

Design for Reassembly

Facing the Demands of Housing by Imagining a Flexible Future

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ABSTRACT

Design for Reassembly

Facing the Demands of Housing by Imagining a Flexible Future

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The construction of new housing is expected to double over the next decade¹ and the methods by which we currently design and build new homes continues to contribute to a culture of waste. The pressures that our economies face as more and more people move to cities will continue to be a problem and our built environment should be better equipped to handle growth in a sustainable way. Currently, 90% of waste from the construction industry comes from the demolition and renovation of buildings whereas the other 10% comes from new construction.² Imagine if there was zero waste. Could we build the buildings of tomorrow out of the buildings we have today?

We can increase the useful life of the buildings we design and ensure that the materials we use can be reused or ‘up-cycled’ in the future. With ‘design for disassembly’ as an integral part of how we think about and develop new housing, we can build homes that are more readily adaptable and use materials more effectively and purposefully, ultimately reducing waste, labor, and cost over the lifespan of the building.

This thesis will focus on housing needs and growth in Seattle and looks to ‘design for disassembly’ as a guiding tool for developing housing that can adapt to meet changing demands of lifestyles, incomes and family sizes without the need for demolition or destructive renovation.

PREFACE

When I first discovered that I wanted to practice architecture I was 20 years old and had just finished reading William McDonough and Michael Braungart's first book *Cradle to Cradle: Remaking the Way We Make Things*. I was infused with new ideas about how to look at the world around me and I became fascinated at how it was put together. During my education, I continually questioned how things are made and I challenged this through research and a fascination with building architectural models. My interest in design for disassembly began when I traveled to Copenhagen, Denmark as a Valle Scholar. For three months I worked closely with GXN Innovation who are continuing to put ideas about design for disassembly into practice. I owe a lot of my inspiration for this thesis to them.

I want to thank my colleagues, professors, mentors, and all of my friends who have offered me guidance, perspective, and encouragement during this project. I especially want to thank Rob Pena and Peter Cohan who first introduced me to Kasper Guldager Jensen of GXN Innovation, without them none of this would have happened. I would also like to thank the Valle Scholarship and Scandinavian Exchange program which has provided me with the opportunity to live and work abroad in Denmark. The experience was extraordinary. The friends, memories, and experiences I made there are ineffable. I would like to thank Rick Mohler who encouraged me to look more closely at the housing conditions in Seattle and has continually shaped my understanding of land use and city planning. I would also like to thank Mike Mariano for sharing his insights and experience with design for disassembly. A special thanks to Kimo Griggs and all of the staff in the fabrication lab who have continued to inspire me and teach me how to think like a maker. I would like to thank my family for their love and always supporting all of my aspirations. Finally, I would like to thank my grandfather, his artistic spirit and passion for craft has ignited the spark of creativity in my mind and continues to light the way.

DESIGN FOR REASSEMBLY

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PART 1: INTRODUCTION



Figure 1: Destructive Demolition
<http://interactive.wbez.org/curiouscity/chicago-teardowns/>

PART 1: INTRODUCTION

THE ISSUES

A Culture of Waste

“It is well documented that 75% of natural resource consumption occurs in cities. Cities produce 50% of global waste and 60-80% of greenhouse gas emissions. These are symptoms of the ‘take, make, dispose’ linear economic model. The need for change is increasingly evident, with cities feeling the effects ... Cities are where most materials are used and wasted, and where buildings, cars and products are consistently under-used.”³
(Ellen MacArthur foundation)

In the building and construction industry, little regard is given to the value of materials after a building has been constructed. Our resources are limited, harvesting new materials is costly and damaging to our environment. Each day we throw away more and more materials while simultaneously extracting and building things new. According to the EPA “548 million tons of construction and demolition debris was generated in the united states in 2015.” The EPA also states that “Currently 90% of waste from the construction industry comes from the demolition and renovation buildings whereas the other 10% comes from new construction.”² Facing issues like climate change, cities all over the world are

working to reduce their footprint on the earth. The ways in which we currently design buildings do not allow for easy disassembly so that materials can be appropriately recycled or even used again.

