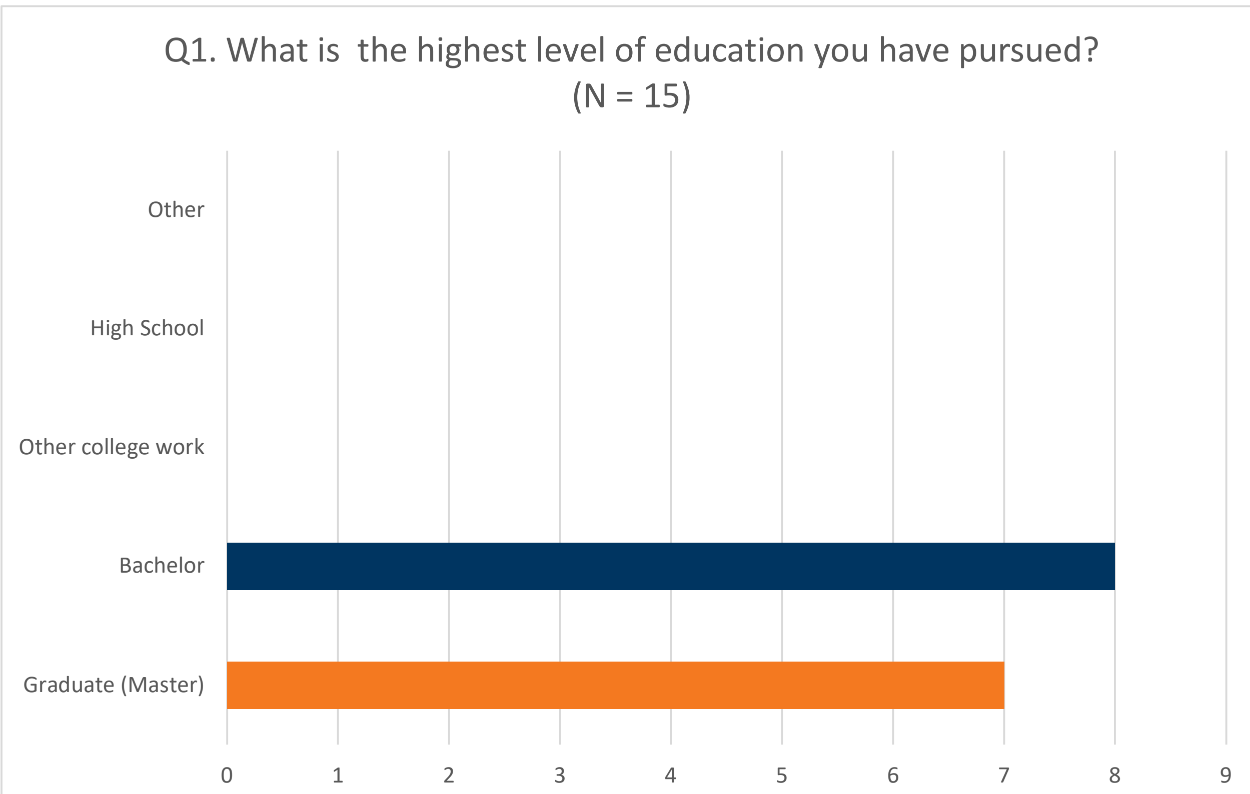

Figure 10: Interviewees' level of education

4.3.2 INTERVIEWEES’ GENERAL EXPERIENCE

To understand the interviewee’s level of experience they were asked how many years they have been working in the construction industry. The answers are portrayed in Figure 11. One-third of the respondents have been in the construction sector for more than 20 years. Another third of respondents have between 10 to 20 years of experience. Three out of the 15 respondents have between 5 to 10 years of experience. One respondent has only of 3 to 5 years of experience and another respondent have less than 3 years of experience in the sector. These results indicate the vast experience of most of the interviewees.

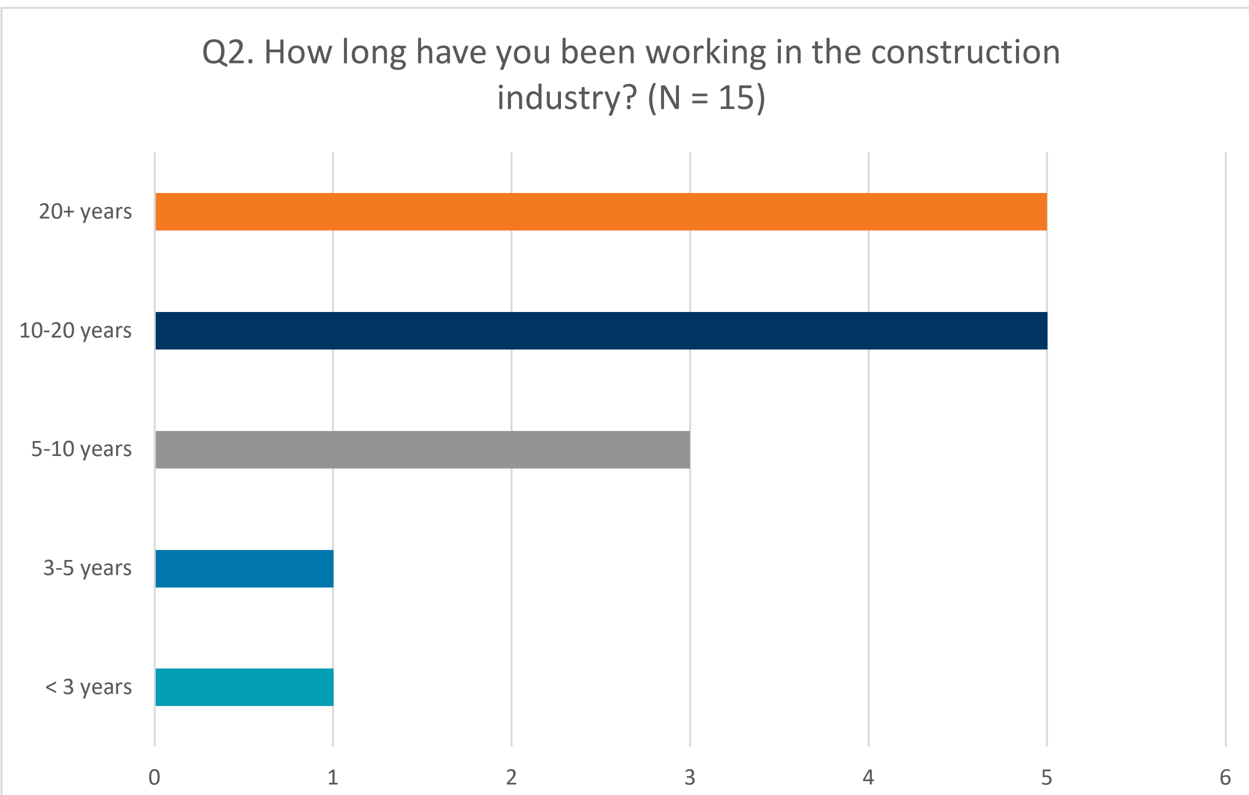

Figure 11: Interviewees' general experience

4.3.3 INTERVIEWEES' CURRENT POSITION

The interviewees were asked about the position that they currently occupy in their companies. This information helped us understand the level of influence they have during the decision-making process. Out of the fifteen interviewees, six of them are working in a Company Executive position, two are Project Executives, and six perform the role of Project Manager. Only one of the participants is a Designer/Architect and three respondents are either sustainability managers or preconstruction managers. Results are shown in Figure 12. These responses show the high level of responsibility hold by the interviewees in their companies.

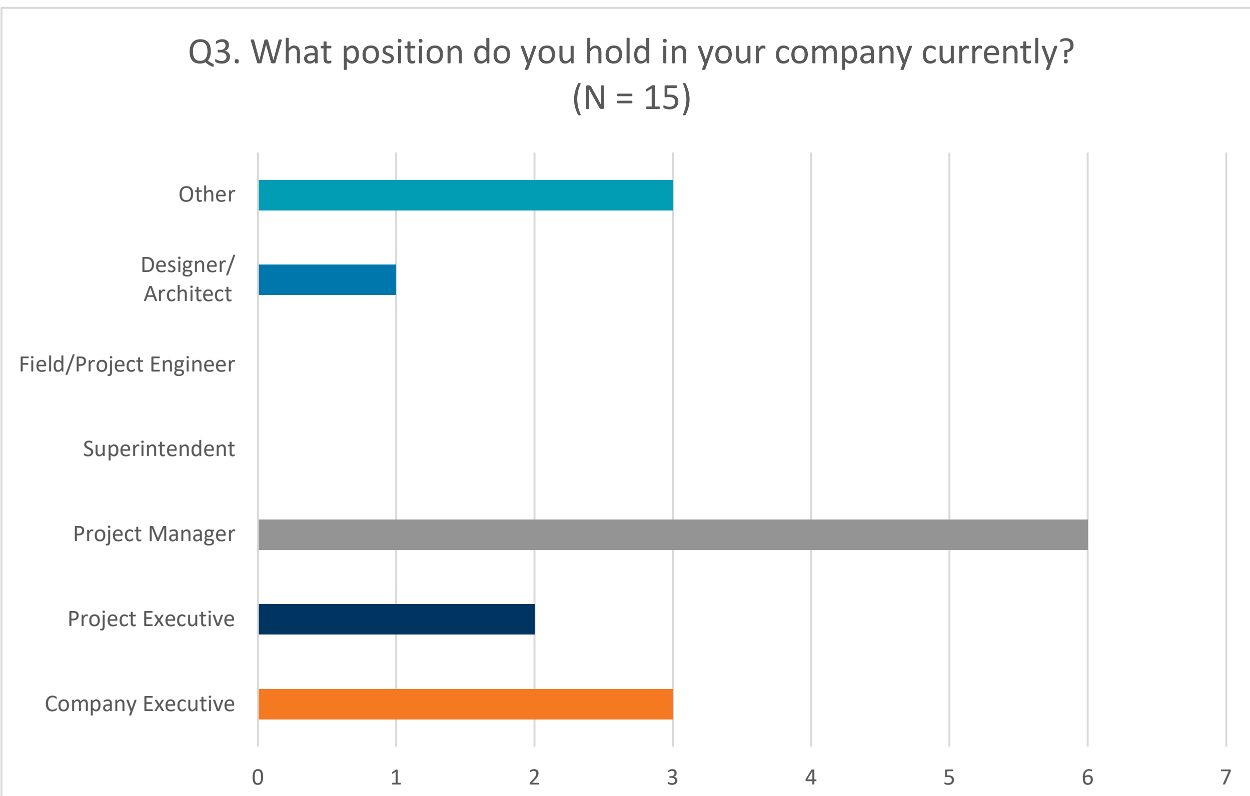

Figure 12: Interviewees current position in their companies

4.3.4 INTERVIEWEES' NUMBER OF YEARS OCCUPYING THEIR CURRENT POSITION

Participants were asked how long they have been working in their current positions. This information helped us understand their level of experience with decision making and solutions proposals from their respective positions. Figure 13 displays the results obtained. Only two respondents have been in their positions for more than 20 years. One has been in their current position between 10 and 20 years and another has been working in their current position for more than 5 years but less than 10. The majority (eight participants) have been current occupying their positions between 3 and 5 years. Three respondents have been in their current positions less than 3 years. These responses suggest that most of the participants have medium experience occupying their current positions.

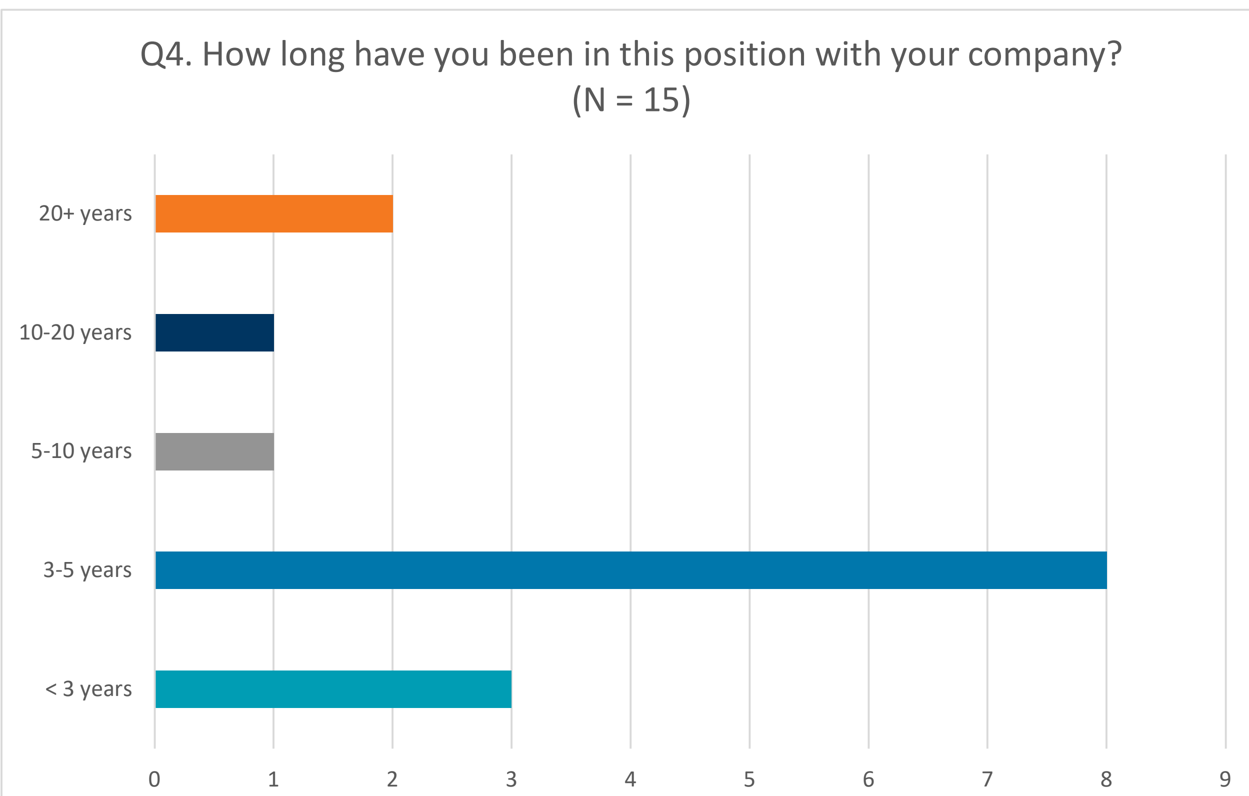

Figure 13: Years of experience in your current position

4.3.5 LARGEST PROJECT APPROXIMATE VALUE

The interviewees were asked about the value of the largest project they were part of in the last 3 years. This helps us understand the size of the project that the participants have worked on recently. Figure 14 shows the highest value of the project that the participants have worked on. Ten participants have worked on projects with a value higher than 100 million. Two participants have worked on projects with a value between 50 and 100 million, and two participants have worked on projects with a value between 15 and 30 million. It is important to note that most of the participants who worked on projects with a value higher than 100 million dollars are employed for a Prime Contractor. Interviewee 7 did not provide an answer to question 5. She indicated to have joined to her company recently, and because of this, she had not been assigned to any project yet.

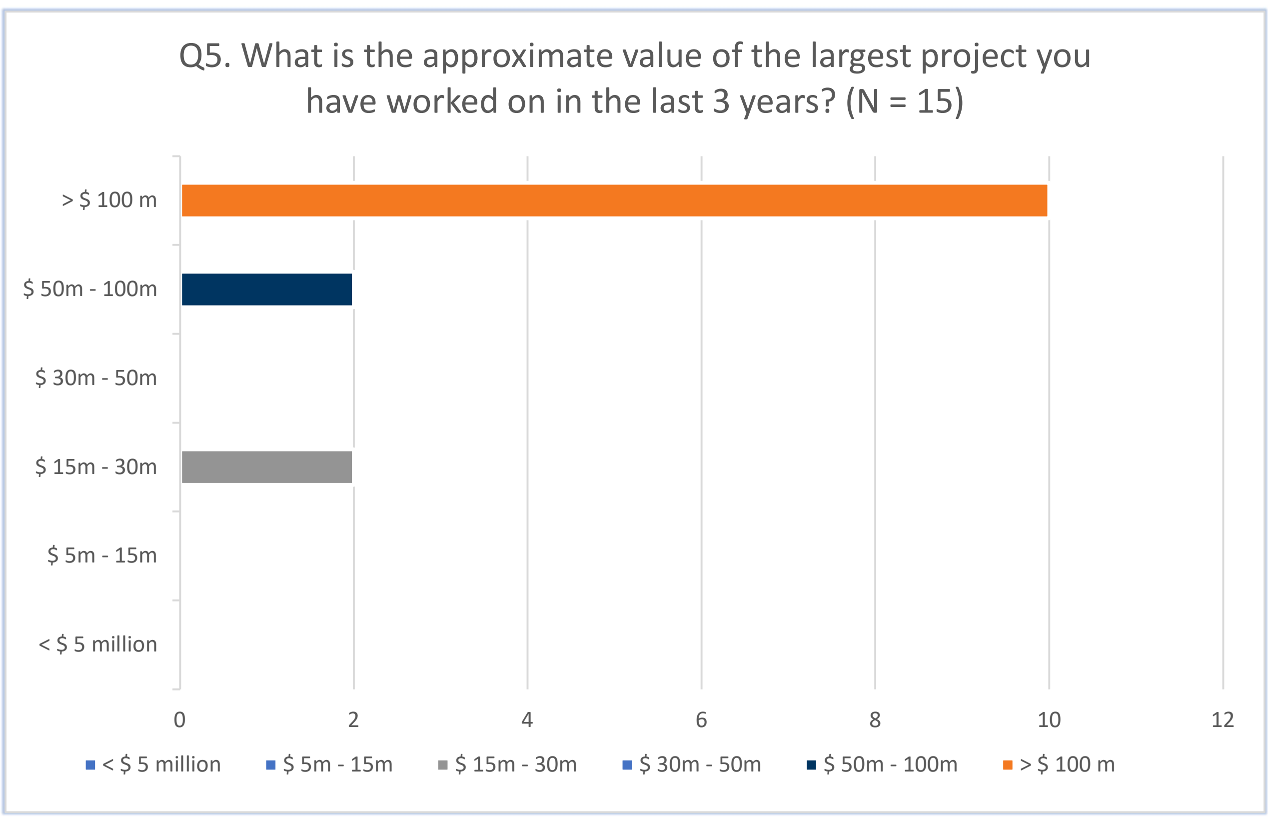

Figure 14: Approximate value of your largest project

4.3.6 ROLE OF THE INTERVIEWEES' COMPANY

To understand the role that the participants' companies have in the construction industry we asked if their companies hold the role of Developers, Designers, Prime Contractors, Sub-Contractors, or others. Figure 15 shows the answers. Nine of the respondents work for a Prime Contractor (60 %). Three works for an Owner/Developer (20 %). Two works for a subcontractor (13 %), and one works for a design company (7 %). This proves that most of the respondents work for a Prime Contractor. This occupation is deeply related to the value of the projects that the participants have worked on before. This information helps us understand the level of influence of the participants during the design and construction phases.

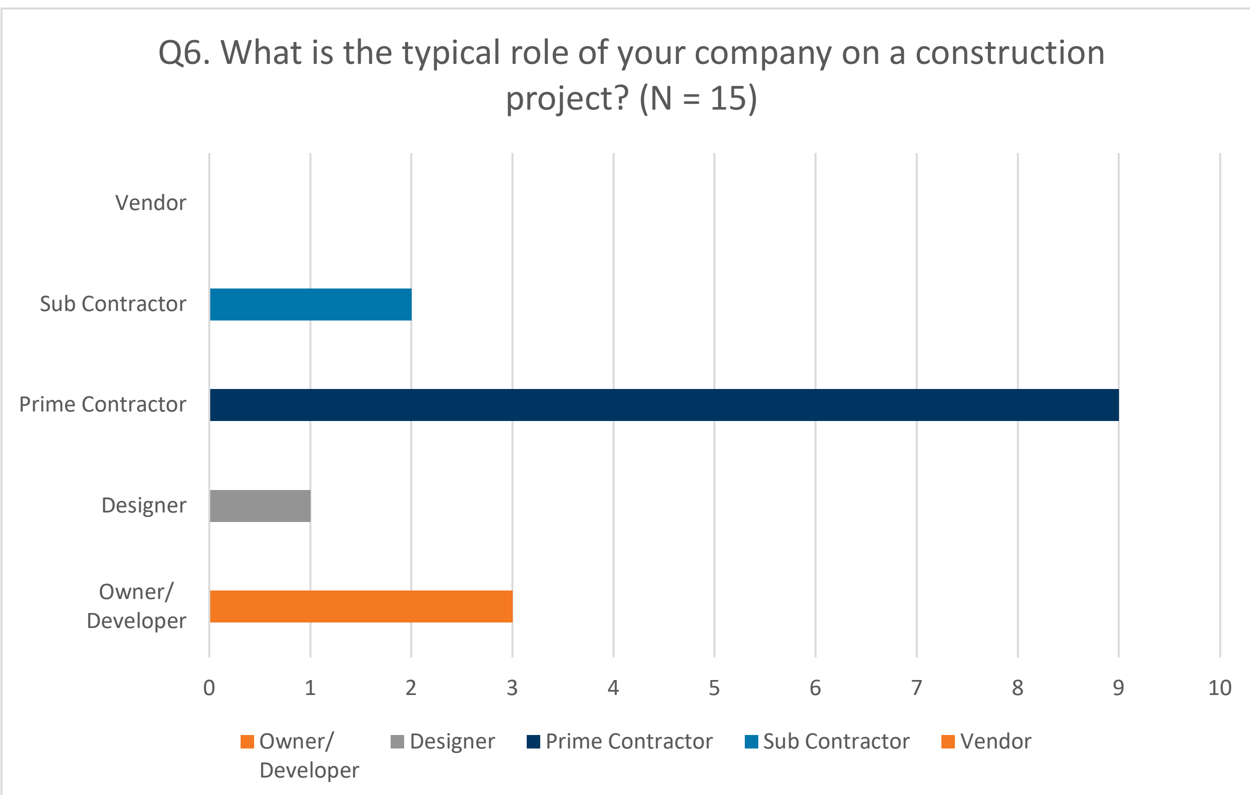

Figure 15: Role of your company

4.3.7 COMPANY'S AVERAGE REVENUE

Respondents were asked about the average revenue of their companies in the last 3 years. We use this information to determine the size of the companies. Figure 16 portrays the answers. Two respondents work for companies that have an annual revenue higher than 1 billion. Five respondents work for companies with annual revenue between 500 million and 1 billion. Five respondents work for companies with annual revenue between 250 and 500 million. Two participants work for companies with smaller revenues (100 to 250 million), and one participant work for a company with an annual revenue lower than 50 million. This information is useful to understand the company size of the respondents, according to the results obtained, most of participants work for medium to large construction firms.