Despite this, people are trying to reduce their waste. The city of Portland, Oregon recently passed a deconstruction ordinance in 2016 for four key reasons.

1. Maximize the salvage of valuable building materials for reuse
2. Reduce carbon emissions associated with demolition
3. Reduce the amount of demolition waste disposed of in landfills
4. Minimize the adverse impacts associated with building removal

According to a 12-month status report of the deconstruction process they have found that on average deconstruction is directing approximately 70% of materials to reuse, not including concrete. However, the market for salvaged materials may be approaching what it can currently absorb without finding new uses for the material.⁴

PART 1: INTRODUCTION

THE ISSUES

William McDonough and Michael Braungart have been influential in working to change our waste culture and bring about a 'Circular-Economy', a culture without waste. The idea is centered around creating closed-loop material streams, and reuse, in order to build an economic model that thrives off of the prolonged value of a material through its inherent life-cycle as opposed to the make, take, dispose 'linear' economic model that is in practice today.⁵ A Circular Economic model is one in which products, businesses, and even whole buildings can be designed to support the reuse of materials and eliminate the concept of waste at every scale. Out of this movement toward a Circular Economy came ideas about 'Design for Disassembly' [DfD], which looks closer at circular design thinking as applied to the architecture, engineering and construction industry.

If we hope to reduce our dependency on raw materials from the earth we can start by learning from those who are putting DfD into practice and look at new ways we can design our buildings in the future.



Figure 1: Destructive Demolition
<http://interactive.wbez.org/curiouscity/chicago-teardowns/>

PART 1: INTRODUCTION

THE ISSUES

Demands on Housing

“At the current rate, humanity may well be 80 percent urban by mid-century. Every week there are 1.3 million new people in cities. That’s 70 million a year, decade after decade. It is the largest movement of people in history.”⁶
(Whole Earth Discipline)

Freddie Mac, the federal loan mortgage corporation has published some alarming data regarding our current state of housing. Firstly, housing growth and demand is increasing at an unprecedented rate. In the United States, approximately 1.62 million units of new housing are needed each year, and there is not currently enough housing being constructed to meet this demand. Among some of the factors that are contributing to the shortage of housing production is the cost of building a home.⁷

“... In some markets like San Jose, Santa Ana, Oakland, and Los Angeles, land can cost upward of 70 percent of the cost of building a home. Laws and regulations such as local zoning restrictions on lot sizes and building height and open space designations also increase the cost of building a home, in turn reducing the supply of new homes.”⁷
(Freddie Mac)

These elevated housing costs are pushing people that can not afford the costs associated with owning a home out of the city, which in turn is diminishing the cultural diversity in our neighborhoods. Other options for young adults seem to be limited to moving back in with their guardians or moving into a shared living arrangement.

Another major factor that is reducing the supply of housing options is the fact that current residents in small neighborhoods close to the city are fighting against increases in development. “So-called NIMBY-ism (Not In My Back Yard)—is restricting new construction in some locales.”⁷ This is a growing issue in many cities across the United States. According to Dr. Arthur C. Nelson as cited by Opticos Design “90% of available housing in the U.S. is located in a conventional neighborhood of single-family homes, adding up to a 35 million unit housing shortage.”⁸

Our current housing stock does not accommodate for changing lifestyles, ages, and the varying income of its users.

PART 1: INTRODUCTION

THE ISSUES

The demand for a variety in housing choice is also high. People want to live in walkable neighborhoods closer to amenities and are willing to live in smaller homes. At the same time, baby boomers want to remain in their communities without being dependent on others for transportation. They might also be looking to find new ways to reduce the maintenance required of a larger home.

Trends in housing show that people typically move as their spatial needs change, for example when two partners decide they need more space to start a family, or when an older family wants to downsize as their children move out on their own. Our housing is not designed to adapt as our needs change.

Simply put, we need more housing and we need more types of housing that are readily flexible and adaptable if we want to reduce the pressures our economies face from the demands on the housing market.



Figure 2: Wallingford Neighborhood, Seattle, Washington

PART 1: INTRODUCTION

POSITION



Figure 3: Deconstructed House

Some of the challenges that our housing market is currently facing could be lessened by using design for disassembly as a strategy to develop new housing projects that are designed with adaptability and material reuse strategies from the beginning.

Materials are finite and we need to be more conscious in the ways that we use them.⁵ We can not continue to build structures that will ultimately end up in a landfill. By using the principals of DfD as demonstrated by other professionals and described in the forthcoming chapters, we can increase the useful life of the structures we design and ensure that the materials we use can be reused, recycled or ‘up-cycled’ in the future.

With adaptability and flexibility at the forefront of DfD, housing should be able to grow, shrink, or even be relocated without the need for demolition or destructive renovation. This strategy can provide a wider variety of flexible housing types that are longer lasting, are easier to maintain, and will be readily adaptable as future needs in the housing market continue to change.

PART 1: INTRODUCTION

PROPOSAL

We can change the way that we think about housing and how materials are used in our cities. Rather than condemning the materials we use to a landfill, this thesis proposes that we can design our buildings to be reassembled. ‘Design for Reassembly’, as a strategy, can face the demands of housing through an adaptable, flexible, dismantlable and re-buildable architecture that imagines a future of construction without waste.

Seattle is one of the fastest growing cities in the United States and as such it will be the testing ground for this thesis. The demand for new strategies to address the issues around climate change and population growth is urgent. According to the Seattle Neighborhood Planning Commission “Since 2010, the city has added more than 105,000 residents, surpassing 700,000 in 2017. One implication of this growth has been a rise in housing prices, creating an increase in the exclusivity of single-family neighborhoods.”⁹

The neighborhood of Wallingford has been identified as a place of contention within the city because of current land use policies,

specifically single-family zoning, which restricts the development in the area to one type of housing. This will be a perfect location to explore how different typologies can better utilize these spaces if the city of Seattle is expected to allow for the addition of new housing in the future. A block consisting of existing single-family homes will be the test site.

The project will be to develop a housing system that is designed for reassembly and test it in a variety of arrangements on the block site in Wallingford, Seattle. The system will encourage disassembly, relocation, or reassembly as opposed to demolition or destructive renovation.



Figure 4: Column Prototype

PART 2: DESIGN FOR DISASSEMBLY: A SMARTER WAY TO BUILD

WHAT IS DESIGN FOR DISASSEMBLY?

“Design for disassembly is a holistic design approach where the intention is to make any given product easy to disassemble into all its individual components. This approach permits the different material elements used in the construction process to remain in a closed material cycle, where they can be re-used, re-assembled and recycled into new products of similar or higher quality” (GXN)¹⁰

Re-use and adaptation are not new ideas. In fact, many buildings that last a long time do so because they are easy to change, remodel, add on to. Steward Brand highlights this in his book *How Buildings Learn* and even though buildings can adapt buildings are inherently not designed to ‘adapt’ from the start.¹¹ It has only been since about the ‘50s when our industry turned to a model of manufacture and rapid consumption that made disposing of products in a landfill more commonplace.⁵ Does this phrase sound familiar to you? ‘Well back in the day my grandfather did everything by hand, when something broke he would fix it.’ This is how things used to be. This is because materials were valuable and expensive to replace and so it would make more sense to repair things instead of throwing them away. Today we continue to find cheaper and faster ways to make things. We make things so cheap and so fast

that when something breaks, its easier to throw that item into the trash than to repair the item that is broken.

‘Design for disassembly’ [DfD] is rooted in the value of a materials’ ‘life cycle’ and it is a design approach that enables closed-loop material streams. This has many benefits, but before we look at those I want to look at a simple example of how design for disassembly looks at a small, manageable scale.

On the next page is an image of a bicycle completely disassembled into all of its parts. These materials are made by different manufacturers and fit seamlessly with one another. They do not require glue or toxic chemicals to bind together, and when one of these parts wears down they can be easily replaced by the user. The parts are manageable by hand and thus they can be delivered and assembled by one person with the appropriate tools. A product like this bicycle will innately last a very long time if it is maintained well. Similarly, this approach can be applied to a much larger scale, like a building.