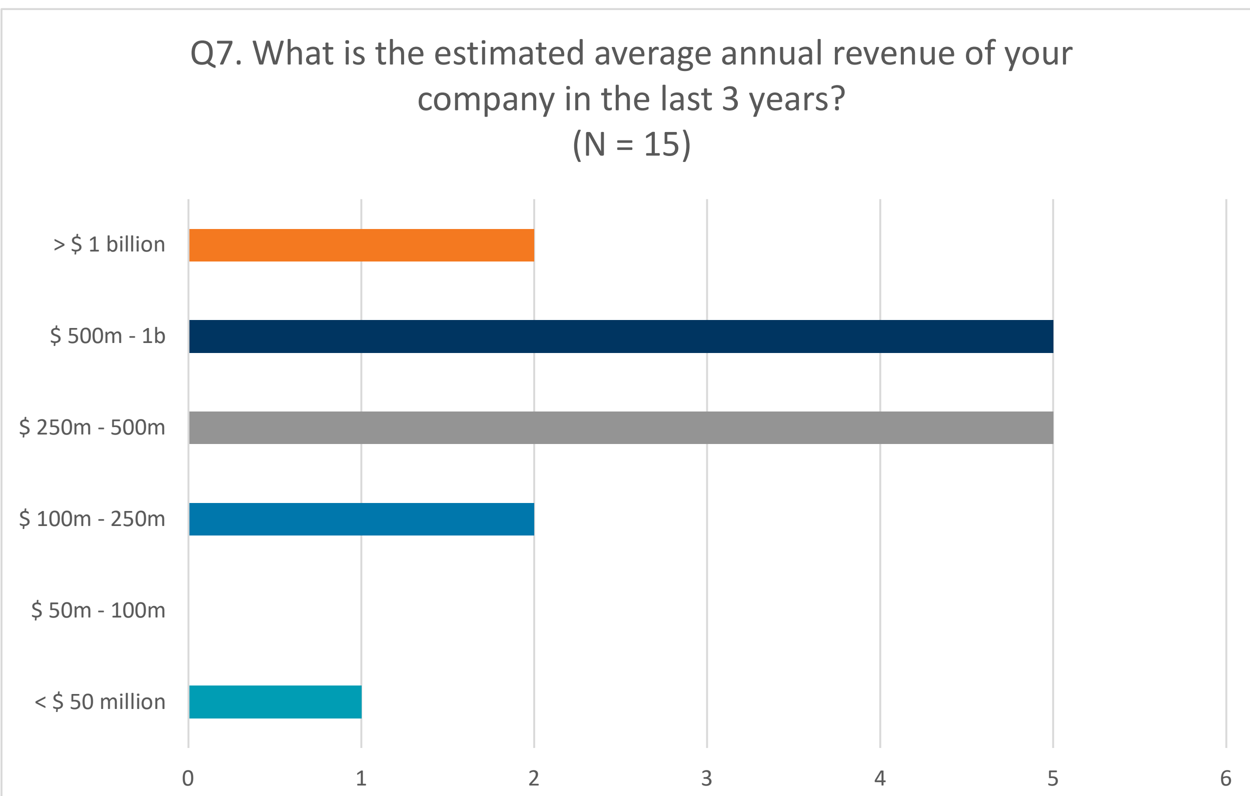

Figure 16: Company's average annual revenue

4.3.8 LEVEL OF INVOLVEMENT IN THE DESIGN DECISION-MAKING PROCESS

To determine the influence of the respondents during the design phase we asked them about their level of involvement in the decision-making process. Figure 17 portrays the answers. Four participants (27%) said that they are fully involved in the decision-making process. Eight participants feel that they are somewhat involved (60 %) and two participants said that they are aware but not involved (13 %). These results show that most of participants are somehow involved in the decision-making process during the design phase.

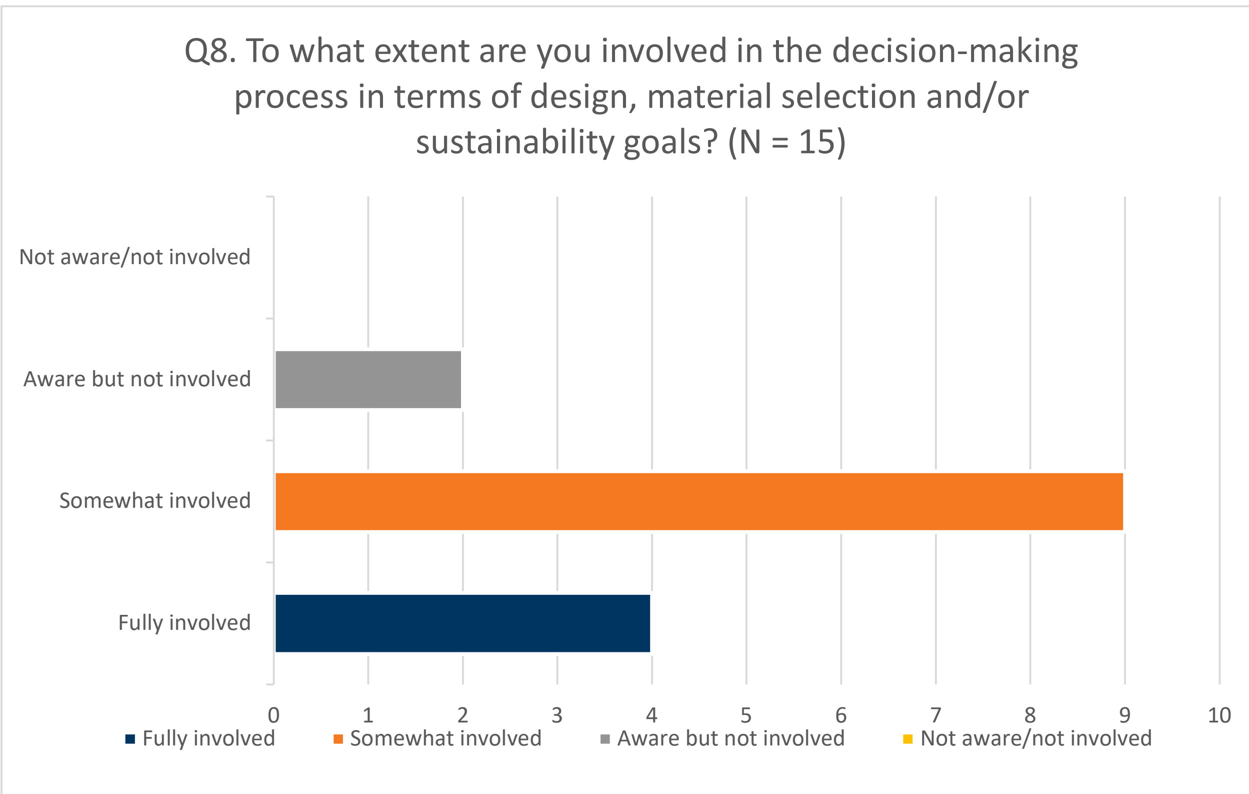

Figure 17: Level of involvement in the design decision-making process

4.3.9 MOST COMMON DELIVERY METHOD USED BY THE INTERVIEWEES' COMPANY

The participants were asked about the most common delivery method used by their companies in their projects. Figure 18 portrays the answers. Seven participants mentioned that the most common delivery method used by their companies was CM@Risk or GC/CM. Five participants affirmed that Design-Bid-Build was the most common delivery method used by their companies. Two respondents said that Design-Build was the most common for their companies and only one participant mentioned that IPD is the most common delivery method used by his company. Some interviewees mentioned that even when their companies have a predominant delivery method used in most of their projects it is not necessarily the method that they use for all projects.

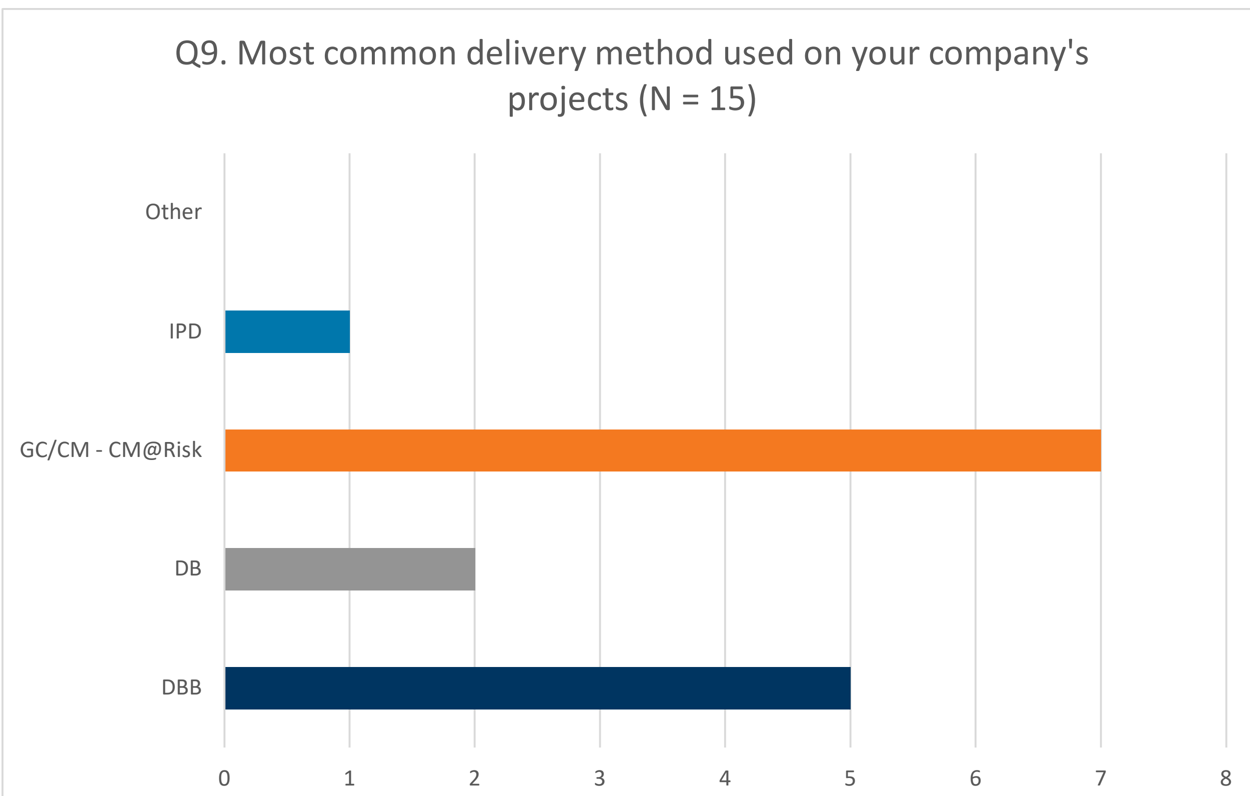

Figure 18: Most common delivery method used for your company

4.3.10 MOST COMMON TYPE OF CONSTRUCTION PROJECTS IN INTERVIEWEES' COMPANY

Participants were asked about the project type in which their companies are involved. The answers are shown in Figure 19. All except one of the respondents (14 out of 15) said that the most common type of construction project is Commercial or Institutional Building. The other participant works mostly in Healthcare projects. Two respondents said that Infrastructure/Heavy Civil is another type of project that their companies work on in addition to Commercial projects, similarly, four respondents said that their companies work on Residential projects and two respondents said that their companies work on Healthcare projects.

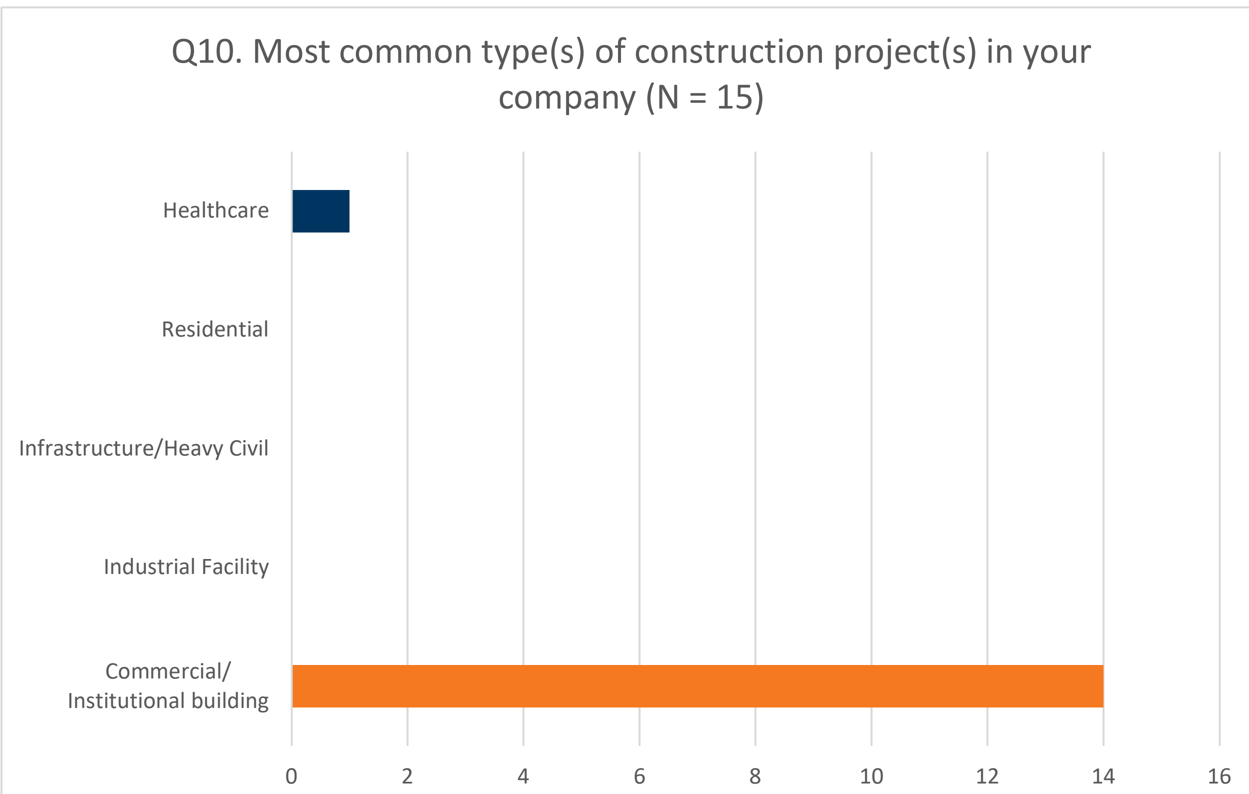

Figure 19: Most common type of construction project

4.3.11 LEED CERTIFICATION

The participants were asked if they had any type of LEED certification. We ask this in order to understand how familiar the participants are with sustainability topics. The answers appear in Figure 20. Seven participants mentioned having a LEED Green Associate Certification (47 %). Three participants have a LEED AP Specialty Certification (20%). Two participants said having another certification and three interviewees mentioned not having any certification but they said that they have general knowledge about the topic.

Figure 20: LEED certification

CHAPTER 5 - INTERVIEW DATA ANALYSIS

5.1 OVERVIEW

Once the fifteen participants responded to the pre-interview survey, they were interviewed using the platform Zoom. The recommendations and guidelines provided by the Human Subjects Division of the University of Washington were followed to conduct these interviews. An interview guide was used during the interview that included questions related to the implementation of Circular Economy Practices in the Pacific Northwest. The interview guide was formatted into a slide deck that helped the conversation over Zoom; this slide deck is included in Appendix C. The answers obtained from these interviews will be shown and discussed further in this chapter. It is important to point out that the enablers and barriers were classified into seven groups based on the participant's responses. These groups served as the basis for creating radar charts that visually explain the main enablers and barriers to each practice. Further description of these enablers and barriers will be provided in Table 5 and Table 6. The summary of the responses regarding the enablers and barriers is shown in Figures 21 and 22.

Table 5: Enablers Description

ENABLER	DEFINITION
E-1 Supply Chain Environment	The Supply Chain Environment refers to the material, suppliers, and vendors' availability in the market. This enabler is particularly important for Design for Prefabrication because this practice requires specialized manufacturers to provide building components and elements.
E-2 Regulatory Environment	This enabler refers to the regulation, policies, and codes that boost the implementation of sustainable practices and the emergence of solutions to generate a positive impact on the environment.
E-3 Preconstruction	Preconstruction refers to the services provided by the prime contractor prior to the project's beginning. Amongst the most common preconstruction services we have scheduling, cost analysis, constructability analysis, value engineering, etc.
E-4 Project Success Factors	Project Success Factors refer to the positive impact on any of the 4 construction pillars: schedule, cost, quality, and safety. This enabler was pointed out as one of the most remarkable because of the benefits that it generates to the project.
E-5 Contractual Requirements	This enabler refers to the requirements established by the owner or the architect in the contract documents. These requirements are usually defined in the specifications, drawings, and general and special conditions.
E-6 Technology	This enabler refers to the use of technology in construction. BIM, virtual design and construction (VDC), augmented reality (AR), and virtual reality (VR) are classic examples of this enabler.
E-7 Training	Training refers to the education of professionals, especially in topics related to sustainability.

Table 6: Barriers Description

BARRIER	DEFINITION
B-1 Poor Stakeholders Experience	This barrier refers to the lack of experienced stakeholders in the local market. An example of this practice is the lack of reliable subcontractors and vendors to build using modular components.
B-2 Building Codes	This barrier refers to the current building codes that rule the construction sector. This barrier is particularly important for practices such as Up-cycling and Down-cycling because most of the materials' quality requirements are established in the building codes.
B-3 Cultural Barriers	This barrier refers to the old mindset rooted in the construction industry. Resistance to change and unwillingness to implement new construction practices and methods are examples of this barrier.
B-4 Construction Business Model	The Construction Business Model refers to the current model that rules the construction sector. This model is based on a take-make-use-dispose system which generates a massive amount of waste.
B-5 Design Characteristics	Design Characteristics refer to the "uniqueness" factor associated with the projects. Many owners desire a building with special characteristics to be distinguished from the rest. However, this uniqueness factor limits the possibility of implementing determined circular economy practices such as modularity, standardization, and prefabrication.
B-6 Project Constraints	This barrier refers to the scheduling and cost constraints of a project. Every project has a determined budget and duration that cannot be exceeded. The success of a project is directly related to these factors.
B-7 Jobsite Physical Constraints	This practice refers to the lack of physical space to store building materials and components. Laydown area is especially important when practices that require additional space will be implemented, for example, prefabrication, selective demolition, or disassembly.

ENABLER	P-1 Selecting Materials and Products	P-2 Design for Modularity	P-3 Design for Adaptability and Flexibility	P-4 Design for Standardization	P-5Design for Disassembly	P-6Design for Prefabrication	P-7 Built out of Waste	P-8 Building in Layers	P-9 Selective Demolition	P-10 Disassembly	P-11 Upcycling	P-12 Downcycling
E-1 Supply Chain Environment	2	2	0	2	2	3	1	0	4	2	4	3
E-2 Regulatory Environment	3	0	1	1	3	0	1	0	0	2	2	1
E-3 Preconstruction	3	4	7	2	2	3	3	1	1	2	3	1
E-4 Project Success Factors	5	8	1	9	1	12	4	4	6	4	5	3
E-5 Contractual Requirements	6	5	7	3	6	2	2	5	8	7	3	6
E-6 Technology	0	0	2	0	1	1	1	1	2	0	2	0
E-7 Training	3	0	0	0	0	0	5	0	2	0	1	1

Figure 21: Enabler's summary (N = 15)

Figure 21 portrays the results obtained regarding the enablers identified. The numbers in the boxes refer to the number of times the interviewees mentioned an enabler while the practices [P1-P12] were discussed. The boxes painted in green show the main enabler to each practice while the boxes painted in yellow show the secondary enablers. It is important to remark that the participants mentioned a main and secondary enabler in some cases. This is the reason why the total sum of the numbers (vertically) is not 15.

BARRIER	P-1 Selecting Materials and Products	P-2 Design for Modularity	P-3 Design for Adaptability and Flexibility	P-4 Design for Standardization	P-5Design for Disassembly	P-6Design for Prefabrication	P-7 Built out of Waste	P-8 Building in Layers	P-9 Selective Demolition	P-10 Disassembly	P-11 Upcycling	P-12 Downcycling
B-1 Poor Stakeholders Experience	7	7	1	5	4	5	2	2	1	3	2	2
B-2 Building Codes	1	1	1	1	3	0	0	3	1	3	4	4
B-3 Cultural Barriers	1	2	2	0	1	0	8	0	1	0	0	0
B-4 Construction Business Model	1	0	0	0	1	0	2	1	2	3	2	1
B-5 Design Characteristics	6	10	5	5	5	7	4	4	3	6	1	1
B-6 Project Constraints	6	0	9	5	5	1	2	3	12	2	4	5
B-7 Jobsite Physical Constraints	0	1	0	2	0	5	1	1	3	2	2	1

Figure 22: Barriers' summary (N = 15)

Figure 22 shows the summary of the barriers identified for each practice. The numbers in the boxes refer to the number of times the interviewees mentioned a barrier while the practices [P1-P12] were discussed. The boxes painted on green display the main barrier identified while the boxes on yellow show the secondary barriers. It is important to point out that the participants mentioned a main and secondary barrier in some cases. This is the reason why the total sum of the numbers (vertically) is not 15.

Each of the enablers and barriers painted, whether green or yellow, will be discussed in detail in the following sections.

5.2 SELECTING MATERIALS AND PRODUCTS

Fifteen interviewees said that they have used this practice on recent projects. When interviewees were asked to assess the possibility of applying P-1 in future projects, they gave P-1 a score of 4.79 out of 5. The score obtained suggests that this practice will likely continue being implemented in future projects.

Interviewees indicated that the delivery method selected influence directly the level of power of the stakeholders during the decision-making process. Under Design-Build and IPD the Prime Contractors possess more authority during the selection of materials and products. By contrast, in Design Bid Build and GC/CM projects the Prime contractors are limited only to providing an opinion about material options and products.

Twelve interviewees mentioned that the key stakeholder that drives the implementation of P-1 is the Owner. Interviewees mentioned that the Designers also play an important role. Interviewees indicated that factors such as the project location, budget, and the current building codes are factors considered by the designers during the materials selection process.

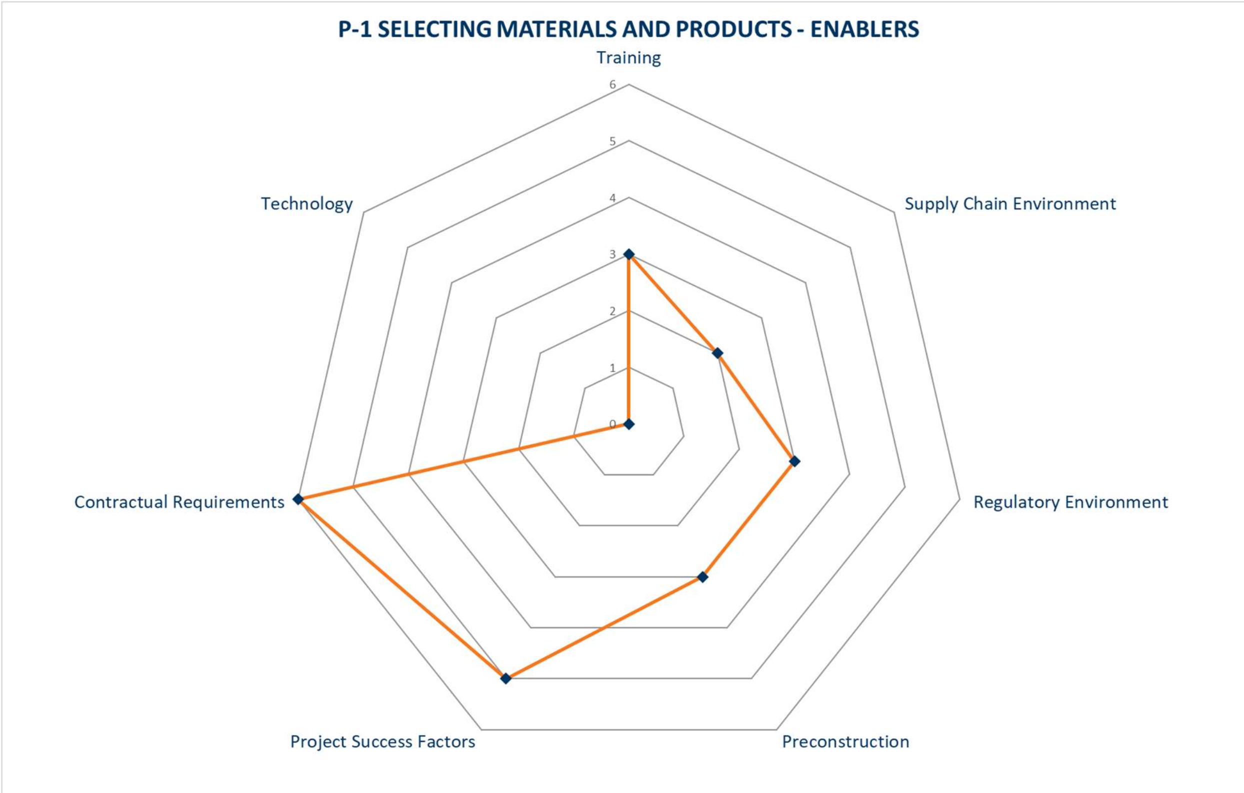

Figure 23:Enablers to P-1 Selecting Materials and Products

According to Figure 23, the main enabler for implementing P-1 Selecting Materials and Products is the *Contractual Requirements*. Interviewee 6 pointed out that the specifications provided as part of the contract documents are the guidelines for the prime contractor. Any decision or suggestion regarding materials or products must be aligned with these specifications. About this enabler, Interviewee 6 mentioned the following:

> "We have some restrictions when it comes to the spec's, we do a lot of preconstruction before we actually work on anything, we are constantly getting recommended ideas from subcontractors of what we should submit in our proposals which drives updates to the spec's for the project […]"

The second biggest enabler to P-1 is the *Project Success Factors*. Regarding this enabler, Interviewee 6 pointed out the following:

> "[…] when we see an opportunity for something that we can get much quicker, which generally means that it's closer, you know, not foreign, I guess, or coming from overseas, or anything like that, we definitely try and push it that way because it's generally cheaper, not really cheaper because of the material, but more so cheaper because we can get it sooner and build faster and it brings our schedule timeline down which saves money for the owner"

Interviewee 4 said that, in his opinion, the *Training* of professionals and the *Regulatory Environment* plays an important role in boosting the implementation of P-1. Regarding these enablers, Interviewee 4 said the following:

> "[…] There needs to be policy in place to enable the industry to shift, which is what we're trying to do. Here in Washington, we could require all State funded projects to take into account the embodied carbon, their materiality and all the labor practices. So, policy is a good place to start […] I would say the other enablers are education in the professional sector. Educating engineering, architecture, and construction industry professionals. That this is the direction we need to have. We need to head towards […]"

Interviewee 5 indicated that *Preconstruction* can also impact the implementation of P-1 positively. He explained this as follows:

> "[…] What we can do (during Preconstruction) is inform products that we're aware of locally, that fit the context of the designers solutions for that project. So you can propose

the materials to the designer or to the owner and it might or might not fit the owners programming criteria […]”

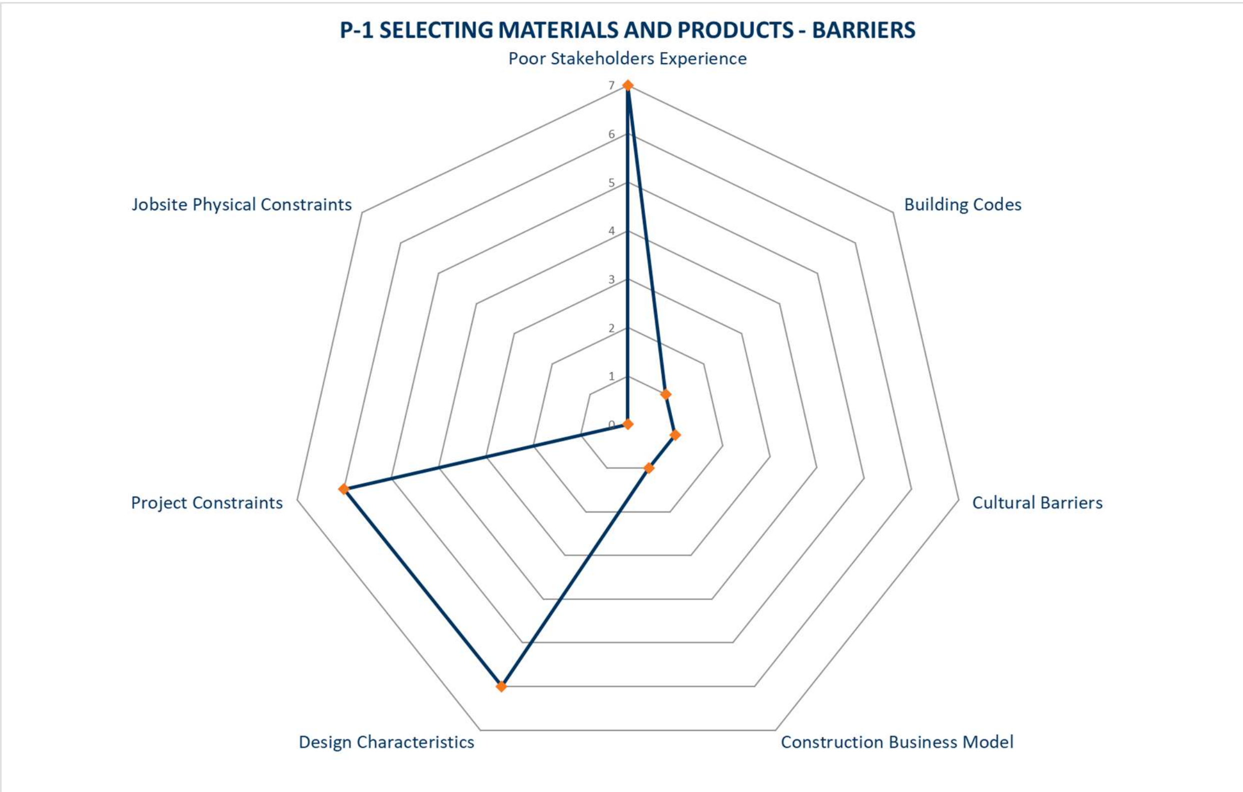

Figure 24: Barriers to P-1 Selecting Materials and Products

Figure 24 shows the barriers identified for P-1 Selecting Materials and Products. The *Poor Stakeholders Experience* appeared as the principal barrier to P-1. This barrier includes factors such as the limited number of suppliers, lack of availability of products in the market, and the low market development for emergent materials. Regarding factors, Interviewee 4 mentioned the following:

“[…] Currently there's, you know, the industry is in flux right now, and there's a limited amount of suppliers for these types of products, there's a shift that's happening, you know, there is a lot of people who are keeping up with the times, and in the latest practices, and

> they're trying to push the emblem of carbon, neutral construction, and engineering and architectural design. There's others who are still coming from an old mindset, who may be looking at least cost instead of highest quality […]"

Moreover, *Design Characteristics* and *Project Constraints* were classified as the second biggest barriers to P-1. Interviewee 10 mentioned that most the Owners and Designers strive to get a unique building with particular and distinctive characteristics which boost the utilization of certain materials over others:

> "[…] Typically, the designer is going to choose the materials and we, as contractors, are going to just simply build what it is that they specified. As an owner representative I'm in a role of challenging the designer often on what they've chosen for materials but a big element for us also is cost. What does it cost? Schedule, when can we get it? And sometimes, you know, things are driven just based on cost and schedule alone, and both designers and owners, are sometimes not that keen worrying about if the materials are sustainable […] every owner, every designer, every contractor, and every project is unique, and they all have their own goals and their own preferences and so you can suggest all right, but you can't demand, you can't require, you can explain options. Ultimately the owner will make the decision, and they are heavily influenced by the design […]"

5.3 DESIGN FOR MODULARITY

Eleven interviewees mentioned that they have used this practice in recent projects. When interviewees were asked about the probability to continue applying this practice in future projects, they gave it a score of 3.87 out of 5. This score suggests that P-2 has a high potential to be implemented in future projects

When interviewees were asked about the stakeholder driving the decision to implement P-2, ten interviewees mentioned that this decision is driven by the Owner or Developer.

Interviewees mentioned that the Designers can influence the Owner's decision towards the implementation of P-2 but eventually the final decision is made by the Owner.

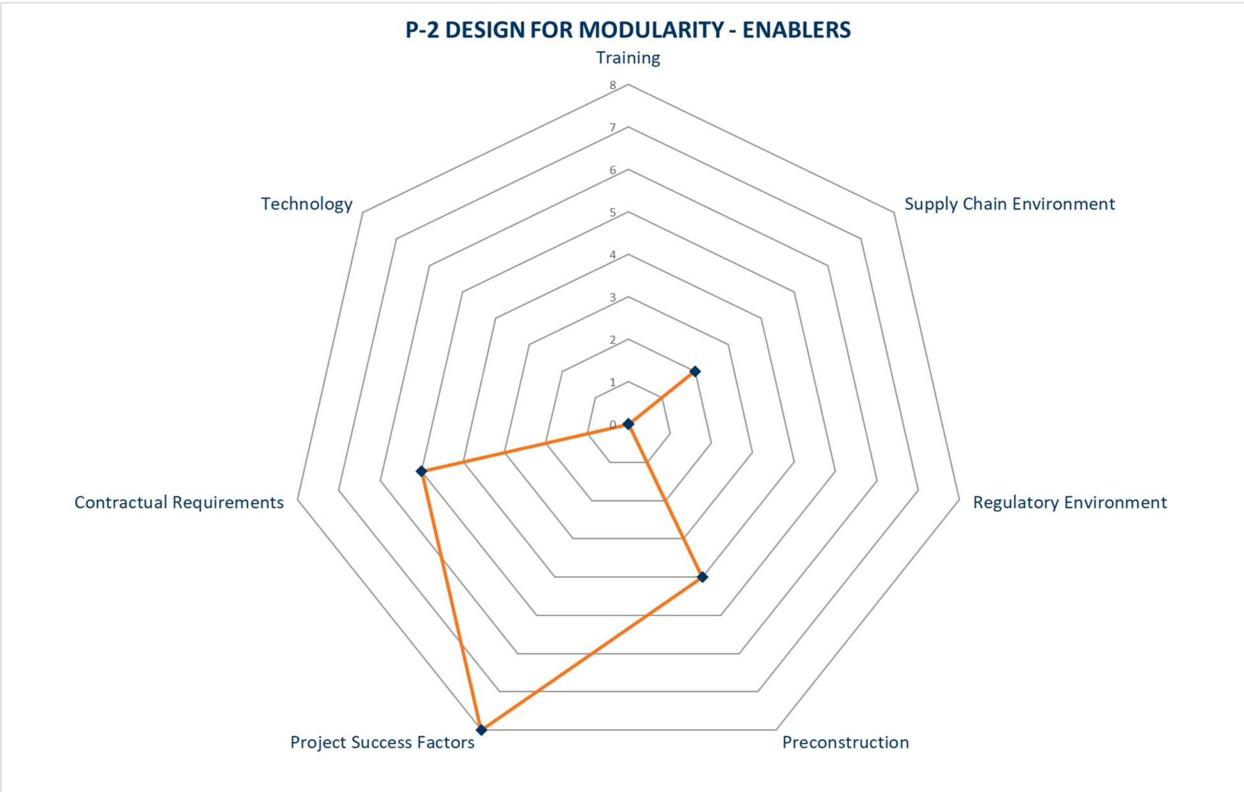

Figure 25: Enablers to P-2 Design for Modularity

According to the interviewees, the main enabler implementing this practice is the *Project Success Factors*, as Figure 25 shows. This enabler involves different aspects such as shorter schedules, less waste generation, and cost savings. Interviewee 11 pointed out some of these benefits and mentioned the following:

"[…] if we talk about the enablers and barriers, you just mentioned this factor that is the simplicity [of the construction process] and also the speed during the construction. Another enabler is cost, so time and money, always two of the most big factors when talking about construction. So I think those are 2, and then I think also just it's like you're not wasting as much material so that helps with both cost and time […]"

Interviewee 8 mentioned that due to the possibility of having a more controlled environment, *Project Success Factors* such as quality control and safety can also be improved considerably and explained this as follows:

"[…] I think, getting the labor out of the field and doing a lot of the prefabrication in the shop which allows for controlled environment. You have all the materials and everything you need, you're not double handling pipe, you're not double handling everything and then you're able to walk it in, put it on a skid and what not, and put it into place, and it saves on the job site, and then also you can have more off-site labor working on it like our shop. I think this is a huge one press […]"

The second and third enablers for the implementation of this practice are *Contractual Requirements* and *Preconstruction*. Interviewee 12 pointed out each of them and mentioned the following:

"[…] Well, what enables this one, I would say, is, first the program. What are you building? Because certain building types are more conducive to doing prefabrication. And then you need a design team that's on board because you have to design to modularity. And so you have to start working early to set up the appropriate rhythm of the job, and the spacing of the job, and have the discipline to design to those constraints so that's something that have to all agree on early on […]"

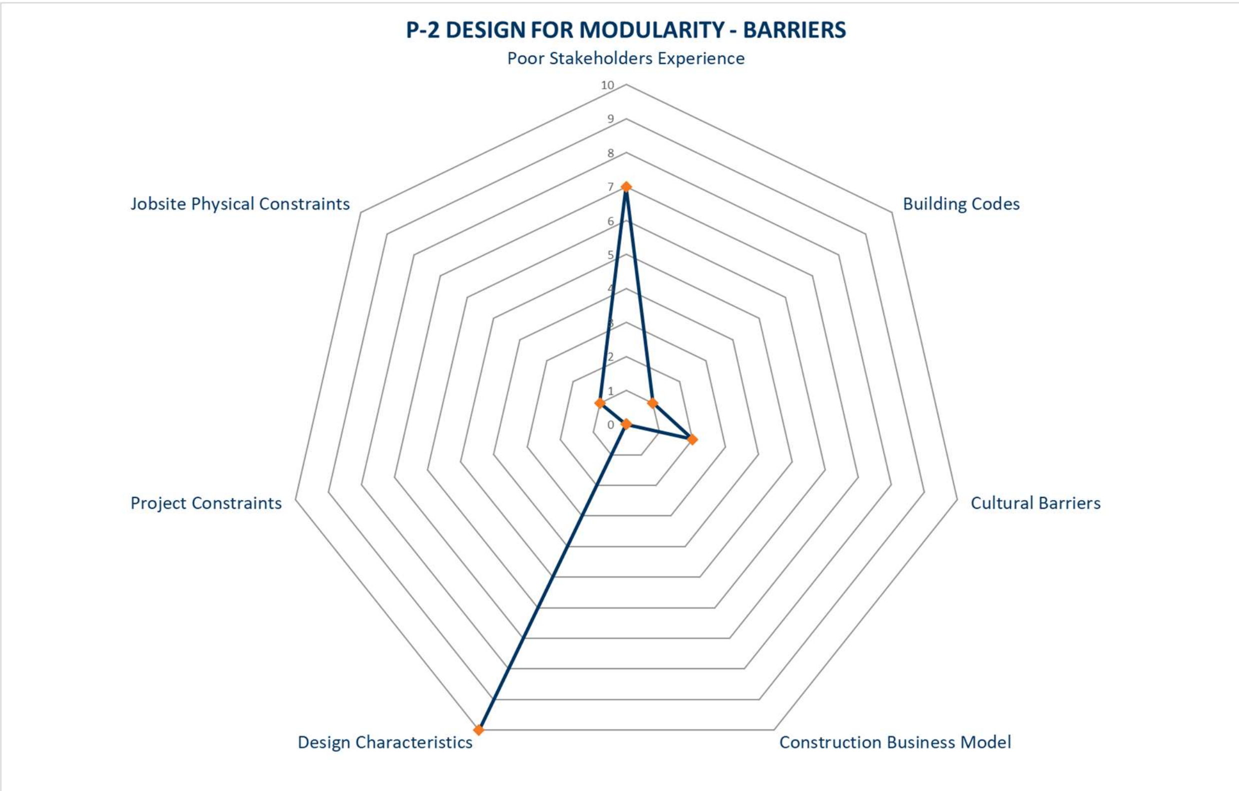

Figure 26: Barriers to P-2 Design for Modularity

According to Figure 26, the main barrier to the implementation of P-2 is the *Design Characteristics*. During the interviews, ten participants mentioned this barrier. Interviewee 13 explained this barrier as follows:

> "[…] I would say some of the barriers are, you know, construction is such a unique manufacturing process, not one building is the same, and so how do you find ways that you can do modularity that makes sense? And I would say, you know, hospitalities, hotel rooms, those make a lot of sense when there's a lot of repeat type work but still there's some nuances in there that are tough to grab a hold of […] But I think, from a programming

> aspect early on in the design stage, how do you build? How do you construct and lay out this building to where you can achieve consistent room layout where there's prefabrication opportunities […]? But that all comes down from experience, right? Your design experience, your owner or developer experience, the general contractors experience on how do you build effective modular systems, and mapping that out early on will break those barriers away […]"

According to Interviewee 14, the *Poor Stakeholders Experience* is the main barrier to P-2. From his perspective, the risks assumed by the General Contractor must be taken into consideration. One of the biggest risks is the additional cost generated due to the low productivity as a result of the lack of experienced subcontractors and vendors. He explained this barrier as follows:

> "[…] I think the biggest disabler risk is simply the fact that not a lot of companies have built fully modular projects and so there's a lot of unknowns and a lot of risks associated, at least from the general contractors' perspective, from the designers' perspective, from the clients perspective. Generally speaking, like with anything if you've never done it before, there's always going to be that hesitation and inevitably, probably some mistakes that are going to be made, there are going to be some growing pains and learning processes at the beginning and it's just finding that right team that is willing to take that leap of faith and take on some additional risk. […] And so, there's also, you know, with risking comfort and if you're getting outside of your typical risk appetite here, typical comfort level, there's potential cost and other impacts that your project can see because of it […]"

5.4 DESIGN FOR ADAPTABILITY AND FLEXIBILITY

The third Circular Economy practice analyzed was Design for Adaptability and Flexibility. Fourteen interviewees said that they have used this practice in their recent projects. We asked them how plausible it would be that they would apply this practice in the future, and they said they would use it and gave it an average score of 4.40 out of 5. Many interviewees said the building type is a factor that influences the applicability of this practice. The practice is best applied to an educational building, a healthcare facility or a commercial/residential. The willingness of the owner to apply this practice must also be taken into consideration.

When the interviewees were asked about which stakeholder drives the implementation of P-3, they had different answers. However, most of them agreed that the owners are the ones who make the final decision based on their needs and goals.

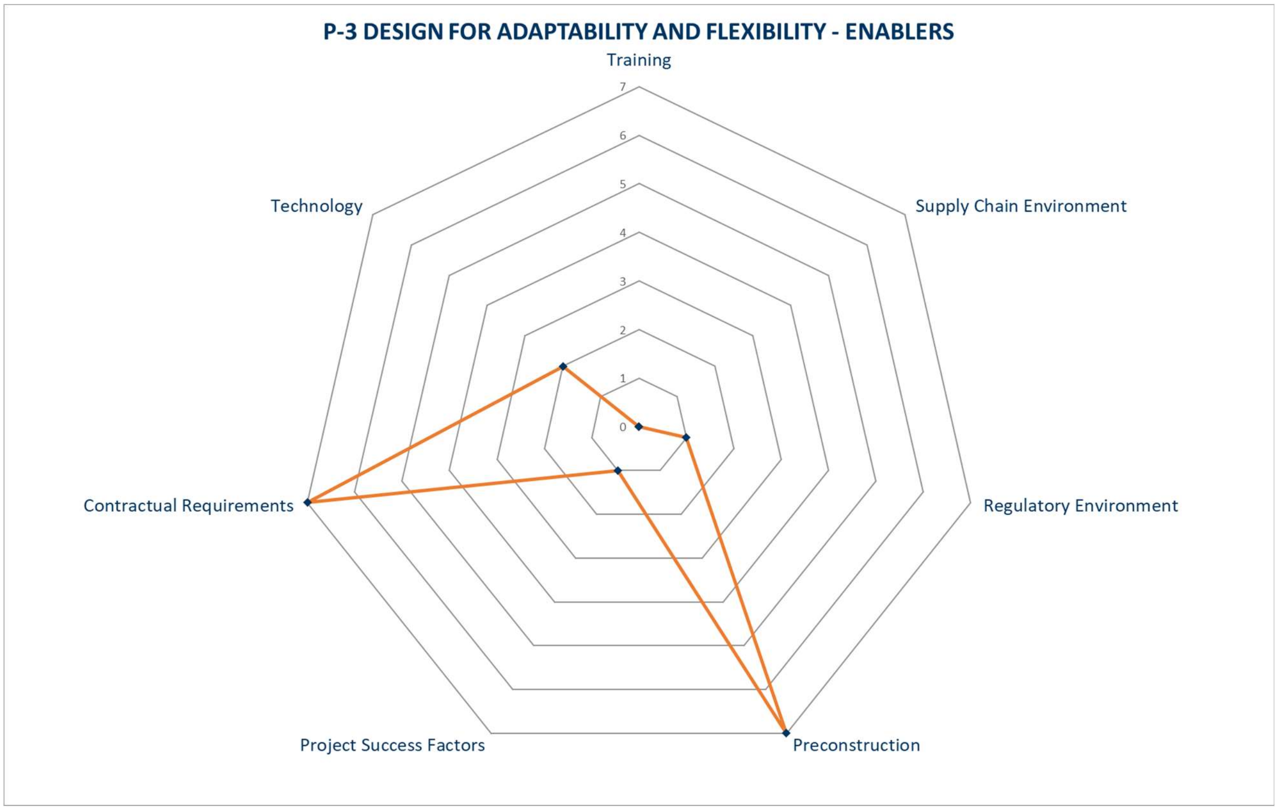

Figure 27: Enablers to P-3 Design for Adaptability and Flexibility

According to the interviewees, the main enablers of P-3 are the *Contractual Requirements* and *Preconstruction*, as shown in Figure 27. According to Interviewee 3, the possibility that the building will belong to the same owner for a long time could open the door for investing additional money early in the project. The additional money would be used to further analyze innovative alternatives related to the building' flexibility. Interviewee 7 explained that efficient communication among the project stakeholders is an important factor when the design and construction team are working together. Interviewee 2 provided some insights about the *Contractual Requirements*. He mentioned the following:

> "[… they show some willingness to have higher upfront costs] when the owner knows that they're going to own and use this facility for more than 7 years […] If you have a developer

> that is planning to sell the building in 2, 3 years, most probably not going to do it but if the owner is able to keep the building for a longer period of time, there are some motivation to think more forward. Because most developers get their money back in 7 years, they want to get rid of it [the building …]"

Preconstruction was pointed out by almost half of the interviewees. According to them, it is significant to implement P-3 to have the design criteria or the schematic design early in the project. Interviewee 4 provides some insights related to this point as follows:

> "[…] I would say enablers are just, you know, having the design team that looks at this as a criteria early on in the schematic design, and I think it has to do with again the owner or the unit, you know, or the college, knowing what they need out of the space. I think sometimes they have a general idea of what they need, and then in the design development process they can get, you know, if they can further refine that […] I guess another enabler to the implementation for this would be the design team really coming up with intelligent solutions that are kind of synergistic solutions […] I think that one is really on the designing team bringing innovation to the clients' needs[…]"

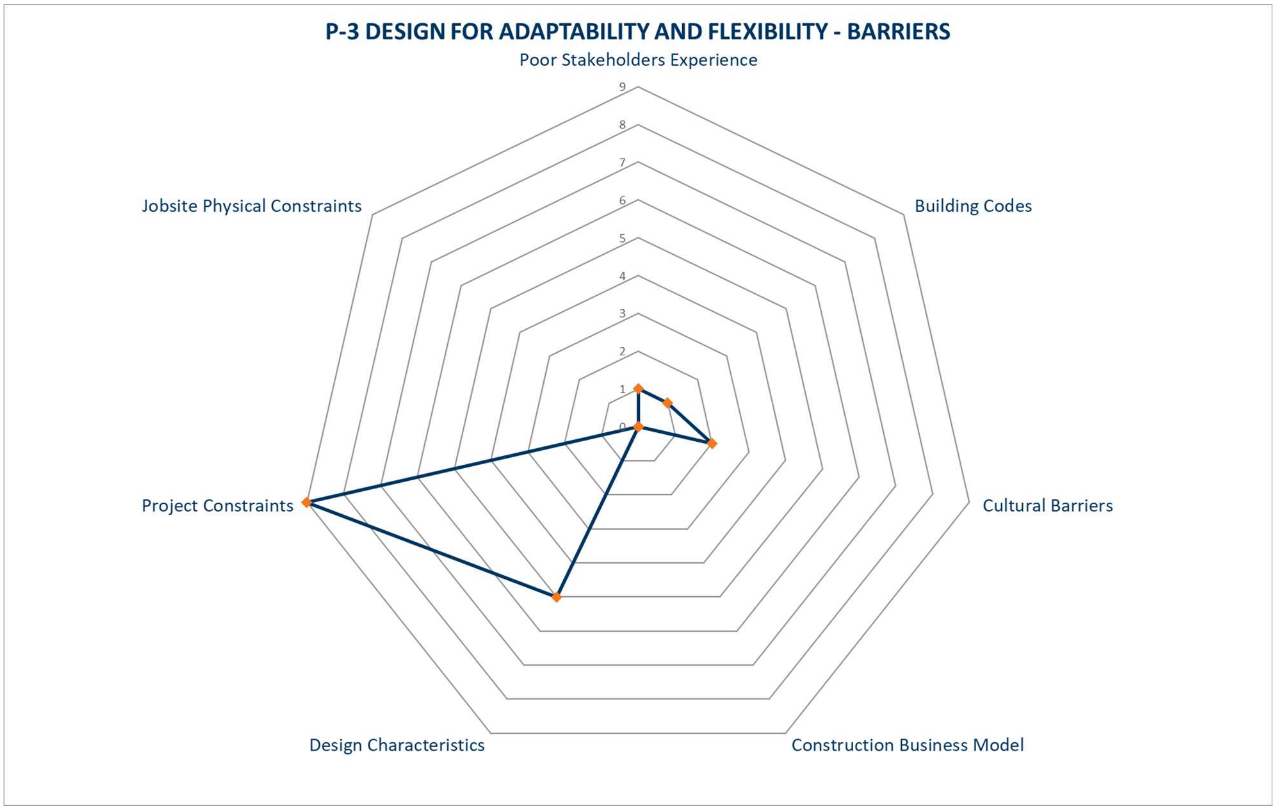

Figure 28: Barriers to P-3 Design for Adaptability and Flexibility

Most of the interviewees mentioned that *Project Constraints* were the main barrier to the implementation of P-3. Interviewee 2 explained this barrier concisely, he said that *"Flexibility costs money".* Also, according to Interviewee 12, it is important to analyze if the implementation of this practice will provide value to the owner or not. He explained it as follows:

> "[…] So you need to understand your client and your client has to understand themselves, sometimes there's cost for flexibility or adaptability and I have to oversize something, you can't necessarily find tune something to be just exactly what it needs, you know, if you've got an eye out towards flexibility. So you have to understand if that actually provides value. […]"

Interviewee 5 mentioned that the cost required to make a building flexible is not always the cheapest. The building type and the specific requirements of the project are factors that need to be considered during the assessment of the implementation of this practice. Interviewee 5 explained the following:

> "[…] it could be cost, and it could be product sourcing. So like, maybe in the example of the demountable walls, kind of depends on the solution but there's a select number of manufacturers that make those types of systems. And there could be a first cost decision by the owner because it may not be the most cost effective first cost so that could be a barrier, depending on the project and the requirement, it may not be the cheapest option […]"

Some interviewees also mentioned that the *Design Characteristics* can be considered a barrier. Interviewee 1 provided an example related to this matter:

> […] I think challenges can really be, you know, depending on the functionality that you need, these routes to sort of to be a chameleon to change. There are certain things you just can't do, maybe there's mechanical/electrical systems that sort of get in the way of preventing you from changing the room dramatically. Or you put too many people in a room and the air conditioning system just won't keep up for example. So that certainly could be a barrier"

5.5 DESIGN FOR STANDARDIZATION

Nine interviewees indicated that they have used P-4 in recent projects. When the interviewees were asked to assess the possibility of implementing this practice in future projects, the average score obtained by P-4 was 3.07 out of 5. This score suggests a poor willingness to implement this practice in future projects. According to the interviewees, the lack of specialized stakeholders and the owner's desire to have a unique building hold back the implementation of this practice on a larger scale.