PART 2: DESIGN FOR DISASSEMBLY: A SMARTER WAY TO BUILD

CIRCULAR ECONOMY

DfD is a major component of ‘Circular Economy,’ an economic business model wherein businesses can develop design strategies and practices which thrive off of the prolonged value of understanding a material’s inherent ‘life-cycle’ in order to create a closed loop material stream.¹² This is in direct opposition to a make, take, discard ‘linear’ economic model that is in practice today.

Michael Braungart and William McDonough have been pioneers of putting the Circular Economy into practice and documenting their discoveries through the writing of two books ‘Cradle to Cradle’ and ‘The Upcycle.’ They point out that “Human industry has been in full swing for little over a century, yet it has brought about a decline in almost every ecosystem on the planet. Nature doesn’t have a design problem. People do.”⁵

This thesis does not intend to investigate or develop a Circular Economic business model for the practice of architecture. Rather, the core elements present in this ideology are learned from in order to make a case for sustainable design and construction.

The two diagrams on the next page, produced by GXN, do a good job of describing how a Circular Economy works. Figure 6 illustrates a linear economic model. In this model materials are harvested and extracted from the earth, the materials are then combined through manufacturing processes to develop a product, and then afterward the composite product is discarded. The materials end up being discarded primarily because they were not designed to be taken apart, and doing so would be more costly than to simply replace the material. For example, asphalt shingles are a composite of papers, aggregates, oils, and adhesives which make them waterproof. After they become damaged from extensive use the paper and aggregates can no longer be separated from each other to be used again. Instead of finding a new use for the worn shingles, they become waste material. In Figure 7 we see the exact opposite. All materials remain separable, not combined with an irreversible process, but designed to come apart. As a result, these biological and technical materials can remain in a continuous ‘closed-loop’ of making, disassembly and re-making.

PART 2: DESIGN FOR DISASSEMBLY: A SMARTER WAY TO BUILD

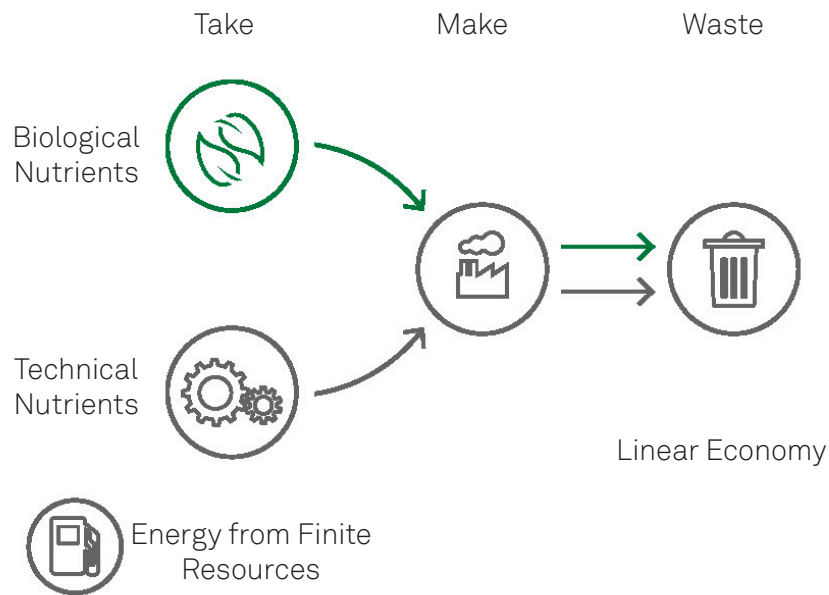


Figure 6: Linear Economy
Source: Jensen, K. G., & Sommer, J. (2016). Building a Circular Future. Copenhagen: GXN Innovation. - Reinterpretations of originals owned by the Ellen MacArthur Foundation

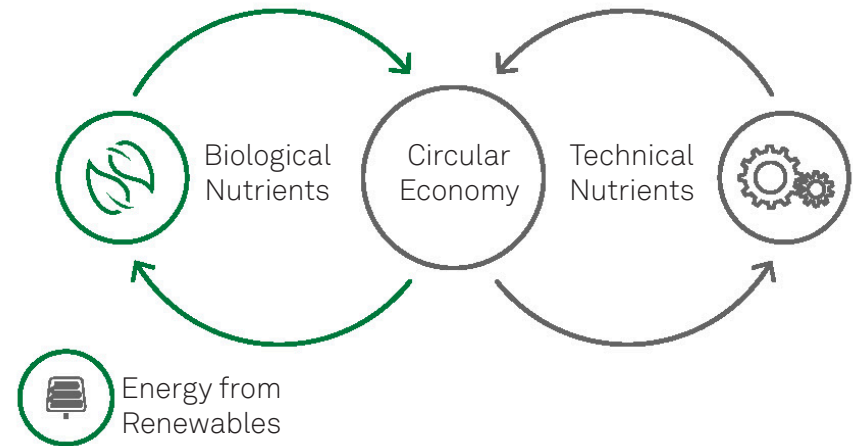


Figure 7: Circular Economy
Source: Jensen, K. G., & Sommer, J. (2016). Building a Circular Future. Copenhagen: GXN Innovation. - Reinterpretations of originals owned by the Ellen MacArthur Foundation

PART 2: DESIGN FOR DISASSEMBLY: A SMARTER WAY TO BUILD

A MATERIAL'S LIFE CYCLE

Perhaps the most important concept to understand when designing for disassembly is that buildings and the materials in them have a 'life cycle.' The 'life cycle' is used in Life Cycle Assessment [LAC], a tool used by professionals in order to fully understand the environmental impacts that occur at every stage in a material's useful life.¹³

The 'life cycle' of any given material begins at extraction from the earth, through its manufacture and use, past the time when it is thrown away in a landfill and it is off-gassing chemicals into our biosphere. The truth is that the life cycle of a material doesn't ever truly end, the molecules of that material will continue to exist in different forms. For example, when wood burns, oxygen and heat alter the wood and a byproduct of mostly carbon dioxide and soot is produced. The carbon dioxide enters our atmosphere as a gas and the soot becomes a deposit into the soil. And the 'life cycle' of this wood ultimately began not just before it was burned but before it started as a seed that grew into a tree.

Now, consider all the different types of materials that make up a building. This list of materials would comprise of concrete, wood, metals, clay, fabrics, plastics, glass, foams, oils, adhesives, binders, sealants . . . and the list goes on.

“Most of these products were made from valuable materials that required effort and expense to extract and make, billions of dollars' worth of material assets. Unfortunately, all of these things end up heaped in a landfill, where their value is wasted. They are the ultimate products of an industrial system that is designed on a linear one-way cradle-to-grave model.”⁵
(Cradle to Cradle)

A cradle-to-cradle model, alternatively suggests that materials can retain their value, be used over and over again, and when their useful life comes to an end they can be safely returned to the earth, or recycled. Every time a material is extracted, produced and used it has negative impacts on our environment which contribute to climate change. By reusing materials as much as possible the negative impacts on this cycle can be reduced. And when the material is no longer suitable for reuse it should be properly recycled, not thrown away.

PART 2: DESIGN FOR DISASSEMBLY: A SMARTER WAY TO BUILD

In Figure 3 I have illustrated a material's 'life-cycle' as described by Katherina Simonen in Pocket Architecture: Technical Design Series, Life Cycle Assessment.¹³ The life cycle starts when raw material is extracted from the earth. It then undergoes processing and manufacture as it is converted into building materials. The building materials are then transported to the construction site and assembled, often in ways that do not allow for easy disassembly. The building is then occupied and used. During that time the building will likely undergo maintenance as materials break down from extensive use. The end of life for a building is usually due to the fact that it is no longer suits its intended use, or someone new purchases the land and wants to build something else. In many cases, it is at this point that the cost of disassembly and the value of the materials that could be reclaimed are far less valuable than the cost and speed of demolition. DfD makes it easier, and less costly to take a building apart and it is at this stage where the value and useful life of the material is increased. The material could then be taken apart, re-used in new applications, recycled to make new materials, or directly reassembled in alternate locations.