When interviewees were asked which stakeholder drives the decision to implement P-4, they said that the Designers play a role in proposing solutions and alternatives, but the Owner makes the final decision. Interviewees pointed out that the implementation of P-4 involves high up-front that need to be considered. It was also explained that depending on the building type, this practice can be more or less effective.

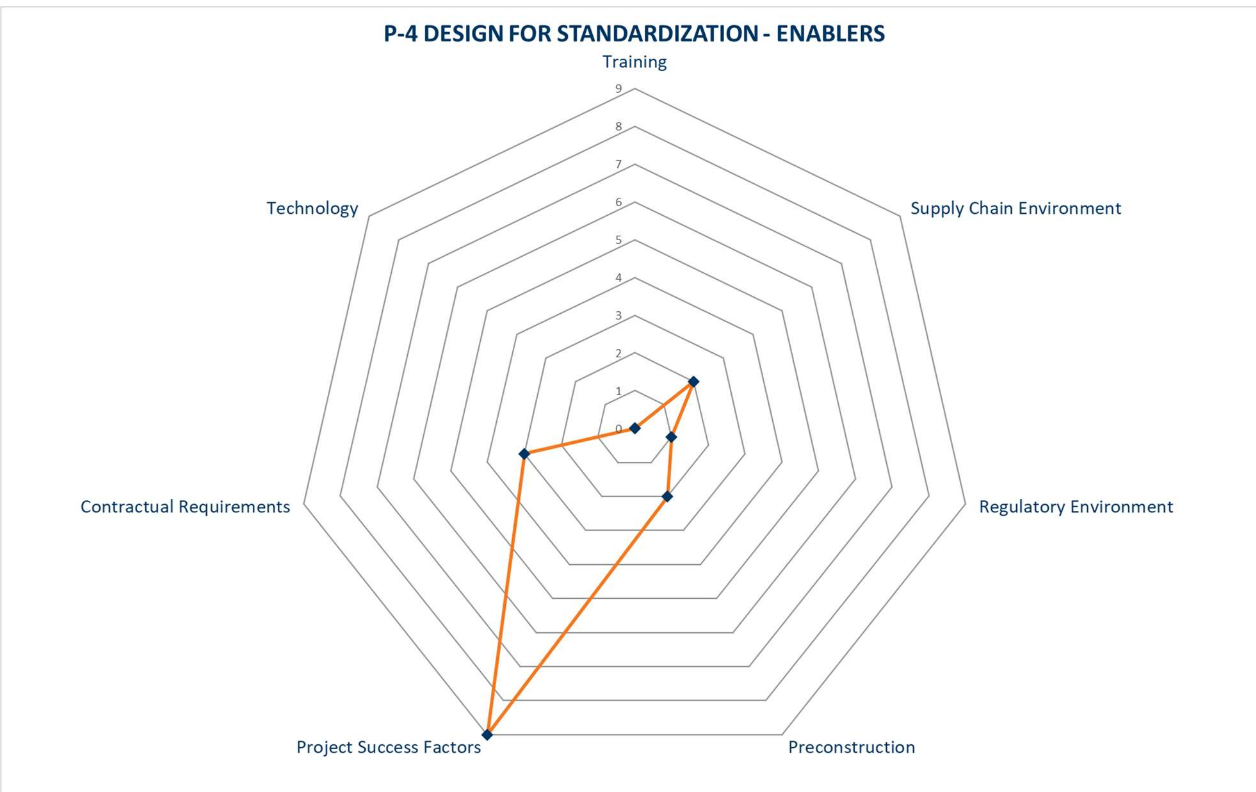

Figure 29: Enablers to P-4 Design for Standardization

As figure 29 shows, nine interviewees mentioned that the *Project Success Factors* are the predominant enabler for the implementation of P-4. Interviewee 10 explained this enabler as follows:

> "[…] in my soul [sic] opinion, the positive thing is from a contractor's perspective, it can save time and save money, and improve quality control. If we're doing the same thing time after time, if we're building the same module over and again, then, you know, it's economy of scale and therefore, we should build it more cost effectively. I don't think the owner plays apart in that decision at all. […] it would be like a learning curve, at the beginning, you have not a very high productivity rate but project after project this rate is going to be better and better […]"

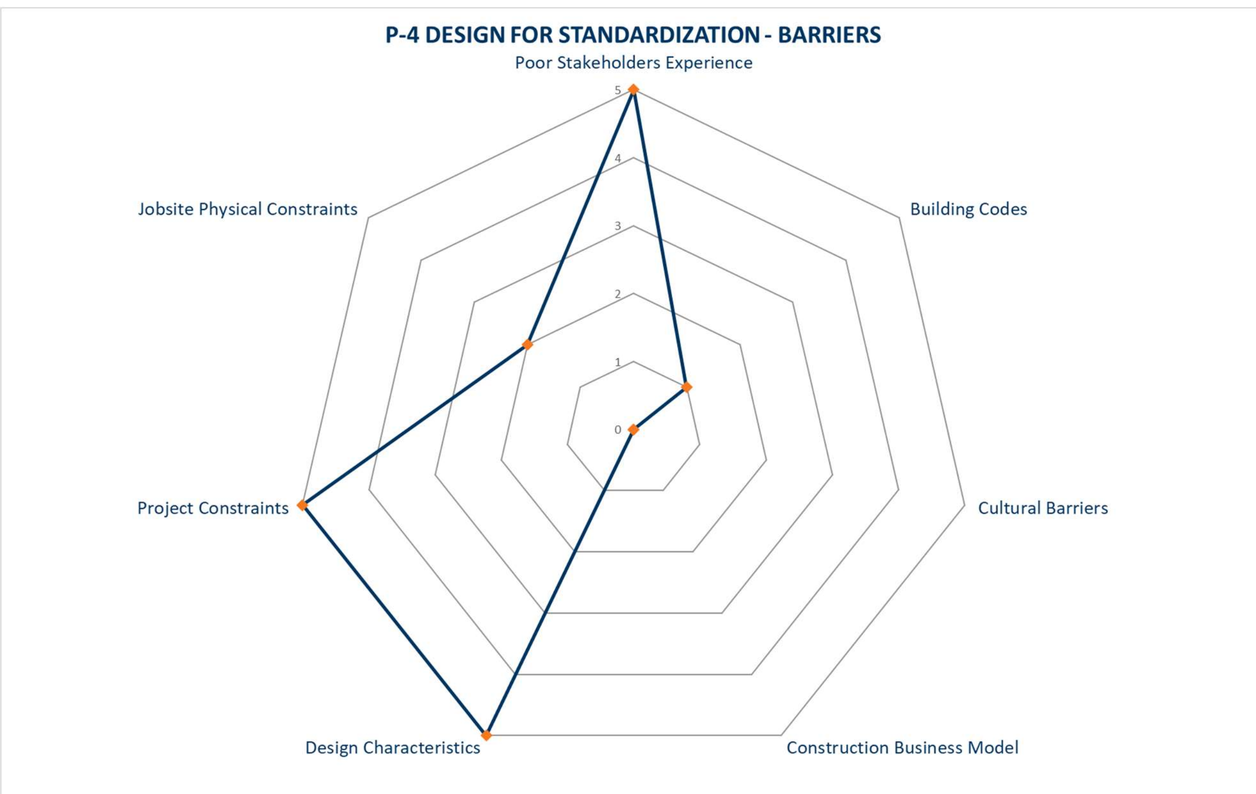

Figure 30: Barriers to P-4 Design for Standardization

When interviewees were asked about the barriers to P-4, the opinions were diverse. Some interviewees mentioned that the *Poor Stakeholders Experience* is a determinant factor. Another group mentioned that *Project Constraints*, especially the money expenditure in the early phases of the project, is a factor that affects the owner's willingness to implement P-4. Finally, a different group of interviewees mentioned that the *Design Characteristics* are a relevant factor that must be considered when standardization is analyzed as an alternative.

Interviewee 11 explained the barrier regarding *Poor Stakeholders Experience* as follows:

> "[…] Think the barriers is it just I don't know how many contractors have worked in this manner. You know, maybe just concerns on the overall quality if you're just kind of piecing things together. Also, I have heard before that maybe an additional barrier could be that we have not so many manufacturers familiar with this this type of practice. Right? And that's kind of what I mean by if you don't have contractors, fabricators, manufacturers who are knowledgeable on it and I think you're opening the door to a lot of issues […]"

Interviewee 10 emphasized that the *Design Characteristics* are a significant barrier to the implementation of P-4. He explained this point by mentioning the following:

> "[… for me] The barrier is the designer. The design team wants to be unique, and they don't want to set things on grids because they feel like that might be boring. So the designer is the barrier […]"

Interviewee 9 pointed out that *Project Constraints* is a determinant barrier and explained it as follows:

"[…] So what usually the cost that people have to understand is usually your bell curve that you see in a construction, the cost of when do you spend the money, that curve shifts left to where you're spending more money in the design phase in order to enable this standardization to occur. And that's a cash flow change of approach that the developer and the owner have to understand. It's very unique. When you start to get into this more standardization, in this modularization, in this process you're talking about, that curve has to pull left, and they spend more money up-front because they have to bring in some construction and manufacturing know-how into that design phase in order to implement this out on their projects […]"

5.6 DESIGN FOR DISASSEMBLY

Design for Disassembly (P-5) appeared as one of the least popular practices. Seven interviewees mentioned having used this practice in recent projects. The high upfront costs appeared as the principal factor that retracts the interviewees from applying this practice in their projects. When the interviewees were asked to assess the possibility of implementing this practice in future projects, the score obtained by P-5 was 2.40 out of 5. This score suggests that this practice is one of the practices with the lowest potential to be implemented in future projects. Interviewees mentioned that the quality issues that can arise due to the lack of experienced stakeholders, in addition to the high upfront costs, are critical factors for the implementation of P-5.

Interviewees asserted that the key stakeholder that drives the decision to implement this practice is the Owner.

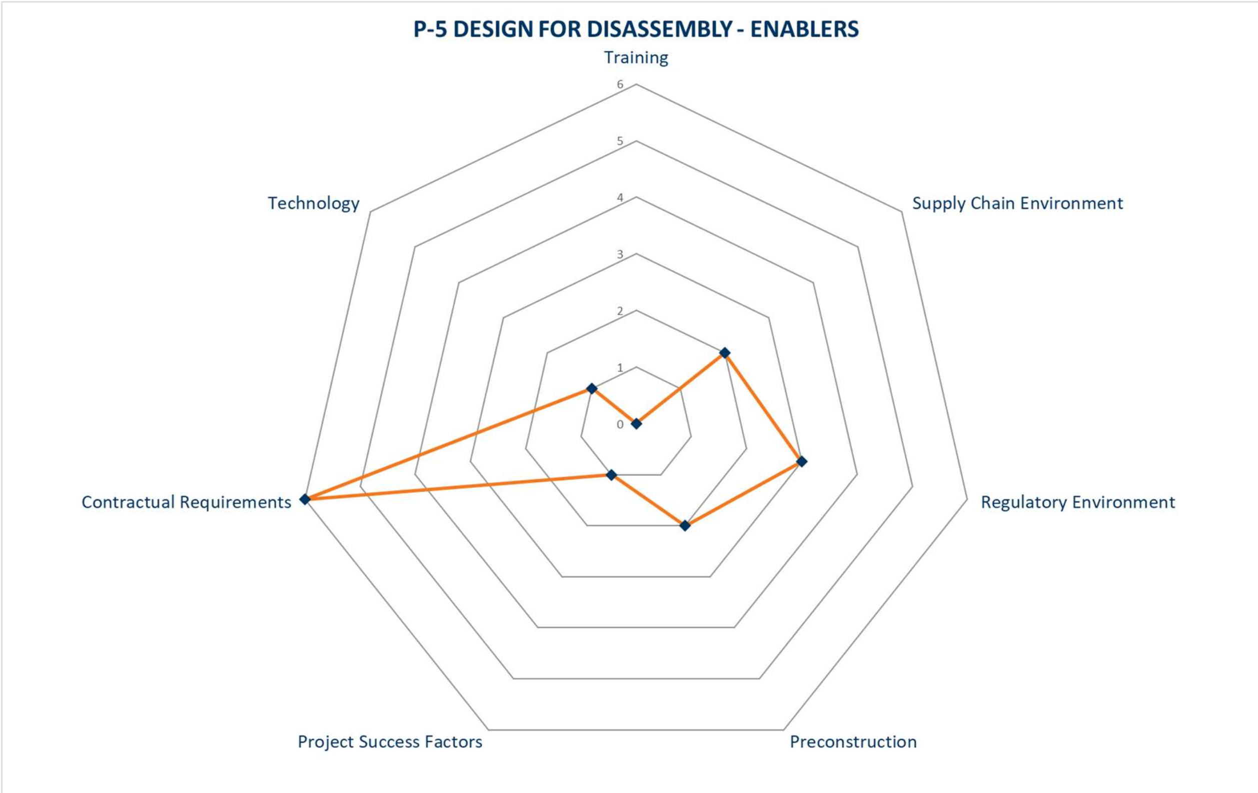

Figure 31: Enablers to P-5 Design for Disassembly

According to Figure 31, the main enabler to P-5 is the *Contractual Requirements*. Interviewees pointed out that the building lifespan and the building's ownership lifespan are factors that need to be considered before proposing the implementation of P-5. For example, temporary facilities can be designed to be easily disassembled because the building lifespan was defined early in the project and it was used as an input during the design phase. Interviewee 6 explained the following about this enabler:

> "[…] I think the enablers or definitely the factors that enable that are the owner's desire to get out of the space. If they truly intend to, you know, move things around the project. So I think that may be a factor, is just them wanting to have that ability to do that [disassembly and move the buildings around …]"

Interviewee 4 said that, in his experience, the *Regulatory Environment* plays an important role in implementing of P-5. He explained it as follows:

> "[…] the enabler would be also having in place again policy at the State level. That says, you know, you must design or incorporate whatever certain aspects of the structural elements to be designed for disassembly for your projects, and that kind of requirement would become a forcing function. But I think it's hard for the state to do that until their industry is there and I think it will be hard for the industry to change […]"

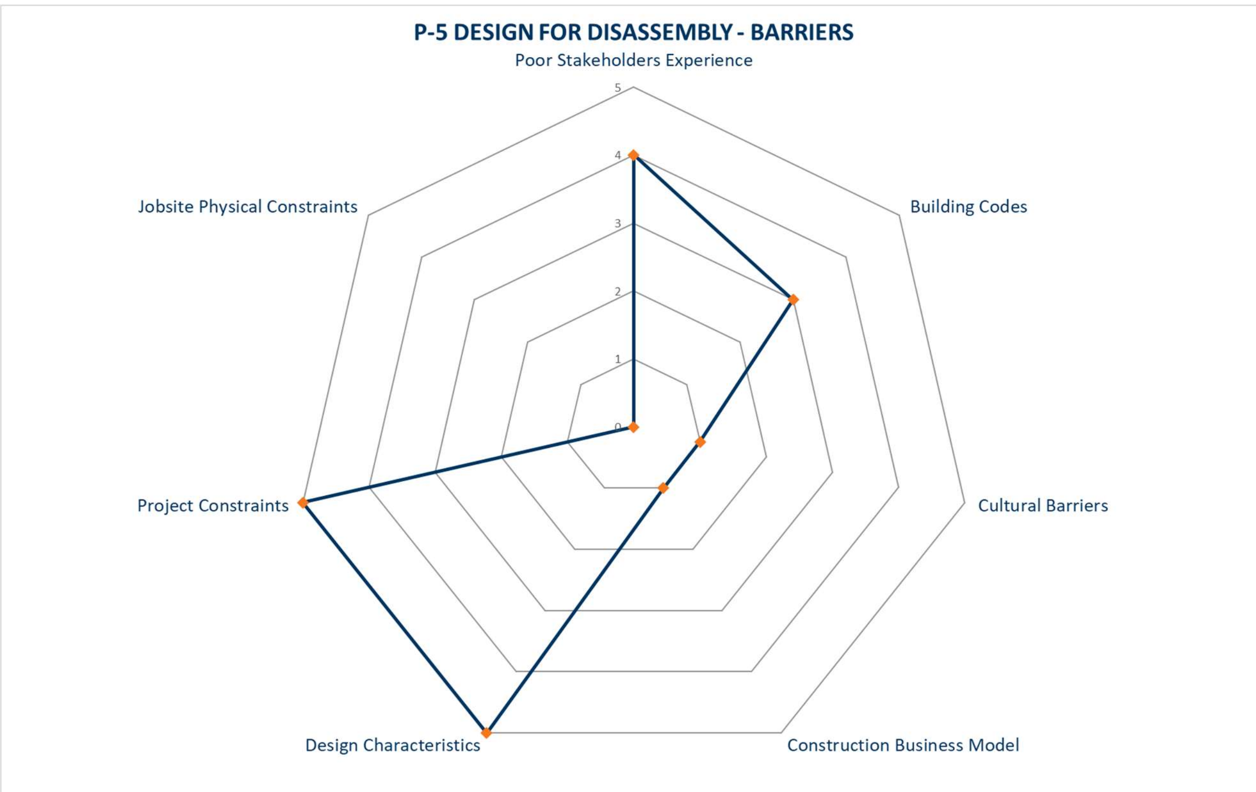

Figure 32: Barriers to P-5 Design for Disassembly

As Figure 32 shows, the opinion of the interviewees was divided when they were asked about the barriers to P-5. Some participants pointed out that the *Design Characteristics* are the main barrier while another group considered that the *Project Constraints* are the most significant. About *Design Characteristics*, Interviewee 11 mentioned the following:

> “[…] I think with a mechanical or electrical system, or even an external metal panel or window, or glazing item, I think any time you remove something from a project and replace it, you're putting a potential for that system to never work quite as well as it did when it was originally installed. So it could be potential issues with quality control. If you know we're doing something on the exterior of a building over time, you have small shifts in the system, or there's slight movements, so when you take something off and put it back on, just might not ever be kind of that's joint sealed system that you had originally […]”

Interviewee 10 pointed out that many owners are not willing to invest money in materials and components that could make the building easier to disassemble because their business model does not consider long building ownerships. This is the description provided by Interviewee 10 about this:

> “[…] Barrier is the fact that, really I have seen in my career, the design be split up into smaller and smaller pieces, and they don't work together very well. And so the structural engineer and the architect are not designing to allow for removable mechanical systems in the future. I would also say the barrier is that we design buildings to be at least 30 years old and most of us who have the money to fund the building do not see that we will be here when it's disassembled. So it's not my issue. It someone else' issue it's, I'm not going to be here, so I'm not going to spend my money putting in a bunch of removable panels that may or may not ever be used […]”

Interviewees pointed out that the *Poor Stakeholders Experience* is also a barrier for P-5. According to them, currently it is difficult to find companies with vast experience in disassembly. Another group of interviewees mentioned that the current Building Code indirectly promotes the utilization of new materials with determined quality' characteristics. This factor diminishes the willingness of the owners to invest additional money in disassembling and recovering materials.

5.7 DESIGN FOR PREFABRICATION

According to the interviewees, this practice is one of the most common and popular in the Pacific Northwest. Fourteen interviewees mentioned having used this practice in recent projects. Interviewees explained that the implementation of this practice relies on the existence of experienced Prime Contractors and Subcontractors and the support of a reliable supply chain. By contrast, the lack of laydown areas in the project or a complex building design can reduce the possibility of implementing P-6.

When interviewees were asked to assess the possibility of implementing this practice in future projects, the average score obtained was 4.73 out of 5. This score places this practice in the fourth position among the practices with the biggest potential to be implemented in the future. According to the interviewees, the utilization of technological tools such as Building Information Modelling (BIM) can boost the utilization of this practice.

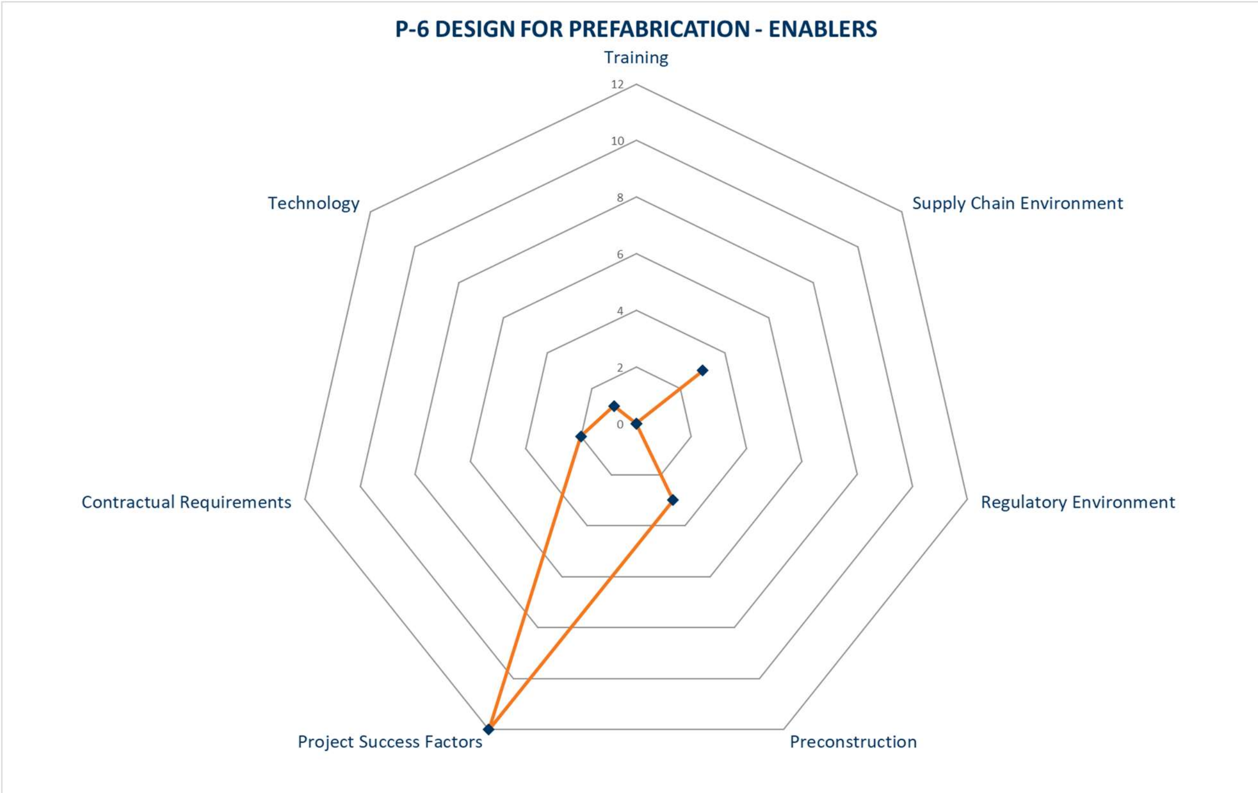

Figure 33: Enabler to P-6 Design for Prefabrication

When interviewees were asked about the enablers to Design for Prefabrication (P-6), twelve interviewees mentioned that the *Project Success Factors* are the most remarkable, as shown in Figure 33. The possibility of having shorter schedules, better productivity rates, less waste, quality improvements, the possibility to perform tasks in parallel (jobsite and factory), and the ability to avoid delays due to bad weather were among the main reasons why the interviewees would be willing to implement P-6.