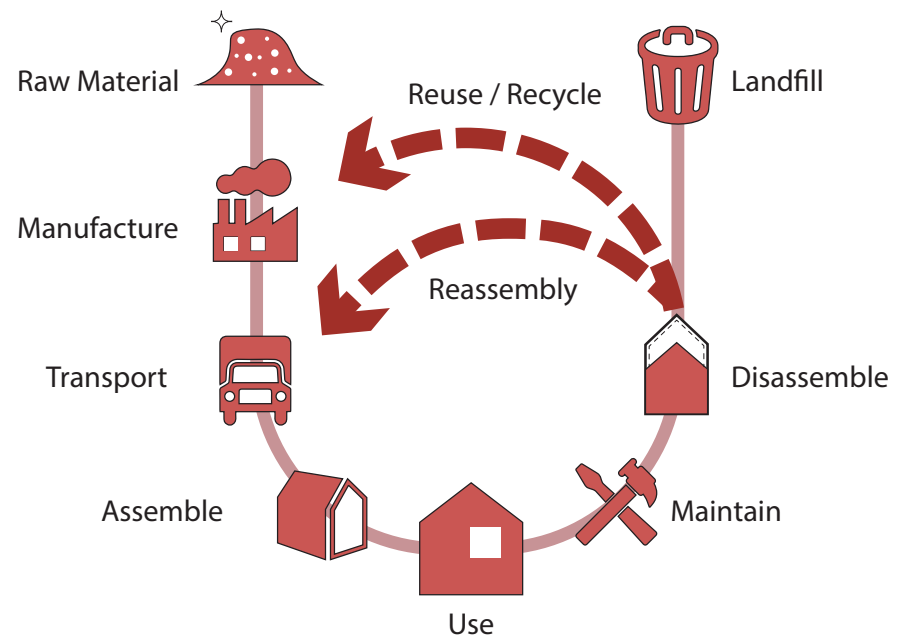


Figure 8: A Material's Life Cycle as reinterpreted from Pocket Architecture: Technical Series, Life Cycle Assessment

PART 2: DESIGN FOR DISASSEMBLY: A SMARTER WAY TO BUILD

A MATERIAL'S LIFE CYCLE

Michael Braungart and William McDonough describe how to avoid composite materials in order to extend the useful life of the materials we use. When designing with the intention of being able to dismantle the material components used it is critical to understand the difference between biological materials, technical materials, and monstrous hybrids. They define these materials as such:

“Monstrous hybrids - mixtures of both technical and biological, neither of which can be salvaged after their current lives.

A Biological nutrient is a material or product that is designed to return to the biological cycle - it is literally consumed by microorganisms in the soil and by other animals.

A technical nutrient is a material or product that is designed to go back into the technical cycle, into the industrial metabolism from which it came . . . isolating them from biological nutrients allows them to be up-cycled rather than recycled-to retain their high quality in a closed-loop industrial cycle.”⁵
(Cradle to Cradle)

Examples of each are shown on the next page. Wood is a great example of biological or organic material. It is organic, it can be

used many times, and it can be returned to the earth at the end of its useful life. Technical materials are ones produced by industrial processes like steel and plastics. As long as they remain separable, they can be used again or recycled by the industrial processes from which they came.

Monstrous hybrids are the key elements to avoid in a closed-loop design approach. These hybrids combine biological and technical materials in ways that make them inseparable and thus gives them a single serving purpose which increases their likelihood of being disposed of when they are no longer useful. For example, when a house is built it is very common to use OSB (oriented strand board) as a load bearing material and as a surface to mount exterior siding. OSB is created by using heat-cured adhesives and layering of wood strands. The heat-cured process cannot be reversed. The wood, now impregnated with toxic adhesives can no longer return to the environment through decomposition. The adhesives used during the process also render the material unsafe to burn. After it's used in a building most OSB ends up in landfills.