> "[…] I would say that an enabler of this practice is that we can boost a faster construction, and to have a more organized jobsite. It's also safer, especially if you have a tower crane, and you can control the quality much better in a warehouse than you can control in a job site. Sometimes costs can go either way, so you got to run the numbers, and if you base it

solely on costs, sometimes you might not make the right decision, you need to factor quality, and schedule, and safety into it […]"

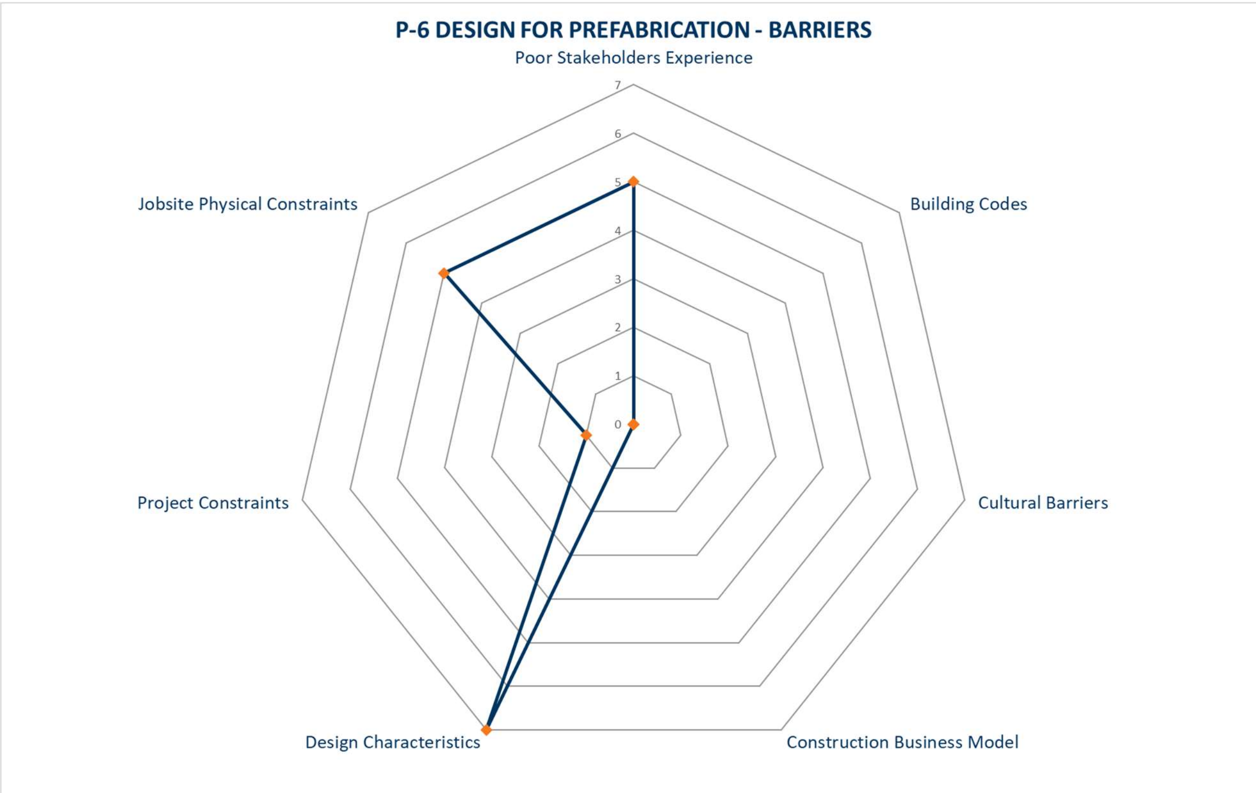

Figure 34: Barriers to P-6 Design for Prefabrication

As shown in Figure 34, interviewees pointed out that the main barrier to Design for Prefabrication (P-6) is the *Design Characteristics*. According to the interviewees, many projects have a "uniqueness" factor that makes it difficult to implement P-6. There are building elements that cannot be prefabricated because of their special characteristics. Interviewees pointed out that the project team must consider the *Jobsite Physical Constraints* when prefabrication is analyzed as an option. This factor is crucial because the additional costs associated with the material transportation and the warehouse rental can be significant.

According to the interviewees, the *Poor Stakeholders Experience* is another barrier to P-6. General contractors and suppliers/vendors should be able to provide important feedback about the feasibility of implementing P-6 in their projects. This feedback must be based on their experience, the available technology, and the project characteristics.

5.8 BUILT OUT OF WASTE

According to the interviews conducted, Built out of Waste (P-7) is one of the most applied practices in the Pacific Northwest. Fourteen interviewees indicated to have used P-7 in recent projects. When interviewees were asked about the possibility of using this practice in future projects, they pointed out that there is nothing that impedes the companies from implementing lean thinking. They also explained that the general contractor is the one who must lead the implementation of P-7 because of the potential benefits that this practice can generate during the construction phase. These opinions were reflected in the score obtained by P-7. This practice obtained an average score of 4.73 out of 5.

When interviewees were asked which stakeholder drives the implementation of P-7, twelve interviewees answered that the General Contractor leads this implementation.

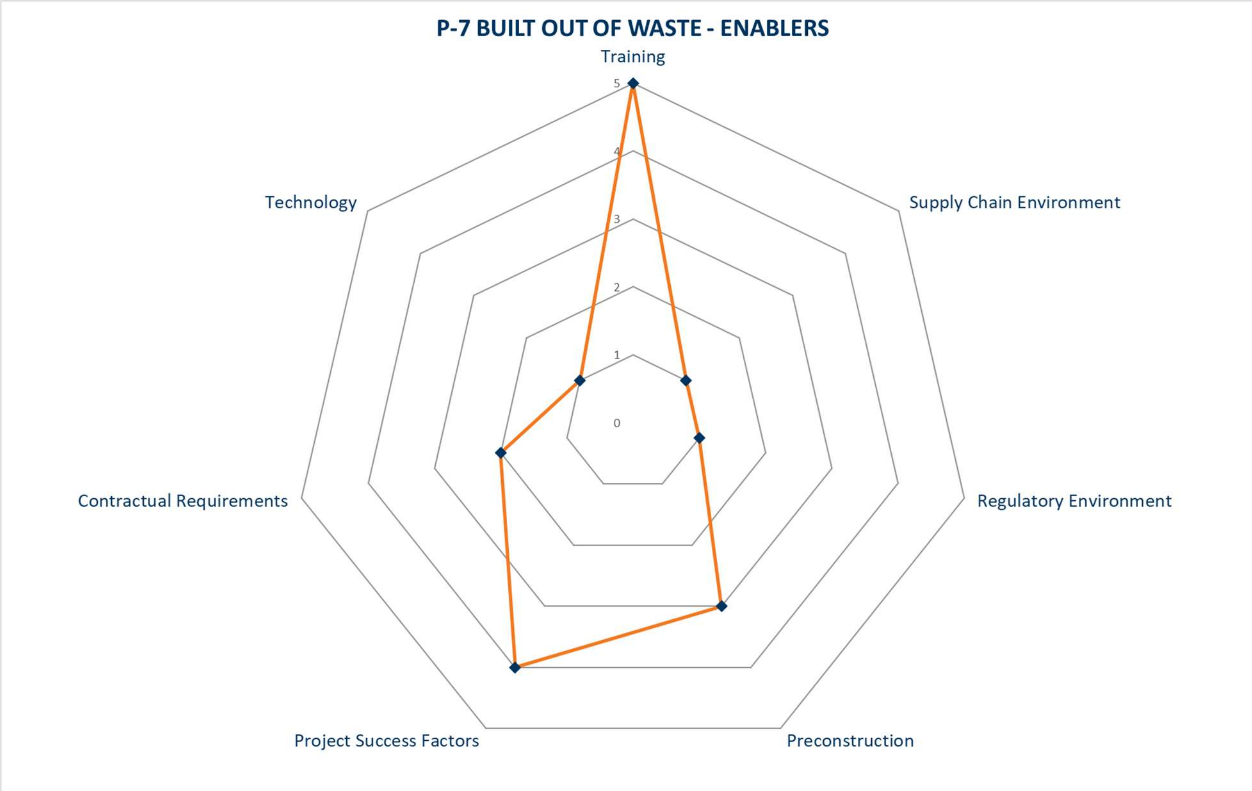

Figure 35: Enablers to P-7 Built out of Waste

According to figure 35, *Training* is the main enabler for implementing P-7. According to the interviewees, professionals in the industry need to gain the ability to identify areas of improvement at a jobsite level and a company level. Interviewees mentioned that the education's development would allow the professionals to think out of the box and acquire more awareness about the benefits obtained through the implementation of P-7.

Interviewee 11 said that the general contractor must lead the implementation of P-7. The overall objective is that every worker must understand the concept of lean construction. Once the workers understand the lean concept, they will be able to extrapolate this to the activities they execute daily. He explained it as follows:

> "[…] You need a general contractor who's leading a charge and has the knowledge of what lean construction is because I don't know if every worker on site would be able to tell you what lean construction actually means. But once you get that understanding, and start thinking in those lean ways, it's amazing how many things you can apply to on the day-to-day basis. So, I think that the overall education and knowledge of the workers is probably an enabler, and I also think that serves as a barrier just in a sense of not every company is going to be willing to spend the time to improve and learn on certain areas […]"

Interviewees agreed that other enablers to P-7 are the *Project Success Factors* and *Preconstruction*. Regarding *Project Success Factors*, interviewees explained that once Lean practices start to be implemented, the benefits in terms of cost, quality, and schedule that come afterward are evident. Interviewees also explained that *Preconstruction* could play an important role in the implementation of P-7. Services such as scheduling can be matched with Lean practices and tools such as pull planning, look-ahead plan, and critical path can be seized at a project level.

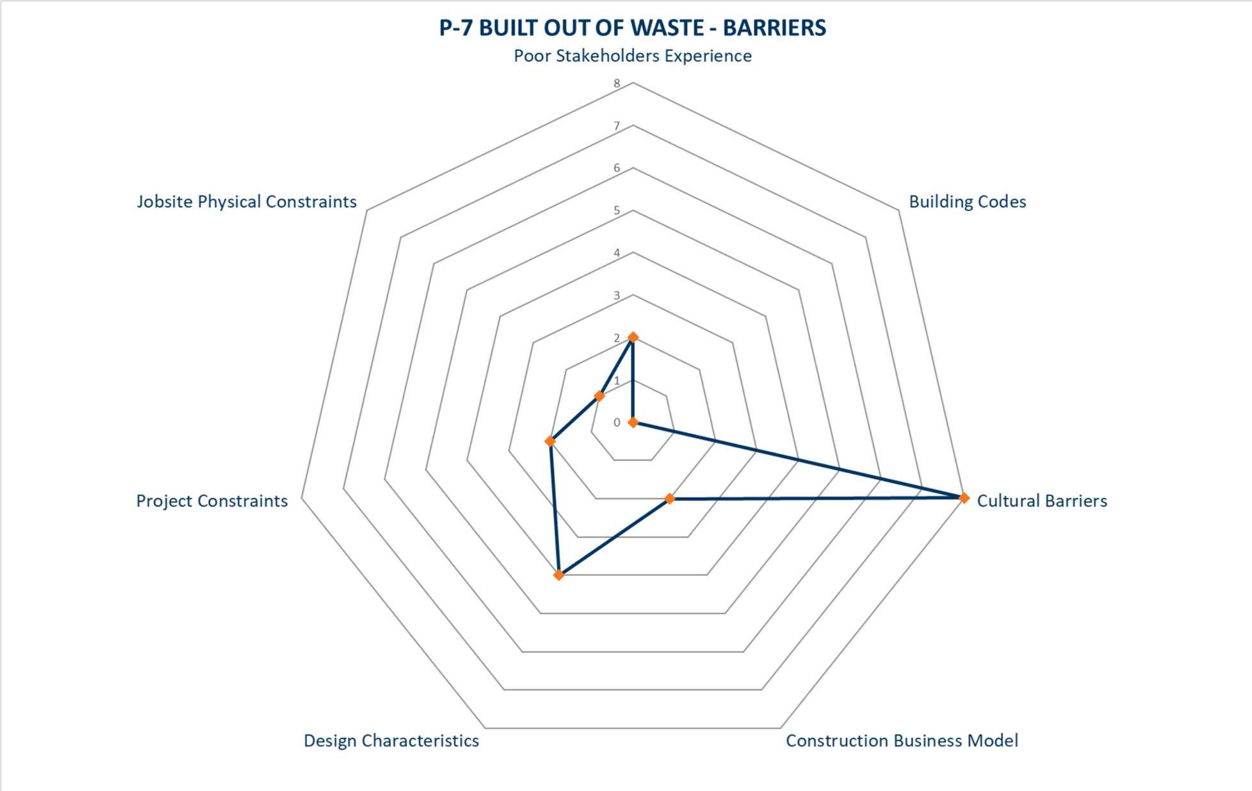

Figure 36: Barriers to P-7 Built out of Waste

When interviewees were asked about the barriers to P-7, most of them agreed that the main barrier is the *Cultural Barrier*. Interviews explained that not everyone in the construction industry is willing to change the way how they have been building in the last 20 to 30 years. Participants said that an uncoordinated design process, isolated minds in the project, and the challenge of tracking positive results could diminish the willingness to implement this practice.

Related to these points mentioned above, Interviewee 13 mentioned the following:

> "[…] I think there's always more ways to be lean and more efficient on jobs. But there's definitely the old mindset of "this is how we build, is how we do it", and so bringing in, new, fresh perspectives will help destroy those barriers and think outside the box ideas, but

> that's just an ongoing challenge that I've seen a lot, you know, I'd say there's a lot of energy towards this change […]"

Interviewee 8 explained that the *Design Characteristics* represent an important factor in the waste generation. According to her, some buildings require many custom fabricated pieces, so the laborers have to prepare them using standard elements, generating a considerable amount of waste.

5.9 BUILDING IN LAYERS

Building in Layers is one of the less implemented practices. Eight interviewees mentioned having applied P-8 in recent projects. Interviewees explained that even when the construction of a building is executed in different layers such as foundations, structure, MEP systems, and façade, all these elements still have a certain level of interdependency. For example, most of the façades are connected to the structure, or the structural columns and beams act as a monolithic element in combination with the foundations. Participants mentioned that the goal for this practice is to build in a sequence in which you can keep everything protected, and at the same time, you have the possibility to come back and repair any element when needed. Interviewees pointed out that the education and experience of the professionals in the construction industry will be the basis for the implementation of P-8. The willingness to have a mind shift to leave the old construction methods and techniques is another determinant factor in implementing this practice.

When interviewees were asked about the probability of implementing this practice in future projects, P-8 obtained an average score of 2.62 out of 5. The score obtained suggests that this practice is one with the least potential to be implemented in the future. Participants indicated that one of the main concerns about this practice is the quality of the final product. They explained that if a building is built in independent layers, characteristics such as waterproofing could be diminished. These aspects should be analyzed and studied during the design phase.

Finally, when interviewees were asked about which stakeholder is the one that drives the decision to implement this practice, they all concur that this is a joint effort between the Owner, the designer, and the General Contractor.

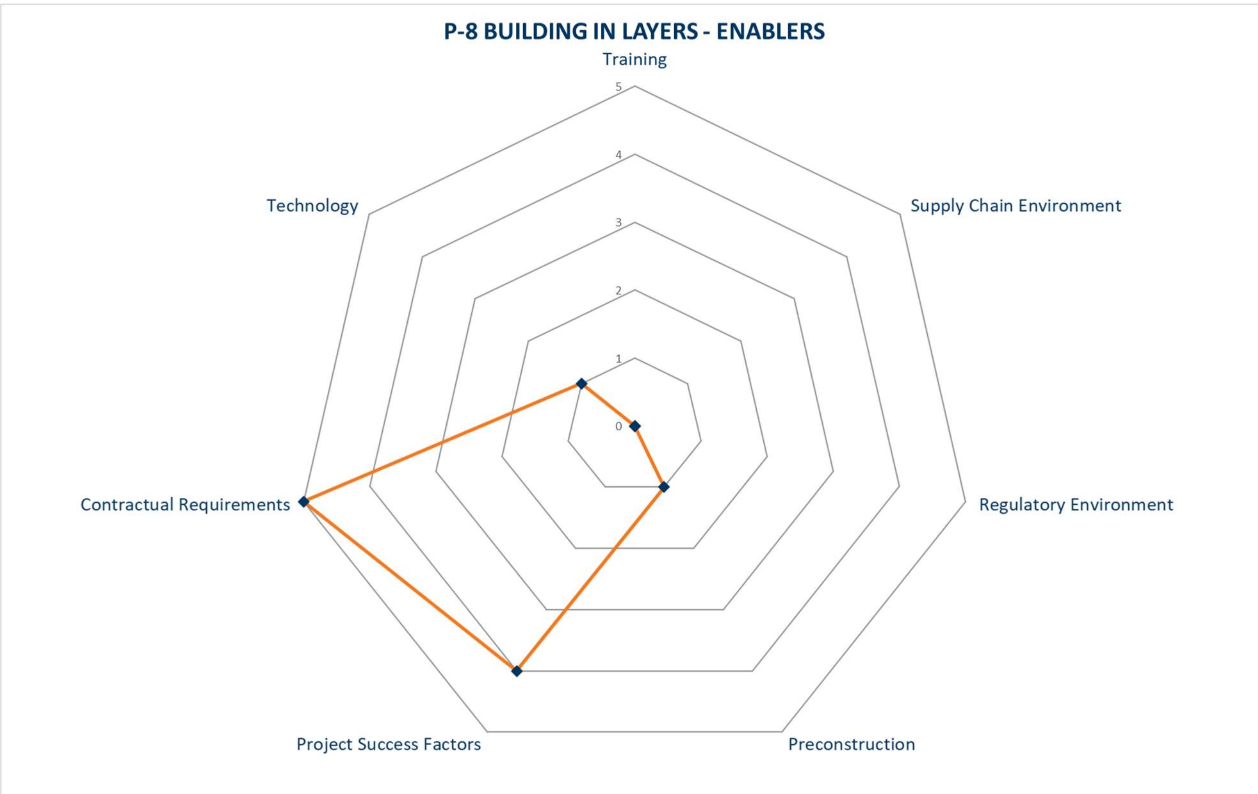

Figure 37: Enablers to P-8 Building in Layers

Interviewees said that the *Contractual Requirements* are the main enabler of P-8. The Owner has the power to ask for a building with independent layers. If that is the case, the general contractor will have to develop the constructability analysis to provide the best solution for fulfilling this requirement. Participants pointed out that technological tools will be fundamental for the implementation of P-8. These tools would facilitate the identification process of clashes and incompatibilities. Another group of interviewees mentioned that the *Project Success Factors* is a big enabler for implementing P-8 as well. They indicated that if they can perform significant work in different areas or layers of the building simultaneously, this practice will become more popular because of the schedule reduction that this will generate.

Related to the construction process and its relationship with the different layers, Interviewee 6 mentioned the following:

> "[…] So, the main idea is, for example, if you need to change any part of the facade, you can do it without affecting the structure or without affecting any internal services of the building. So you can disassemble each part individually without affecting this, I mean at least at some point. I know that, for example, if you want to disassemble the structure, it's impossible if you don't disassemble the facade first, right […] there's definitely a sequence we always use in the projects because it works, it protects all the materials, and it also gives an opportunity for us to understand how to go back and peel back a layer and adjust it if we need to, without affecting another layer […]"

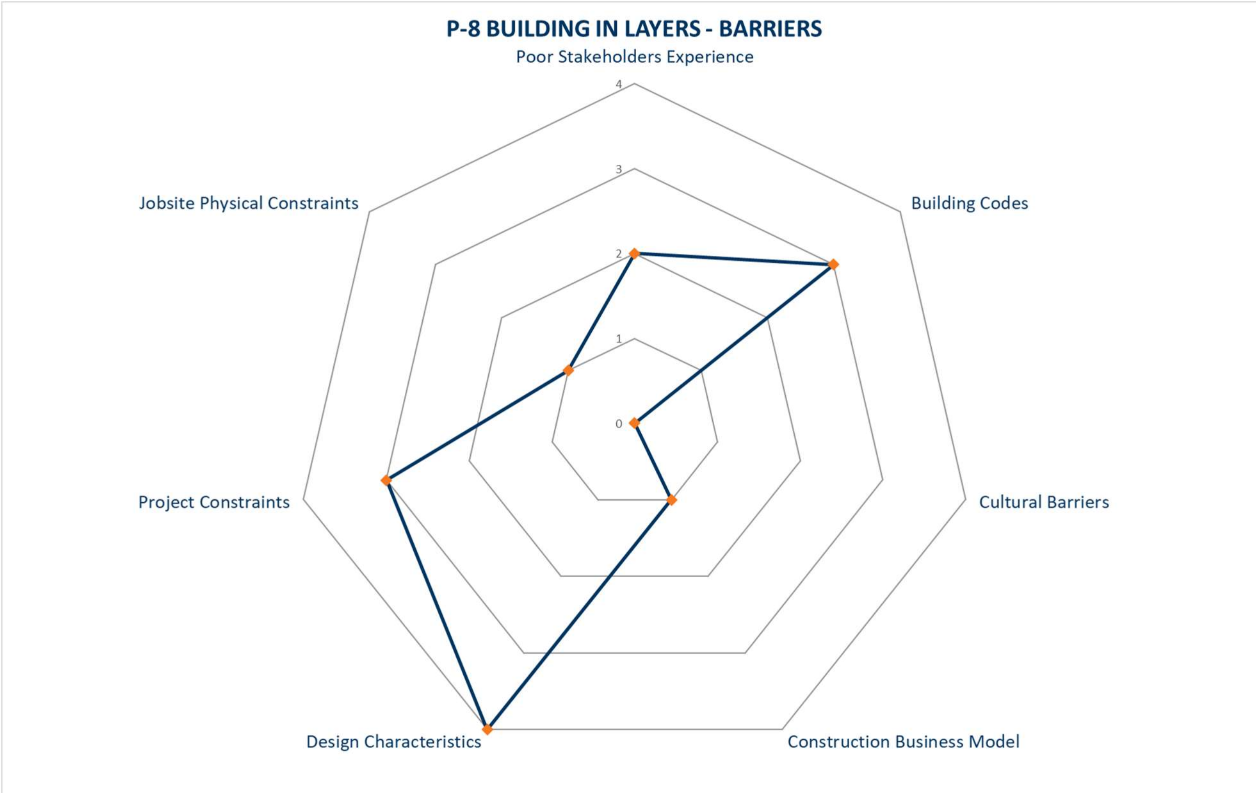

Figure 38: Barriers to P-8 Building in Layers

Interviewees said that the *Design Characteristics* are the most significant barrier to P-8. They asserted that there is too much interdependence between the different layers of a building because of the construction process we use nowadays. These construction techniques are similar to the techniques we used 20 years ago. During the design phase, the building is thought to be composed of highly interconnected systems that act monolithically and cannot be disassembled.

Interviewees also pointed out that the Building Code is another barrier to P-8. In case of a natural disaster, such as an earthquake, it is a must that the building acts as a whole in order to provide a safe environment for the occupants.

Interviewee 10 mentioned the following regarding these barriers:

> "[…] The other thing is because of energy consumption. Everything has to be tight, right. And so when you do that, you know seismic that you mentioned, we also have high wind zones here, and in addition many years ago we had a volcano here. So, when you build using all these codes as well as energy codes, everything has to be tight. […] You know barriers are there, I would say, building codes, and also in construction we have this phrase, if it isn't broke don't fix it. It is why we're slow to change construction more than like the automobile industry, which is much faster to change, and so that's a barrier in in construction. I know how to build it this way and I'm always going to build it this way […]"

Interviewee 8 indicated that the *Project Constraints* are also a remarkable barrier to P-8. According to her, the lead times of the materials required to build in layers can be a critical factor because these materials often have special characteristics for being installed in individual layers.

5.10 SELECTIVE DEMOLITION

The next practice discussed with the interviewees was Selective Demolition (P-9). Fourteen interviewees indicated to have applied this practice in recent projects. According to the answers received, P-9 is one of the most popular circular economy practices. Interviewees explained that the project's sustainability goals and the eagerness for a LEED certification are factors that boost the implementation of this practice. Interviewees also said that this practice offers additional benefits such as the cost savings generated through the reduction of waste generation on the jobsites. When interviewees were asked to assess the possibility of implementing this practice in future projects, P-9 obtained an average score of 4.79 out of 5. This score places Selective Demolition as one of the practices with the most potential to be implemented in future projects.

Interviewees indicated that technology development and the implementation of BIM would increase the efficiency of P-9. Efficient identification of building elements and materials with the potential of being recovered will be possible through the implementation of these BIM tools.

Participants mentioned that the key stakeholder that drives the implementation of this practice is the Owner.

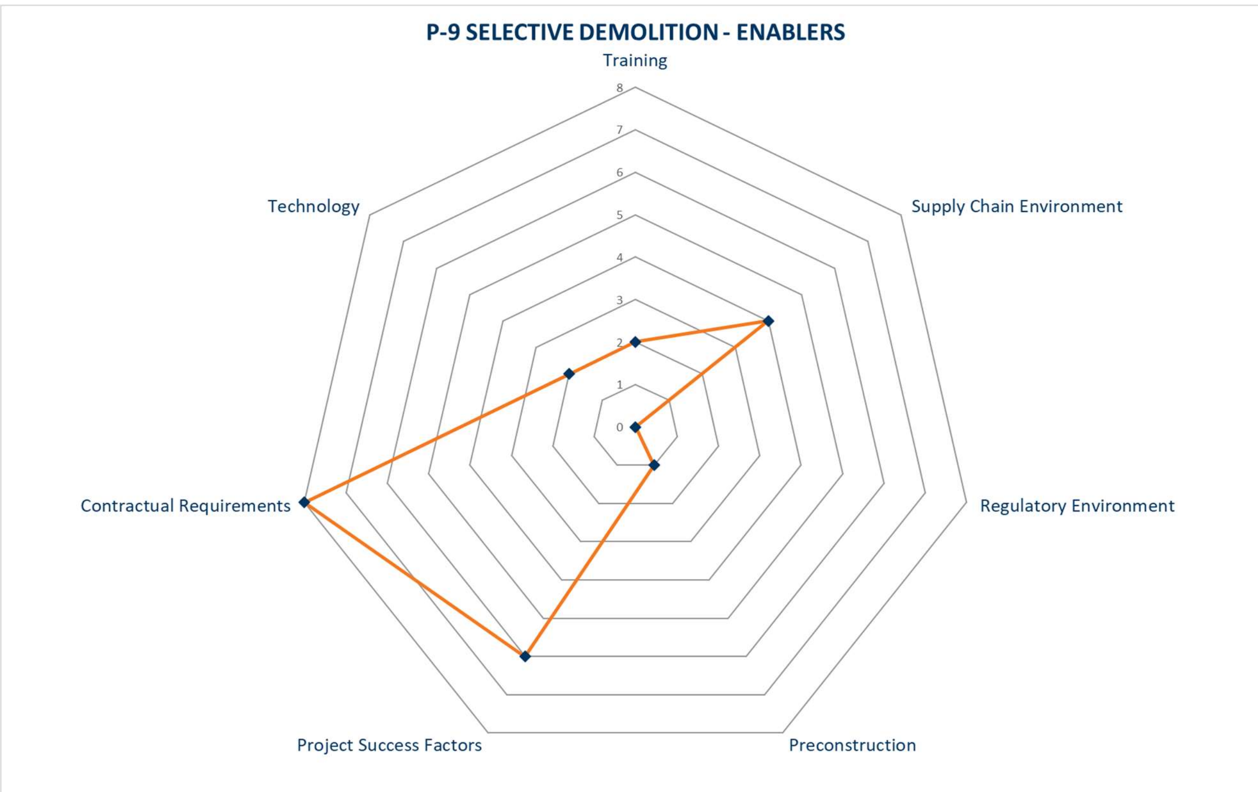

Figure 39: Enablers to P-9 Selective Demolition

The main enabler to P-9 is the *Contractual Requirements*, as shown in Figure 39. Interviewees explained some building elements have a historical or special value for the owners. In this case, the Owner can strive to reuse as many elements as possible to keep the value of these materials and elements.

When interviewee 7 was asked about this practice, she answered the following:

> "[…] well, it's cheaper and easier to do so (selective demolition). Keeping some structure, some components not taking it all down, I think that the value of the material is the reason why it's not being demolished and it's usually driven by the owner that is wanting that […] it would also be driven by the contractor team saying, "hey, you're going to save a lot of embody carbon and this is really important, you shouldn't destroy this […]"

According to the interviewees, another enabler for this practice is the *Project Success Factors*. Among these factors, the most remarkable is the schedule reduction that can be obtained through the implementation of P-9. Regarding this enabler, Interviewee 8 mentioned an example related to piping systems. She mentioned the following:

> "[…] if you do the selective demolition, such as taking out a small section of pipe instead of demolishing out the whole duct or the pipe run back to the main core, and it allows for us to be on site less, I mean it's less work for us but also it reduces the schedule because you're able to reuse existing elements […]"

Interviewee 4 pointed out that another enabler of P-9 is the *Supply Chain Environment*. According to him, the implementation of P-9 must be supported by a local ecosystem for storing, classifying, and reusing the materials that come from selective demolition. He explained it as follows:

> "[…] part of the enablers would be having a local ecosystem that supports (this practice) like a material reuse warehouse. We already have things in place with the department of ecology about the proper disposal of hazardous materials from building and construction. But I think we're still getting the other piece of the actual larger building elements […]"

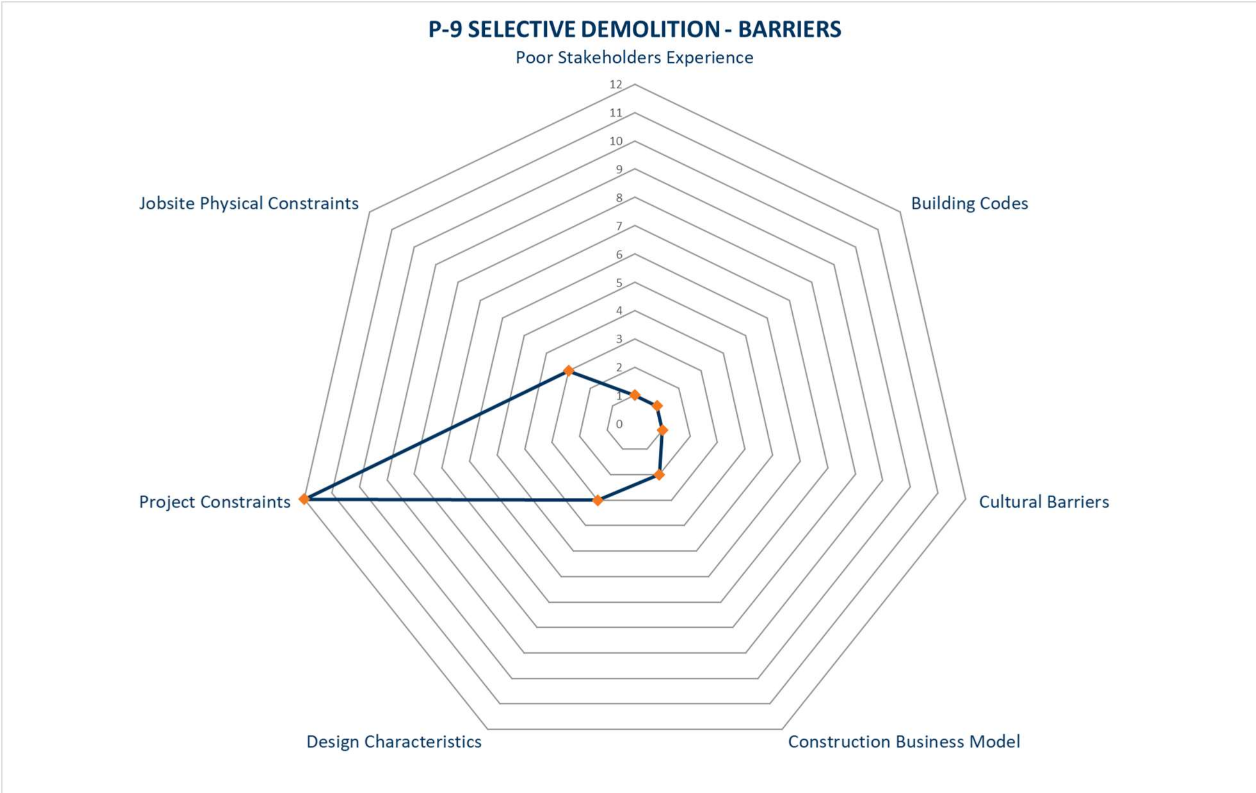

Figure 40: Barriers to P-9 Selective Demolition

Most of the interviewees asserted that the *Project Constraints* are the main ones, as shown in Figure 40. Interviewees indicated that it is more expensive to execute selective demolition than massive demolition because it requires more time to perform. Another consideration for implementing P9 is the additional space required to store the materials recovered. This requirement brings one more time the money factor to the table.

Interviewees also pointed out that there is a gap in the market because there are no companies specialized in providing additional value to the materials recovered, and the current policies and regulations do not boost the implementation of this practice but create a type of "imaginary barrier" for the materials reuse.

5.11 DISASSEMBLY OR DECONSTRUCTION

According to the answers received, this practice is one of the least implemented. Four interviewees indicated to have used this practice in recent projects. Participants explained that this practice is still in the early stages and requires more involvement of the stakeholders and the development of policies to boost the material reuse and a change in building code to support the use of salvaged materials. Interviewees also mentioned that the implementation of P-10 involves the use of laydown areas to store the materials and additional labor to classify the materials salvaged. Considering that these factors will represent an additional cost for the project, interviewees recommended performing a cost-benefit analysis before implementing P-10. When interviewees were asked to assess the possibility of implementing this practice in future projects, the average score obtained by P-10 was 1.67. This score suggests that the probability of implementing this practice in the future is very low.

When participants were asked which stakeholder is the decision-maker for implementing P-10, all the interviewees agreed that the owner is the one who drives this implementation.

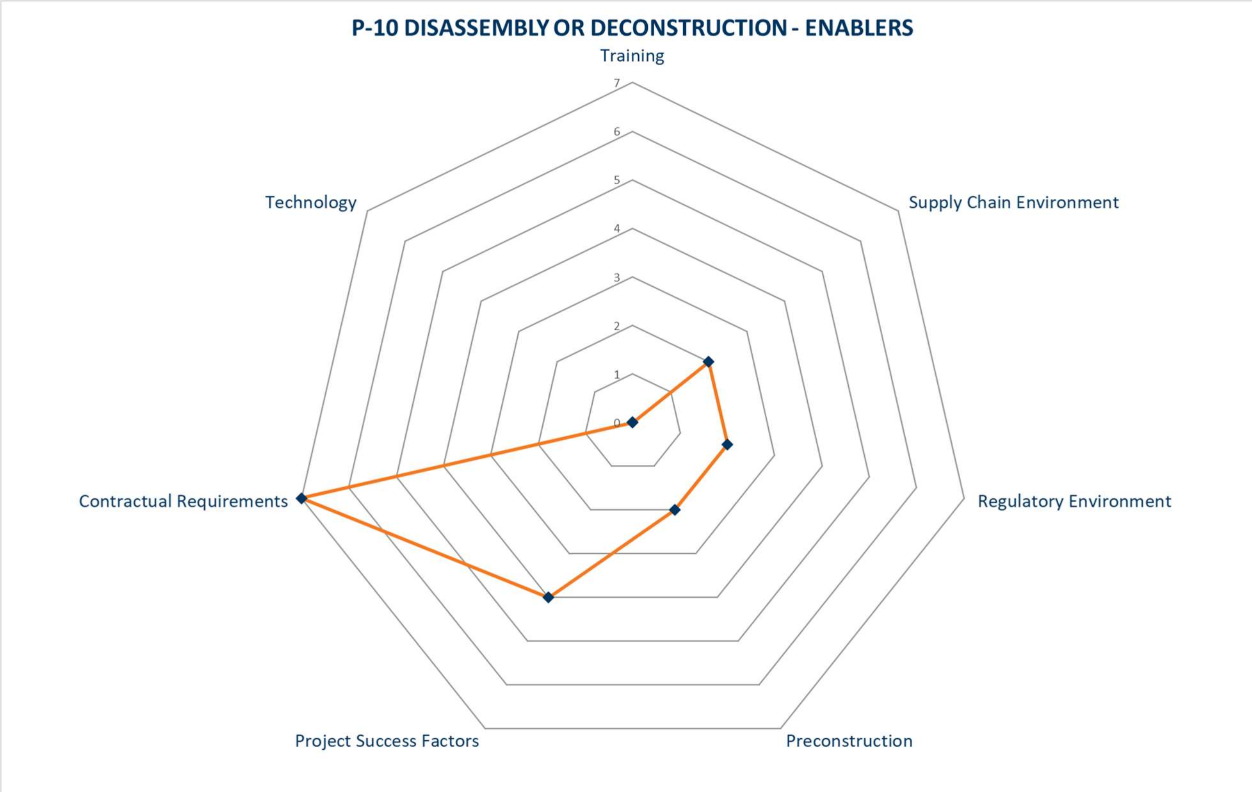

Figure 41: Enablers to P-10 Disassembly or Deconstruction

Figure 41 shows that the main enabler to P-10 is the *Contractual Requirements*. An interviewee mentioned that the nature of the building plays an important role in this case. For example, if the building is temporary, it will be designed and built to be easily disassembled in the future. Regarding the *Contractual Requirements*, Interviewee 9 mentioned the following:

> "[…] you've got to design for that disassembly approach. So you've got to create, I'm going to use a term called couplings, or you have to create specific coordinated joint locations that you can access and get to in a finished building that allows you to unhook the system, pulled the modular wall or ceiling or floor, and shift that off to a new location, and then reconnect those same connectors in a new location. You have to design for how you're going to assemble and reassemble these elements wherever you move them to […]"

Interviewee 3 mentioned that the *Project Success Factors* is another enabler for P-10. According to her, the possibility of reducing the materials' lead time due to the availability of materials recovered through deconstruction would accelerate the construction process. This benefit would generate a positive impact in terms of schedule and cost reduction. Interviewee 3 explained it as follows:

> "[…] I think just being able to install something very quickly, because you'll have it, and you know, say this isn't your first time doing it you know you have all the systems in place in order to put these skins out and set up a system, and in such a short amount of time, which we actually did at some of the hospitals around Washington […]"

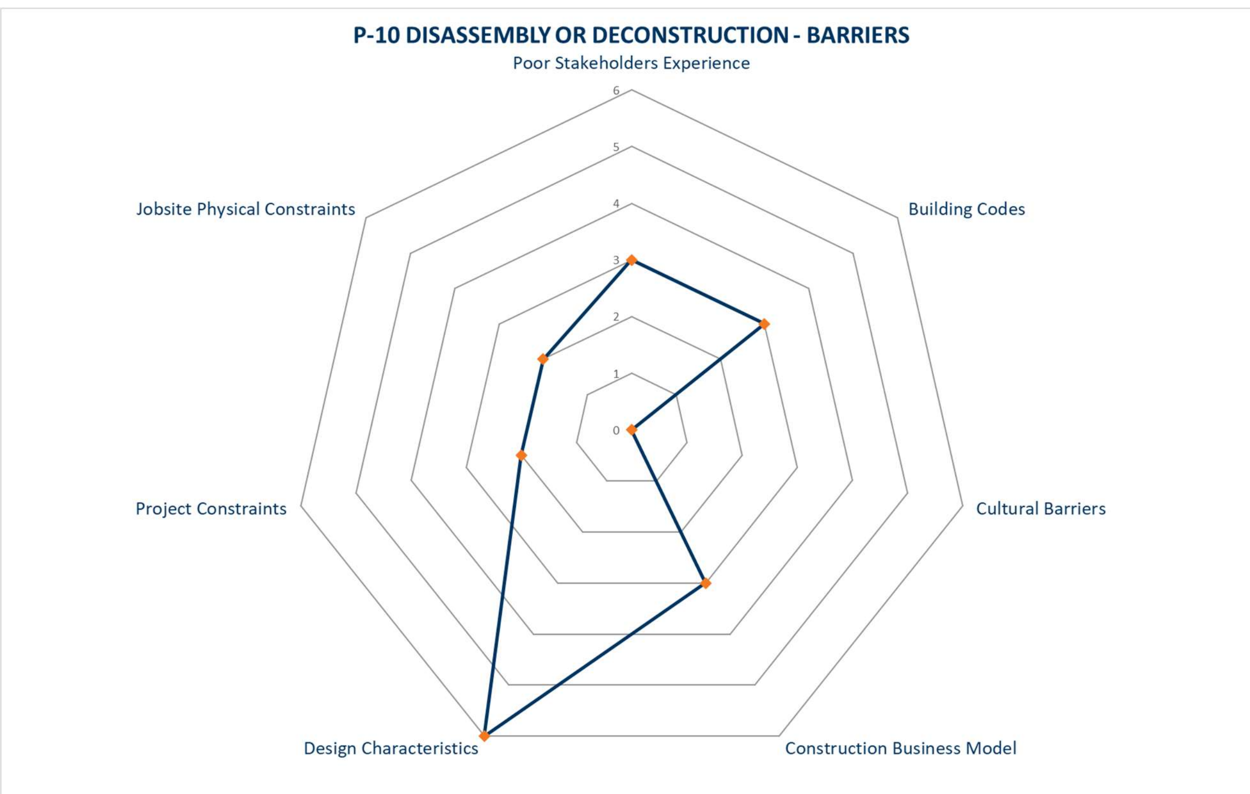

Figure 42: Barriers to P-10 Disassembly or Deconstruction

When interviewees were asked about the barriers to P-10, they mentioned that the *Design Characteristics* are the main barrier. Interviewees explained that designers work towards fulfilling the owners' requirements which in most cases do not consider disassembly as an option. Interviewees pointed out that the Construction Building Model is another barrier to P-10. According to them, the *Construction Business Model* aims to utilize new materials instead of reused ones. This factor makes the purchase of new materials cheaper than the use of recovered materials. Interviewees also indicated that implementing this practice will require the development of new markets such as material banks where all the salvaged materials can be classified, stored, and tested.

Interviewee 9 pointed out that the quality of the materials disassembled and reassembled could be a concern for the contractors because they would be assuming responsibility for any issue that could arise. He mentioned the following:

> "[…] How do we ensure that the material itself that is invisible has the same integrity, and still has a usable lifespan downstream? And then the last barrier that I would throw there at least from our perspective is we would have to ensure that, while those buildings are being maintained correctly […]. So, the one additional barrier I could think of is that the risk of reuse, usually the risk of the installation draw is limited to the contractor of the collective system. But when the contractor comes in and is just simply moving components from one place to the next, I, as a contractor or a subcontractor, would not want to warranty the systems that are still good. The client has to own that risk of the reassembled element […]"

Building Codes and *Poor Stakeholders Experience* also appeared as barriers to P-10. According to the interviewees, the quality requirements specified in the building codes are a determinant factor in construction. In many cases these requirements can be obtained using only new materials. Regarding the *Poor Stakeholders Experience*, interviewees pointed out an evident lack of knowledge about P-10. They indicated that before implementing P-10, the local stakeholders will need time to get familiar with this practice's ideas.

5.12 UPCYCLING

Nine participants mentioned having implemented this practice in recent projects. Interviewees pointed out that cost savings and a shorter schedule are some of the benefits of implementing P-11. These benefits can be reached by reducing the materials' lead time. Interviewees explained that this practice has a good potential to be implemented in the future, but it will require the development of environmental policies and economic incentives to boost it.

When interviewees were asked to assess the possibility of implementing this practice in future projects, they gave P-11 an average score of 3.20 out of 5. This score locates P-11 in the 7th position among the 12 practices. Interviewees mentioned that implementing this practice on a larger scale requires the development of a market for commercializing used materials. The education of the industry participants to understand the positive impact that this practice generates is also a must.

The fifteen participants mentioned that the stakeholder who drives the implementation of P-11 is the Owner. They mentioned that the implementation of this practice starts with the Owner's desire to keep some materials because of their special value or the cost savings that this practice can generate.

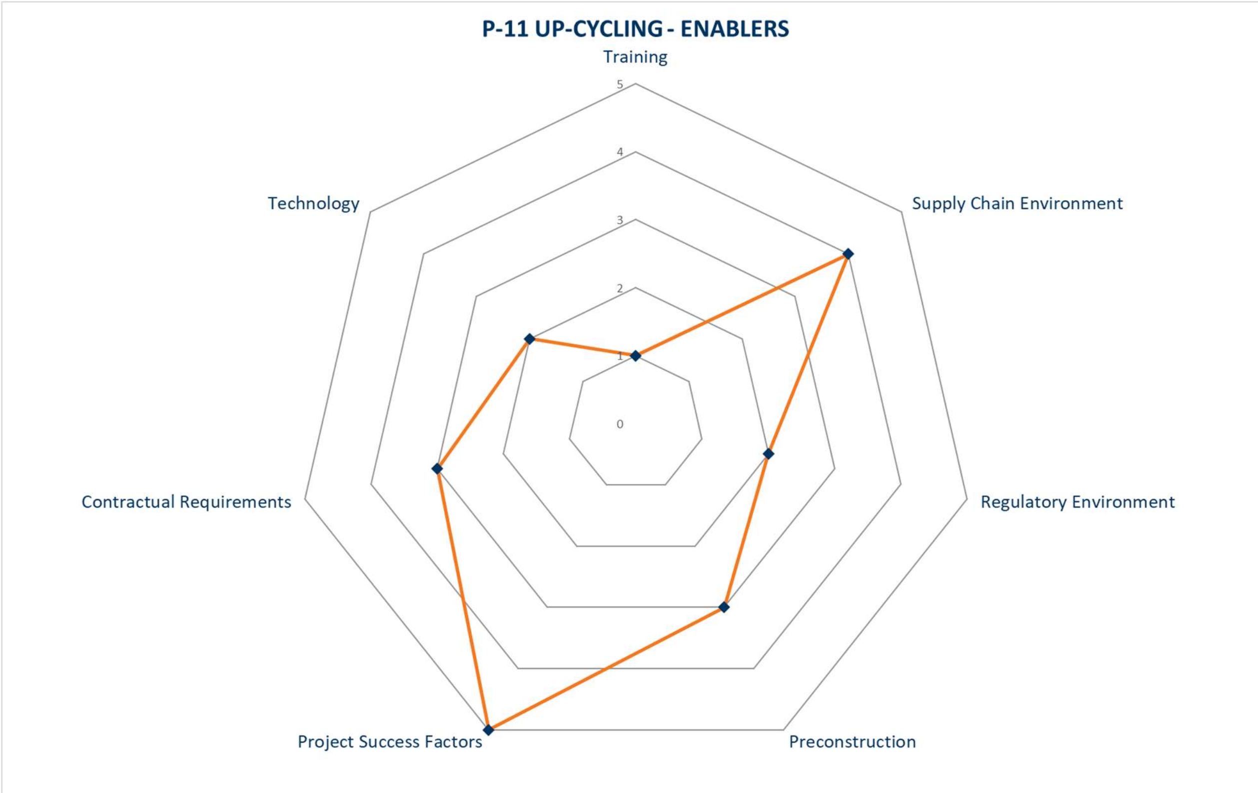

Figure 43: Enabler to P-11 Upcycling

Figure 43 shows the enablers to P-11. According to the interviewees, the main enabler of P-11 is the *Project Success Factors*. Participants who implemented this practice in recent projects pointed out that reducing the materials' lead time is a remarkable advantage. Interviewee 14 indicated that the cost savings obtained through avoiding waste disposal are significant in many cases. Regarding these benefits, Interviewee 14 mentioned the following:

> "[…] there's a really great opportunity to think creatively about how we can upcycle materials. There's also a really great community engagement potential with upcycling materials […] one person's waste is another person's treasure or whatever you want to call it, and so there's a lot of great opportunity for us like material or waste that we might see us nuisance or waste on our job sites could end up being really valuable material to

someone especially in the community who might need it […] in the past we've had some good examples of upcycling materials in a way that didn't affect our project schedule or a project budget and actually ended up helping our project budget because all of a sudden we're donating waste materials to an organization, we're not paying to dispose of that material […]"

According to Interviewee 6, the *Supply Chain Environment* plays an important role in implementing P-11. He indicated that the emergence of companies that leverage the use and commercialization of recovered materials is fundamental. The materials recertification was another important point mentioned by Interviewee 6. This recertification could allow the reused materials to compete with the new ones, ensuring that their quality characteristics are similar.

Interviewee 13 pointed out that *Preconstruction* can also be considered an enabler to P-11. According to him, up-front activities and pre-planning can boost the implementation of P-11 because these allow the design team to identify the materials that can be disassembled and recovered in the end-of-life of the building. Regarding the *Contractual Requirements*, Interviewee 10 explained that some owners and final users recognize the historical value of determined building elements and decide to recover and reuse them.

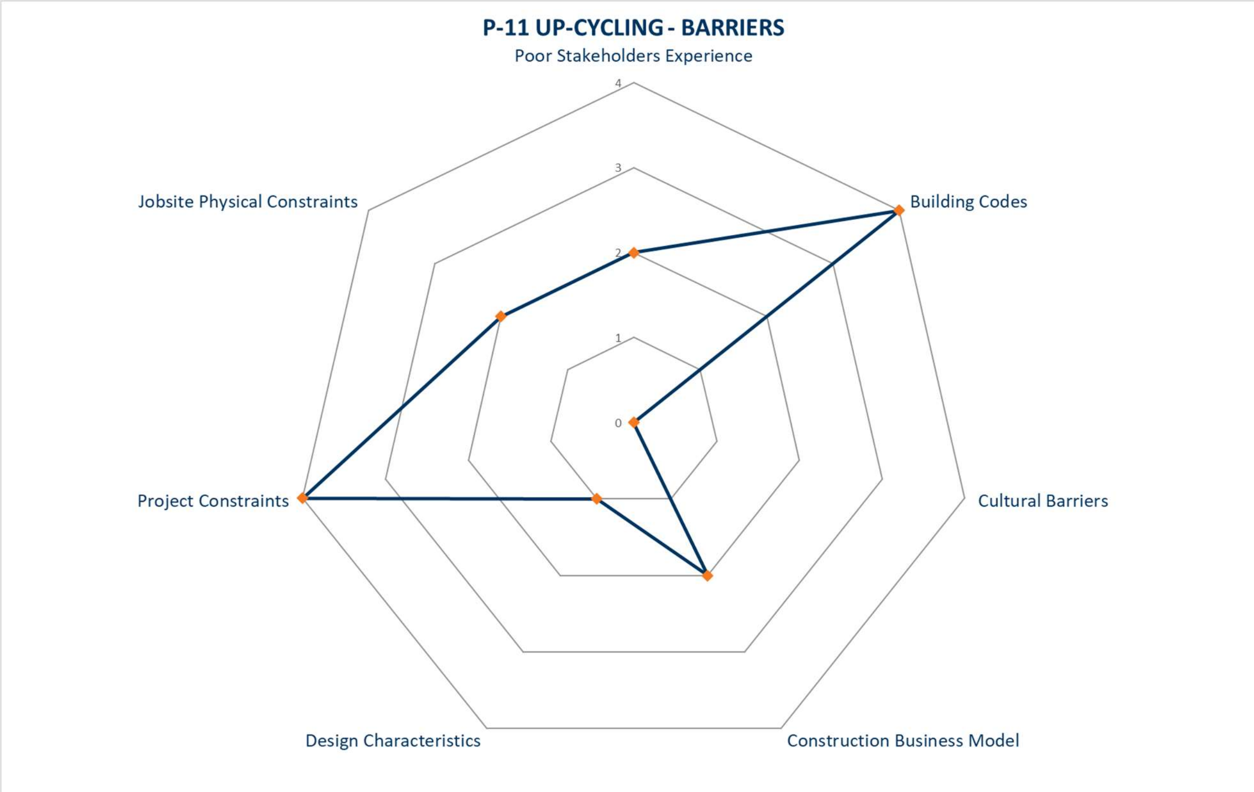

Figure 44: Barriers to P-11 Upcycling

When interviewees were asked about the barriers to P-11, they mentioned that the *Building Codes* and the *Project Constraints* are the most important. Interviewees pointed out that the characteristics of the materials that can be used in construction are specified in the building codes. In most cases, these characteristics can be reached only by new materials. Regarding the *Project Constraints*, interviewees indicated that the Pacific Northwest's labor cost is considerably higher compared to other states. This factor makes P-11 less likely to be implemented because of the high costs of handling materials. To determine how beneficial for the project is to implement P-11, a cost-benefit analysis was recommended. Interviewee 9 mentioned the following regarding the barriers:

"[…] We would have to be able to do a cost benefit analysis that says, am I saving more money?, Am I able to provide the client a costs competitive way of reusing this material? Is it more cost effective for me just to demo it out and install new systems versus just relocating and reusing old systems? […] one thing to consider is regionally across the United States, you have more expensive labor in the State of Washington, in Chicago and New York and these high high-cost labor areas, the cost of labor is the driver for decision-making versus the cost of material. If I'm in Colorado, New Mexico, Kansas, Nebraska, the cost of material becomes more of a impact through the overall schedule versus the labor, so it's in those regions this process of upcycling might be more beneficial to the client than in the high labor cost regions […]"

Interviewee 6 said that the *Construction Business Model* is also a barrier to P-11. According to him, the "make-use-dispose" model has to change along with the mindset of the industry participants who are not willing to use recovered materials in their projects.

5.13 DOWNCYCLING

The last practice discussed with the interviewees was Downcycling (P-12). Seven participants mentioned having applied this practice in recent projects. Participants mentioned that the main advantage of P-12 is cost savings generated through the avoidance of material disposal. When interviewees were asked to assess the possibility of using this practice in future projects, they gave P12 an average score of 3.14 out of 5. This score suggests that this practice will likely continue to be implemented in future projects.

Interviewees were asked which stakeholder drives the implementation of P-12 and they indicated that the Owner and the Designer are the principal ones. Participants explained that there are cases in which the Owner wants to know how the materials will be disposed of, especially when there are sustainability goals involved. Interviewees pointed out that the owner, through the contractual documents developed by the designer (drawings and specifications), has the power to require the implementation of this practice.

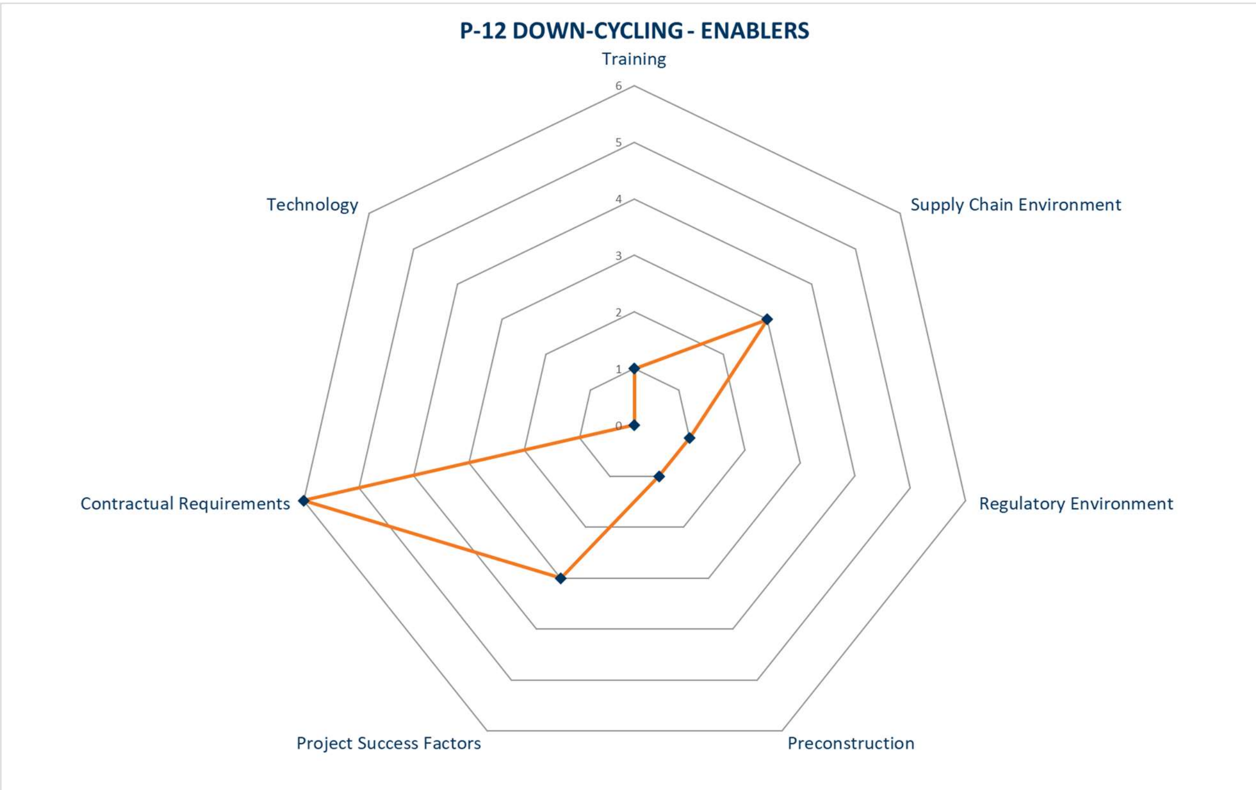

Figure 45: Enablers to P-12 Downcycling

Figure 45 shows the results of the answers obtained when interviewees were asked about the enablers of P-12. According to the participants, the main enabler is the *Contractual Requirements*. In this case, the designers can propose the use of recovered materials or elements that will not be critical for the project. Regarding this practice and its enablers, Interviewee 12 provided the following example:

> "[…] So most of the down cycling I saw is just things get repurposed in things that don't have a lot of responsibility, such as decorative elements, for example, a new feature of my lobby that's comprised of something that used to be something else. […] if there's certain value, or certain history behind the materials, you know, a lot of times it comes down to a history like this thing used to be, or this is from our first ever headquarters, this history is a big one that usually enables it [P-11 …]"

Interviewee 10 said that the *Project Success Factors* is an additional enabler to P-12. According to him, the savings generated through the waste disposal avoidance and the reduction of the costs associated with the materials purchase are significant. Interviewee 10 explained this as follows:

> "[…] The enablers are it's sustainable, and so you can get LEED points, you know, so you can get credit for doing that. It's enablers are were you reduce the amount of dumpster material you have, so you might be able to save some money […]"

According to Interview 4, the *Supply Chain Environment* is another enabler of P-12. He pointed out that the emergence of suppliers and vendors involved in the generation of additional value from used materials will be determinant for the implementation of P-12.

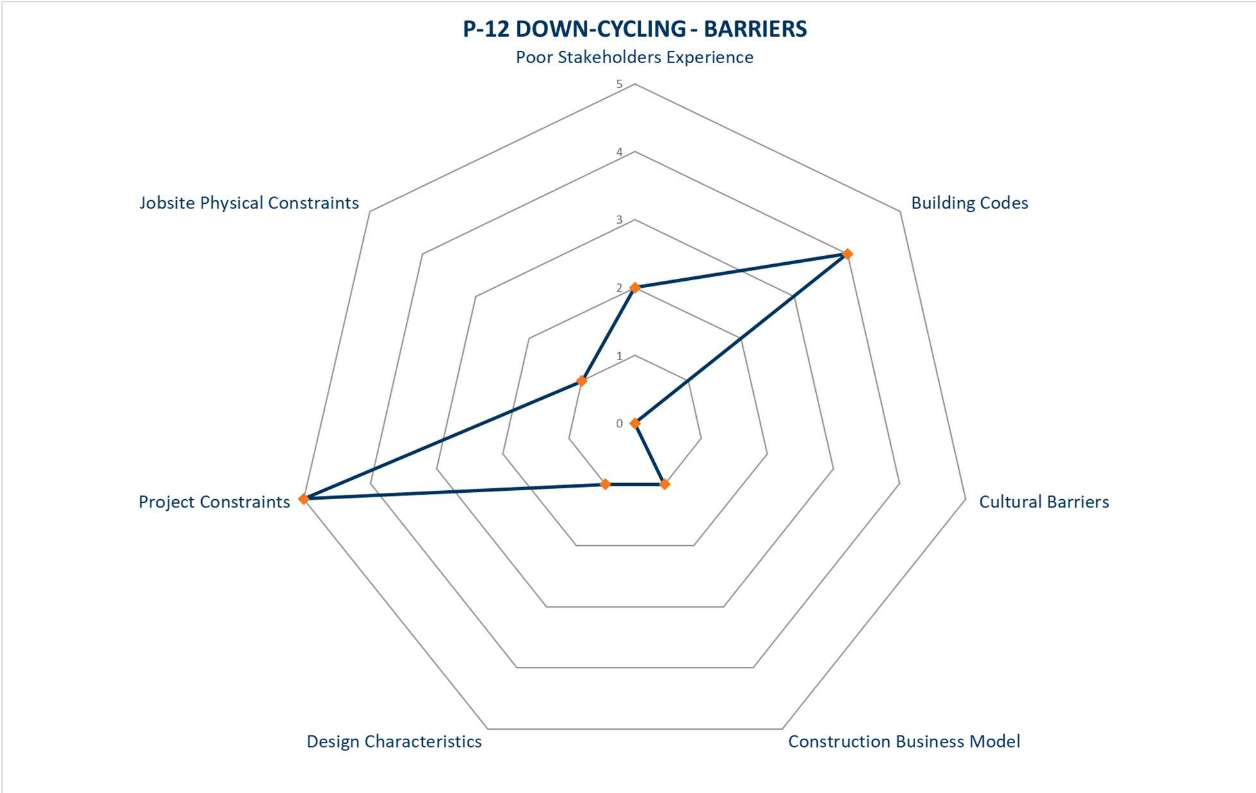

Figure 46: Barriers to P-12 Downcycling

Lastly, when interviewees were asked about the barriers to P-12, they mentioned that the *Project Constraints* and the *Building Codes* are the most remarkable. Regarding the *Building Codes*, interviewees pointed out that there is low tolerance for using materials of reduced quality. Regarding the *Project Constraints*, interviewees explained that the implementation of P-12 can be discouraged if the costs associated with the material's salvage, classification, storage, and reprocess are higher than the costs associated with the purchase of new materials.

CHAPTER 6 - DISCUSSION

This discussion is based on the interviews conducted with 15 industry representatives. The group of interviewees was composed of people with different experiences, backgrounds and positions in the construction sector (owners, designers, prime contractors, and subcontractors). In the interviews we discussed a group of Circular Economy practices currently implemented in the Pacific Northwest built environment. We also determined the practices that have the highest potential of being implemented in the following years as well as the enablers and barriers associated with these practices.

The results obtained can be seen as expanding the previous results obtained by Guerra & Leite (2021) that identified major circular economy strategies applicable during the design phase in the US built environment. These results also allow us to analyze in greater depth the enablers and barriers to the Circular Economy practices in the US explained by another study (Cruz, Grau, & Bilec, 2021).

Table 7 summarizes the interviewees' answers when they were asked about what Circular Economy practices they had applied in recent projects. According to the answers obtained the CE practices were separated into three groups. The first group corresponds to the *most implemented* practices (highlighted in green), the second group corresponds to the practices that are *not widely implemented* yet (highlighted in yellow), and the last group corresponds to the *least implemented practices* (highlighted in red).

Table 7: Level of applicability of Circular Economy practices in recent projects

PRACTICE DESCRIPTION	**Owner (n = 3)**		**Designer (n = 1)**		**GC (n = 9)**		**Sub Contractor (n = 2)**		**TOTAL (n = 15)**	
P-1 Selecting Materials and Products	3	100%	1	100%	9	100%	2	100%	**15**	100%
P-3 Design for Adaptability and Flexibility	3	100%	1	100%	8	89%	2	100%	**14**	93%
P-6 Design for Prefabrication	3	100%	1	100%	8	89%	2	100%	**14**	93%
P-7 Built out of Waste	3	100%	1	100%	8	89%	2	100%	**14**	93%
P-9 Selective Demolition	2	67%	1	100%	9	100%	2	100%	**14**	93%
P-2 Design for Modularity	1	33%	1	100%	7	78%	2	100%	**11**	73%
P-4 Design for Standardization	1	33%	1	100%	6	67%	1	50%	**9**	60%
P-11 Upcycling	1	33%	0	0%	7	78%	1	50%	**9**	60%
P-8 Building in Layers	1	33%	1	100%	5	56%	1	50%	**8**	53%
P-5 Design for Disassembly	1	33%	1	100%	3	33%	2	100%	**7**	47%
P-12 Downcycling	1	33%	0	0%	6	67%	0	0%	**7**	47%
P-10 Disassembly or Deconstruction	1	33%	0	0%	3	33%	0	0%	**4**	27%

The most applied practice is Selecting Materials and Products. Fifteen interviewees indicated to have applied this practice in recent projects. Design for Adaptability and Flexibility, Design for Prefabrication, Built out of Waste, and Selective Demolition complete the group of the most implemented practices. The least implemented practices are Design for Disassembly, Downcycling, and Disassembly or Deconstruction.

Table 8 shows the results of the interviewees' assessment of the possibility of implementing these 12 Circular Economy practices in future projects. The practices were again separated into 3 different groups. The first group corresponds to the practices with a score higher than 4 (highlighted in green). This group can be interpreted as the practices with the *biggest potential* to be implemented in future projects. The second group corresponds to the practices with a score between 3 and 4 (highlighted in yellow). This group can be understood as the practices with *some potential*. The last group (highlighted in red) corresponds to the practices with a score lower than 3. Group 3 is here the practices with the *lowest potential* to be implemented in the future.

Table 8: Disposition to apply Circular Economy practices in future projects

PRACTICE DESCRIPTION	YES	%	Score	%
P-9 Selective Demolition	14	93%	**4.80**	96%
P-1 Selecting Materials and Products	15	100%	**4.79**	96%
P-6 Design for Prefabrication	14	93%	**4.73**	95%
P-7 Built out of Waste	14	93%	**4.73**	95%
P-3 Design for Adaptability and Flexibility	14	93%	**4.40**	88%
P-2 Design for Modularity	11	73%	**3.87**	77%
P-11 Upcycling	9	60%	**3.20**	64%
P-12 Downcycling	7	47%	**3.14**	63%
P-4 Design for Standardization	9	60%	**3.07**	61%
P-8 Building in Layers	8	53%	**2.62**	52%
P-5 Design for Disassembly	7	47%	**2.40**	48%
P-10 Disassembly or Deconstruction	4	27%	**1.67**	33%

Interviewees pointed out that Selective Demolition is the practice that has the biggest potential to be implemented in future projects. It is important to point out that the practices on green shown in Table 8 coincide with the practices on green shown in Table 7.

The practices with the least potential of being implemented in future projects are Building in Layers, Design for Disassembly, and Disassembly or Deconstruction. As pointed out in Chapter 5, the implementation of these practices requires the development of new markets for materials trading, the training of professionals in the industry, and a shift in the mindset of the industry stakeholders. Downcycling requires special attention because even though it is one of the least implemented practices, it has some potential to be implemented in future projects.

The enablers of each of the Circular Economy practices were classified into seven groups based on the nature of the answers provided by the interviewees. Table 9 shows the summary of these enablers.

Table 9: Summary of the enablers identified and the number of times these were mentioned

PRACTICE DESCRIPTION	**E-1 Supply Chain Environment**	**E-2 Regulatory Environment**	**E-3 Preconstruction**	**E-4 Project Success Factors**	**E-5 Contractual Requirements**	**E-6 Technology**	**E-7 Training**
P-1 Selecting materials and products	2	3	3	5	6	0	3
P-2 Design for Modularity	2	0	4	8	5	0	0
P-3 Design for Adaptability and Flexibility	0	1	7	1	7	2	0
P-4 Design for Standardization	2	1	2	9	3	0	0
P-5 Design for Disassembly	2	3	2	1	6	1	0
P-6 Design for Prefabrication	3	0	3	12	2	1	0
P-7 Built out of Waste	1	1	3	4	2	1	5
P-8 Building in Layers	0	0	1	4	5	1	0
P-9 Selective Demolition	4	0	1	6	8	2	2
P-10 Design for Disassembly	2	2	2	4	7	0	0
P-11 Upcycling	4	2	3	5	3	2	1
P-12 Downcycling	3	1	1	3	6	0	1
TOTAL	**25**	**14**	**32**	**62**	**60**	**10**	**12**

The numbers in the boxes refer to the number of times the interviewees mentioned an enabler while discussing each practice. The boxes painted in green show the main enabler to each practice while the boxes painted in yellow show the secondary enablers.

E-4 Project Success Factors and E-5 Contractual Requirements were mentioned 122 times during the interviews and drive the implementation of 11 practices. E-7 *Training* is the main enabler for implementing P-7 Built out of Waste. The education of professionals in topics such as Lean Construction will create a positive impact on a project level, a company level, and an industry level.

According to Table 9, E-1 Supply Chain Environment would boost the implementation of P-9 Selective Demolition and P-11 Upcycling. E-2 Regulatory Environment would boost the implementation of P-1 Selecting Materials and Products and P-5 Design for Disassembly. E-6 Technology (BIM, VDC, VR, or AR) could boost the implementation of P-3 Design for Adaptability and Flexibility, P-9 Selective Demolition, and P-11 Upcycling.

E-4 Project Success Factors appear as the main enabler for P-6 Design for Prefabrication. This enabler was pointed out by 12 interviewees when P-6 was discussed. Regarding P-6, interviewees asserted that one of the principal advantages of this practice is the schedule reduction that can be obtained through the execution of activities in parallel, on jobsites and in factories.

The barriers to each CE practice were also classified into seven different groups and these are shown in Table 10.

Table 10: Summary of the barriers identified and the number of times these were mentioned

PRACTICE DESCRIPTION	B-1 Poor Stakeholders Experience	B-2 Building Codes	B-3 Cultural Barriers	B-4 Construction Business Model	B-5 Design Characteristics	B-6 Project Constraints	B-7 Jobsite Physical Constraints
P-1 Selecting materials and products	7	1	1	1	6	6	0
P-2 Design for Modularity	7	1	2	0	10	0	1
P-3 Design for Adaptability and Flexibility	1	1	2	0	5	9	0
P-4 Design for Standardization	5	1	0	0	5	5	2
P-5 Design for Disassembly	4	3	1	1	5	5	0
P-6 Design for Prefabrication	5	0	0	0	7	1	5
P-7 Built out of Waste	2	0	8	2	4	2	1
P-8 Building in Layers	2	3	0	1	4	3	1
P-9 Selective Demolition	1	1	1	2	3	12	3
P-10 Design for Disassembly	3	3	0	3	6	2	2
P-11 Upcycling	2	4	0	2	1	4	2
P-12 Downcycling	2	4	0	1	1	5	1
TOTAL	**41**	**22**	**15**	**13**	**57**	**54**	**18**

The numbers in the boxes refer to the number of times the participants mentioned a barrier while discussing each practice. The boxes painted in green show the main barrier to each practice while the boxes painted in yellow show the secondary barriers.

B-5 Design Characteristics and B-6 Project Constraints were mentioned 111 times by the interviewees and served as barriers for 10 practices. B-1 Poor Stakeholders Experience is the main barrier for P-1 Selecting Materials and Products. B-3 Cultural Barriers are the main barrier to implementing P-7 Built out of Waste in the projects.

It is important to remark that some practices have more than one main barrier. For example, according to Table 10, B-1 Poor Stakeholders Experience, B-5 Design Characteristics, and B-6 Project Constraints are the main barriers to implementing P-4 Design for Standardization. Similarly, B-2 Building Codes and B-6 Project Constraints are the main barriers to implementing P-11 Upcycling.

Twelve participants indicated that B-6 Project Constraints are the main impediment to implementing P-9 Selective Demolition. It is likely because of the additional time that must be invested to identify the materials that will be salvaged and the selection of these materials and the storage. B-5 Design Characteristics were referred to as the main obstacle to implementing P-2 Design for Modularity, ten interviewees pointed this out. These answers indicate that the "uniqueness" factor can play an important role in impeding the modularization of different building elements.

B-1 Poor Stakeholders Experience appears as a secondary barrier to implementing P-2 Design for Modularity. B-2 Building Codes appear as an impediment to the implementation of P-12 Downcycling. B-4 Construction Business Model appears as a barrier for P-10 Design for Disassembly. B-7 Jobsite Physical Constraints appear as an obstacle to implementing P-6 Design for Prefabrication. P-6 requires laydown areas to store the prefabricated elements and components, and not every project has these available areas.

CHAPTER 7 - CONCLUSIONS, LIMITATIONS, PRACTICAL IMPLICATIONS AND FUTURE RESEARCH

6.1 CONCLUSIONS

The conclusions drawn in this section are based on the pre-interview survey and the interviews conducted with 15 industry representatives. The analysis of the pre-interview survey data showed that most of the participants have considerable experience in the construction sector. The role the participants occupy in their companies in addition to the level of involvement during the decision-making and their understanding of sustainability topics gave the research team confidence in the reliability of the participant's responses.

The interviews conducted after the pre-interview survey allowed the participants to discuss in depth the Circular Economy practices proposed in this study and describe in detail their experiences with these practices. This discussion led to the identification of the practices implemented in the PNW construction market, the practices with the biggest potential to be implemented in future projects, the enablers and barriers associated with implementing these practices, and the decision-maker behind the implementation of them.

The general consensus of the interviewees exhibited that Selecting Materials and Products is the most applied practice. Interviewees pointed out that the implementation of this practice is related to factors such as the project phase (design or construction), the delivery method used, and the level of power of the stakeholders during the decision-making process. Design for Adaptability and Flexibility, Design for Prefabrication, Built out of Waste, and Selective Demolition also belong to the group of the most implemented practices. Interviewees indicated that the benefits in terms of cost and schedule reduction obtained through implementing these practices are the reason that boosts their implementation. Disassembly or Deconstruction on the other hand, appeared as the least implemented practice. The lack of specialized stakeholders familiar with this practice and the lack of policies to boost the re-utilization of construction materials are among the reasons why this practice is still in its early stages.

When interviewees were asked about the practices with the biggest potential to be implemented in future projects, Selective Demolition appeared as the first on the list. The cost savings obtained through the reduction of waste generation and the eagerness of the Owners to get a LEED certification are among the factors that make this practice the most probable to be applied in future projects. Selecting Materials and Products, Design for Prefabrication, Built out of Waste, and Design for Adaptability and Flexibility also belong to the group of practices with the biggest potential to be applied in future projects. The results have shown that the list of practices with the biggest potential to be implemented in future projects coincides with the most implemented practices in recent projects. This factor can be interpreted as the benefits gained through implementing these practices on recent projects are likely to make them implemented in future projects. Design for Disassembly, Building in Layers, and Disassembly or Deconstruction appeared as the practices with the least potential to be implemented in future projects. It was also found that although Downcycling was one of the least implemented practices in recent projects, this practice has some potential to be implemented in future projects. Participants mentioned that factors such as the project sustainability goals could boost the implementation of this practice.

The findings regarding the enablers provided us with relevant information. These findings allowed us to confirm that the project stakeholders' willingness to implement any of the practices discussed is directly related to the benefits that can be obtained through the implementation of these practices or the Owner requirements. Project Success Factors and the Contractual Requirements were the main enablers for the implementation of 11 practices. The Project Success Factors comprised cost, schedule, quality, and safety benefits. The Contractual Requirements comprised contractual documents such as the drawings, specifications, special conditions, and contract. The Training was the most significant enabler for Built out of Waste. In this case, the implementation of this practice is directly related to the education of professionals in lean construction topics.

The results obtained from the study of the barriers allowed us to identify that Design Characteristics and Project Constraints are the main barriers for 10 practices. Design Characteristics refer to the Owner's desire to have unique buildings with special attributes or designs. Often this "uniqueness" factor has a price and it is the inability to implement practices such as prefabrication, standardization, or modularity that require a certain level of replicability in the building. Project Constraints refer to the pre-established budget and schedule associated with a project. The implementation of some practices requires the investment of additional costs upfront or in the end-of-life of a building and many Owners are not willing to incur these costs. It was also found that the Poor Stakeholders Experience is the main barrier to implementing Selecting Materials and Products, while Cultural Barriers are the most significant to implementing Built out of Waste.

Finally, the interviews revealed that the decision-maker for the implementation of 9 practices was the Owner. This answer was expected considering that the Owner is the one who has the final decision regarding the implementation of the practices discussed before. As explained, many Owners are not willing to invest additional money in their projects because their business models do not allow that. However, a group of Owners pays additional attention to the life-cycle costs instead of the design and construction costs only. Owners of institutional buildings or healthcare facilities are a good example of this. The Designer drives Building in Layers. Designers do their job following the building codes that specify the level of integration and dependency that each layer must have. Prime Contractors are the decision-makers for implementing Design for Prefabrication and Built out of Waste. According to the results obtained, prime contractors must have the experience, knowledge, and networking to propose Design for Prefabrication as a potential solution. Regarding Built out of Waste, prime contractors are the ones who can obtain the most significant benefits from the implementation of lean construction practices to avoid waste generation during the construction phase.

6.2 LIMITATIONS, PRACTICAL IMPLICATIONS AND FUTURE RESEARCH

A major limitation of this research was the data collection. Not all the respondents felt confident discussing about circular economy because this topic is new in the US construction industry. The number of interviews that we could have conducted was reduced considerably because of this. Only fifteen of the forty invited participants were willing to be part of the research. Because of this reason, this research must be considered as an exploratory study.

The target audience was another limitation. Even though we invited a diverse group of Designers, Owners, Prime Contractors, Subcontractors and Suppliers did the Prime Contractors show more interest in our research and this might generate bias in the results obtained.

The final limitation was associated with the Covid-19 pandemic. The whole planet was affected by the pandemic, and this made our research more difficult. Many projects were delayed or incurred cost overruns which generated Project Managers, Superintendents, and Project Executives to have a very busy schedule that impeded them from participating in this research.

This study will help construction practitioners and researchers better understand a group of 12 Circular Economy practices that can be applied during the different phases of a project (design, construction, and end-of-life). In turn, the groups created to sort the enablers and barriers can be used as a reference for future research and expand the knowledge on the topic. Finally, the results obtained will serve as a point of comparison between this research and others that consider a bigger group of participants, different geographical areas, and different types of projects.

It is essential to draw attention to the fact that this research was focused on the Pacific Northwest market. We recommend that new research covering a wider geographical area should be developed to attain a broader understanding of the implementation of Circular Economy in different regions of the United States.

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APPENDIX A – Invitation Email

Hello Mr./Mrs. XXXXXXXXXXX,

My name is Ruben Salazar, I am a master's student in the Department of Construction Management at the University of Washington. Under the supervision of Professor Giovanni Migliaccio, I am working on my master thesis on the topic of Circular Economy Practices in Construction: Evaluating Adoption in the Pacific Northwest. Circular Economy refers to a new economic model aiming at keeping the materials at their highest value in a closed loop. Selective demolition, deconstruction/disassembly, and recycling are examples of circular economic practices in construction.

We would like to invite you to an interview that will help us to define the level of implementation of twelve circular economy practices as well as identify the main barriers and drivers for the adoption of these practices. This interview will have a duration of around 40 – 60 minutes, and we are planning to conduct it using the platform Zoom.

We expect that this topic could be of interest to you, and hope you are willing to share your knowledge and experience with us in order to complete this research.

Thank you very much

Ruben Salazar

Giovanni C. Migliaccio

APPENDIX B – Email to Schedule Interview and Invite to Fill Pre-Interview Survey

Hello XXXXX,

First, thank you for your willingness to help us in this research. Could you please provide us with dates/times that you will be available to have this interview?

Meanwhile, please complete the attached pre-interview survey. This will help us to have a better understanding of your background and experience.

Thank you

Ruben Salazar

PRE-INTERVIEW SURVEY

NAME:

1. What is the highest level of education you have pursued?	Graduate (Master)	Bachelor	Other college work	High School	Other

2. How long have you been working in the construction industry?	< 3 years	3-5 years	5-10 years	10-20 years	20+ years

3. What position do you hold in your company currently?	Company Executive	Project Execut.	Project Man.	Superintendent	Field/Project Engineer	Designer/Architect	Other

4. How long have you been in this position with your company?	< 3 years	3-5 years	5-10 years	10-20 years	20+ years

5. What is the approximate value of the largest project you have worked on in the last three years?	< $5 m	$ 5m - 15m	$15m - 30m	$ 30m - 50m	$ 50m - 100 m	> $100m

6. What is the typical role of your company on a construction project?	Owner/Developer	Designer	Prime Contract.	Sub Contractor	Vendor	Other

7. To understand the general size of your company, what is the estimated average annual revenue of your company for the last 3 years?	< $50m	$ 50m - 100m	$ 100 - 250m	$ 250 - 500 m	$ 500m - 1b	$ >1b

8. To what extent are you involved in the decision-making process in terms of design, material selection and/or sustainability goals?	Fully involved	Somewhat involved	Aware but not involved	Not aware / not involved

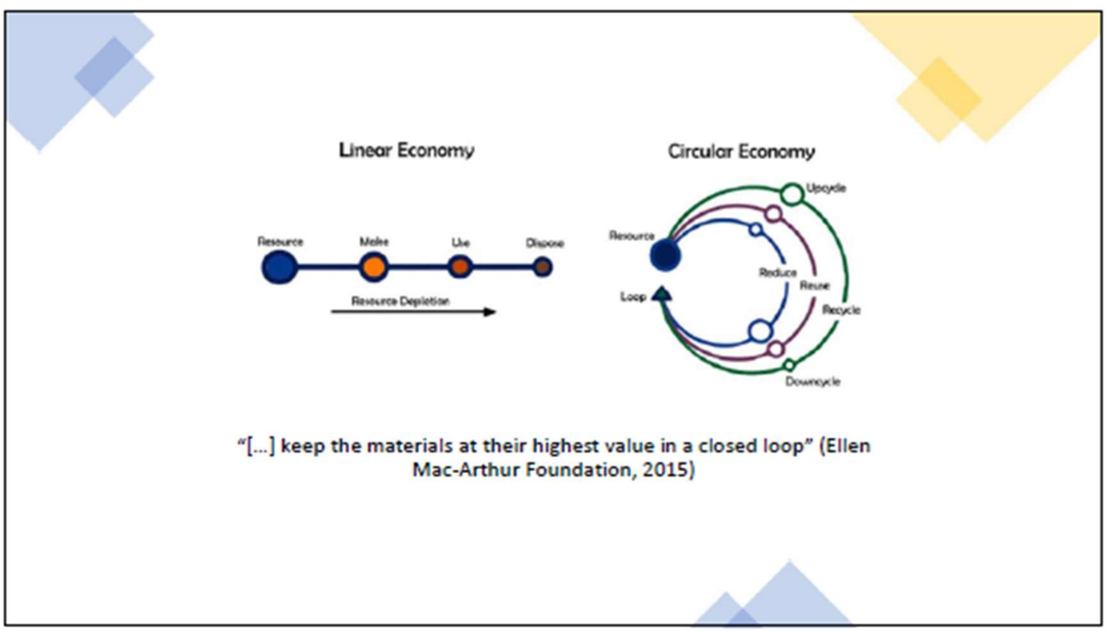
9. Most common project delivery method(s) used on your company's projects	DBB	DB	GC/CM - CM@Risk	IPD	Other

10. Most common type(s) of construction project(s) in your company	Commercial/ Institutional Building	Industrial Facility	Infrastructure/ Heavy Civil	Residential	Other

11. Have you ever received a special training or certification related with any sustainability topics?	LEED Green Associate	LEED AP Specialty	Other	None

APPENDIX C – Interview Guide

1



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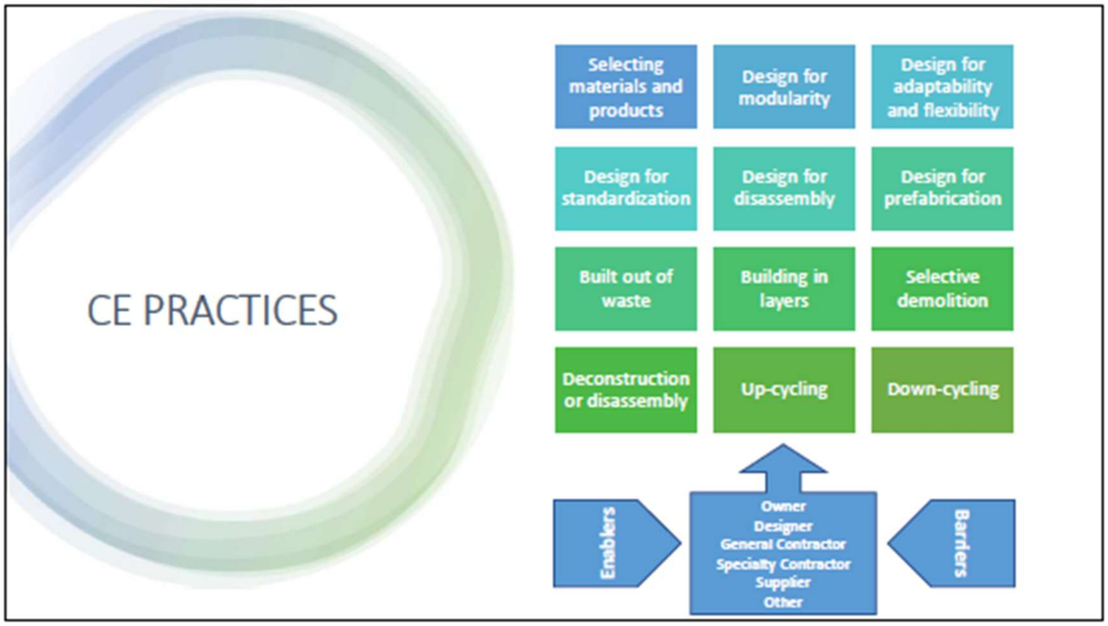


3

P1. Selecting materials and products

- Description: Selection of materials/products considering factors such as lifespan, project location, components (e.g. steel, glass, etc.), and re-usability potential.
- Example: use of local materials, use products that allow the separation of the biodegradable and non-biodegradable materials

Cardboard duct

4

P1. Selecting materials and products

- Have you used P1 on your recent projects?
- Can you provide an example?
- Can you assess the possibility to apply P1 on your next projects (1-5 scale)?
  - **5 = most probable to apply**
  - **1 = least probable to apply**
- What factors may enable its implementation?
- What factors could serve as barriers?
- Which stakeholder could be the decision-maker for the implementation of P1?

5

P2. Design for modularity

- **Description: Design and built using materials and elements that are compatible with different systems in terms of functionality and dimensions (different components brought together to shape a specific module. e.g walls+finishes, restrooms, racks+piping systems)**
- **Example:**

6

P2. Design for modularity

- Have you used P2 on your recent projects?
- Can you provide an example?
- Can you assess the possibility to apply P2 on your next projects (1-5 scale)?
  - 5 = most probable to apply
  - 1 = least probable to apply
- What factors may enable its implementation?
- What factors could serve as barriers?
- Which stakeholder could be the decision-maker for the implementation of P2?

7

P3. Design for adaptability and flexibility

- Description: The main purpose is to design and build in a way that allows any adaptation or modification of the building during its lifespan
- Example: an educational building that allows an easy rearrangement of its internal elements such as demountable walls

8

P3. Design for adaptability and flexibility

- Have you used P3 on your recent projects?
- Can you provide an example?
- Can you assess the possibility to apply P3 on your next projects (1-5 scale)?
  - 5 = most probable to apply
  - 1 = least probable to apply
- What factors may enable its implementation?
- What factors could serve as barriers?
- Which stakeholder could be the decision-maker for the implementation of P3?

9

P4. Design for standardization

- Description: Standardization of materials and building elements such as connectors in order to simplify the disassembly process at the end-of-life
- Example: Martini hospital is made of uniform building blocks with a standard dimension of 2.4 x 7.2 m (8 ft x 24 ft)

Martini hospital, Netherlands

10

P4. Design for standardization

- Have you used P4 on your recent projects?
- Can you provide an example?
- Can you assess the possibility to apply P4 on your next projects (1-5 scale)?
  - **5 = most probable to apply**
  - **1 = least probable to apply**
- What factors may enable its implementation?
- What factors could serve as barriers?
- Which stakeholder could be the decision-maker for the implementation of P4?

11

P5. Design for disassembly

- Description: The objective is to design elements and components that can be easily disassembled, recovered, and reused at the end of their lifespan
- Example: having mechanical and reversible connections, use independent and easily separable elements of the building such as the structure, façade, or internal finishes

12

P5. Design for disassembly

- Have you used P5 on your recent projects?
- Can you provide an example?
- Can you assess the possibility to apply P5 on your next projects (1-5 scale)?
  - 5 = most probable to apply
  - 1 = least probable to apply
- What factors may enable its implementation?
- What factors could serve as barriers?
- Which stakeholder could be the decision-maker for the implementation of P5?

13

P6. Design for prefabrication

- Description: Manufacturing of some building components outside of the jobsite in order to reduce the amount of waste generated during construction and facilitate the assembly/disassembly process (individual elements)
- Example: concrete beams/columns, walls

14

P6. Design for prefabrication

- Have you used P6 on your recent projects?
- Can you provide an example?
- Can you assess the possibility to apply P6 on your next projects (1-5 scale)?
  - 5 = most probable to apply
  - 1 = least probable to apply
- What factors may enable its implementation?
- What factors could serve as barriers?
- Which stakeholder could be the decision-maker for the implementation of P6?

15

P7. Built out of waste

- **Description: Use lean construction principles in order to reduce the waste produced during the construction process.**
- Example: reduction of waste produced due to rework, overproduction, or excessive processing. Similarly avoid material waste

16

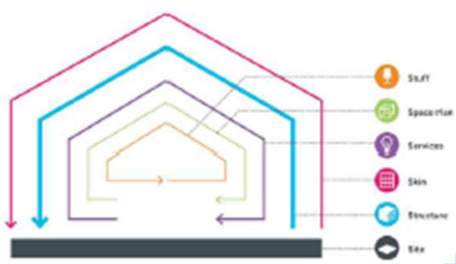
P7. Built out of waste

- Have you used P7 on your recent projects?
- Can you provide an example?
- Can you assess the possibility to apply P7 on your next projects (1-5 scale)?
  - 5 = most probable to apply
  - 1 = least probable to apply
- What factors may enable its implementation?
- What factors could serve as barriers?
- Which stakeholder could be the decision-maker for the implementation of P7?

17

P8. Building in layers

- **Description: Building the building in different and individual layers considering the lifespan of each of these elements, for example, structure, facades, finishes, fixtures.**
- Example:



18

P8. Building in layers

- Have you used P8 on your recent projects?
- Can you provide an example?
- Can you assess the possibility to apply P8 on your next projects (1-5 scale)?
  - 5 = most probable to apply
  - 1 = least probable to apply
- What factors may enable its implementation?
- What factors could serve as barriers?
- Which stakeholder could be the decision-maker for the implementation of P8?

19

P9. Selective demolition

- Description: This practice has two steps, the first is called soft stripping and consists of the removal of hazardous wastes, and in the second step different building elements are separated, sorted, and provided with a new life.
- Example: removal of materials such as asbestos during the first step of the demolition process, and the removal of materials such as bricks, metal, doors, or timber during the second step

20

P9. Selective demolition

- Have you used P9 on your recent projects?
- Can you provide an example?
- Can you assess the possibility to apply P9 on your next projects (1-5 scale)?
  - 5 = most probable to apply
  - 1 = least probable to apply
- What factors may enable its implementation?
- What factors could serve as barriers?
- Which stakeholder could be the decision-maker for the implementation of P9?

21

P10. Deconstruction or disassembly

- Description: The main idea is to disassembly the building with the purpose of reusing elements and components, and thus to avoid waste coming from the demolition process.
- Example: Efficiency House Plus, Berlin. This building is disassembled every 3 years and assembled again in a different location

22

P10. Deconstruction or disassembly

- Have you used P10 on your recent projects?
- Can you provide an example?
- Can you assess the possibility to apply P10 on your next projects (1-5 scale)?
  - 5 = most probable to apply
  - 1 = least probable to apply
- What factors may enable its implementation?
- What factors could serve as barriers?
- Which stakeholder could be the decision-maker for the implementation of P10?

23

P11. Up-cycling

- Description: Reuse/remanufacture building elements and materials for the same purpose these were manufactured initially
- Example: the reuse of steel beams for the same purpose in future projects

24

P11. Up-cycling

- Have you used P11 on your recent projects?
- Can you provide an example?
- Can you assess the possibility to apply P11 on your next projects (1-5 scale)?
  - 5 = most probable to apply
  - 1 = least probable to apply
- What factors may enable its implementation?
- What factors could serve as barriers?
- Which stakeholder could be the decision-maker for the implementation of P11?

25

P12. Down-cycling

- Description: Materials are remanufactured into different products with lower value
- Example: use of crushed concrete as an aggregate

26

P12. Down-cycling

- Have you used P12 on your recent projects?
- Can you provide an example?
- Can you assess the possibility to apply P12 on your next projects (1-5 scale)?
  - **5 = most probable to apply**
  - **1 = least probable to apply**
- What factors may enable its implementation?
- What factors could serve as barriers?
- Which stakeholder could be the decision-maker for the implementation of P12?

27

APPENDIX D – Pre-Interview Survey Summary

Interviewee #	1. Level of Education	2. General Experience	3. Position	4. Years in current position	5. Biggest project in which participated	6. Company's role	7. Company's size	8. Level of involvement in design	9. Contract type	10. Project Type	11. Leed Certification
Interviewee 1	Bachelor	20+ years	Company Executive	5-10 years	> $ 100 m	Prime Contractor	$ 500m - 1b	Somewhat involved	IPD	Institutional building	LEED Green Associate
Interviewee 2	Graduate (Master)	20+ years	Project Executive	3-5 years	> $ 100 m	Prime Contractor	$ 250m - 500m	Somewhat involved	GC/CM - CM@Risk	Institutional building	LEED Green Associate
Interviewee 3	Graduate (Master)	10-20 years	Project Manager	3-5 years	$ 50m - 100m	Owner/ Developer	$ 500m - 1b	Somewhat involved	DBB	Institutional building	Other
Interviewee 4	Graduate (Master)	3-5 years	Project Manager	3-5 years	$ 50m - 100m	Owner/ Developer	$ 500m - 1b	Somewhat involved	DBB	Institutional building	LEED Green Associate
Interviewee 5	Bachelor	10-20 years	Company Executive	3-5 years	> $ 100 m	Prime Contractor	> $ 1 billion	Somewhat involved	DB	Institutional building	LEED Green Associate
Interviewee 6	Bachelor	5-10 years	Project Manager	3-5 years	$ 15m - 30m	Prime Contractor	$ 100m - 250m	Somewhat involved	DBB	Healthcare	Other
Interviewee 7	Graduate (Master)	< 3 years	Other	< 3 years	N/A	Prime Contractor	$ 250m - 500m	Fully involved	DBB	Institutional building	LEED AP Specialty
Interviewee 8	Bachelor	5-10 years	Project Executive	3-5 years	$ 15m - 30m	Sub Contractor	$ 250m - 500m	Somewhat involved	GC/CM - CM@Risk	Institutional building	None
Interviewee 9	Graduate (Master)	20+ years	Project Manager	20+ years	> $ 100 m	Sub Contractor	$ 250m - 500m	Somewhat involved	DB	Institutional building	LEED AP Specialty
Interviewee 10	Graduate (Master)	20+ years	Company Executive	20+ years	> $ 100 m	Owner/ Developer	< $ 50 million	Aware but not involved	GC/CM - CM@Risk	Institutional building	None
Interviewee 11	Bachelor	10-20 years	Project Manager	< 3 years	> $ 100 m	Prime Contractor	> $ 1 billion	Aware but not involved	GC/CM - CM@Risk	Institutional building	None
Interviewee 12	Bachelor	20+ years	Other	10-20 years	> $ 100 m	Prime Contractor	$ 500m - 1b	Fully involved	GC/CM - CM@Risk	Institutional building	LEED AP Specialty
Interviewee 13	Bachelor	10-20 years	Project Manager	3-5 years	> $ 100 m	Prime Contractor	$ 250m - 500m	Somewhat involved	GC/CM - CM@Risk	Institutional building	LEED Green Associate
Interviewee 14	Bachelor	5-10 years	Other	3-5 years	> $ 100 m	Prime Contractor	$ 500m - 1b	Fully involved	GC/CM - CM@Risk	Institutional building	LEED Green Associate
Interviewee 15	Graduate (Master)	10-20 years	Designer/ Architect	< 3 years	> $ 100 m	Designer	$ 100m - 250m	Fully involved	DBB	Institutional building	LEED Green Associate