PART 2: DESIGN FOR DISASSEMBLY: A SMARTER WAY TO BUILD

BIOLOGICAL MATERIALS



Wood flooring



Heavy timber structure

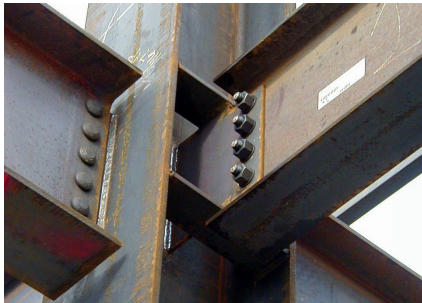


Organic mushroom bricks



Clay tiles

TECHNICAL MATERIALS



Steel structure



Corrugated metal siding



Glass facade system



Up-cycled plastic shingles

MONSTROUS HYBRIDS



Concrete + re-bar



Wood stud wall + spray foam



Liquid nail adhesive binder



Torch down roofing

PART 2: DESIGN FOR DISASSEMBLY: A SMARTER WAY TO BUILD

A BUILDING HAS LAYERS

The 'Building Layers' diagram that is commonly referred to when writing about a building's composition of parts was originally found in Stewart Brand's book 'How Buildings Learn.' These layers are broken down by how long each 'layer' of the building lasts or is constructed to last. In his book Stewart Brand breaks down the layers as such; Stuff, Space Plan, Services, Skin, Structure, and Site. Each of these components refers to that element's service life within a building. They are required for specific purposes and act as a whole, however, the materials selected for each often last varying amounts of time during the useful life of a project.¹¹ For example, the structural system will certainly outlast the 'Stuff' such as furnishings or a rug that you might have in your home.

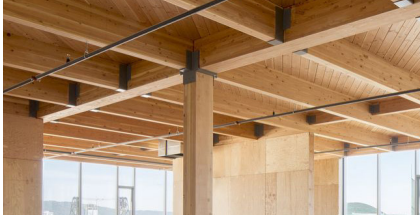
These six categories have been further broken down, renamed or added on to by other architects. Bernard Leupen changes them a bit too, and calls them as such; Structure, Skin, Services, Access, and Scenery.¹⁴ The important change here is the addition of access which refers to the layer of accessibility commonly grappled within larger housing projects.

For the purpose of this thesis, I am going to describe design for disassembly with a combination of the two. The importance of understanding each of these layers comes at their intersection, how each layer is attached to one another in order to create the entire system.

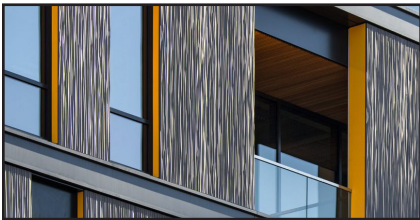


Figure 9: A Building's Layers as reinterpreted from Stewart Brand and GXN

PART 2: DESIGN FOR DISASSEMBLY: A SMARTER WAY TO BUILD



Structure consists of all components integral to the stability of the building; the frame, columns, trusses, beams, floors, shear elements, bracing. These elements should be built to last the longest but still need to have the ability to be taken apart and replaced with visible and accessible connections.



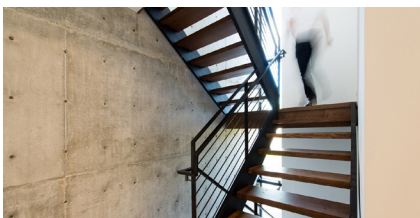
Skin consists of the weather proofing elements of a building, the enclosure. Because this layer effects the longevity of the other layers, it should be the most versatile in its ability to be maintained.



Services are the mechanical, plumbing and electrical equipment. These items include everything from toilets and HVAC systems, to fire suppression, lighting, data and security systems. An important part about this layer is that technology, as well as building codes, keep changing. A building's ability to adapt and have new systems installed and old ones updated is vital to its longevity.



Stuff is everything else in a building. It's the interior finishes, furniture and fixtures. These items endure the most wear by the user and as such need replacing the most frequently.



Access is a major component of larger buildings. Stairs, elevator cores and shafts for equipment and trash management in a building hold a similar integrity as the 'Structure' layer.











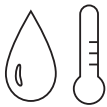





PART 2: DESIGN FOR DISASSEMBLY: A SMARTER WAY TO BUILD

CONSIDERATIONS

All material assemblies must come together by means of joinery and their connectors are what enables them to be assembled easily and taken apart many times without being damaged.¹⁰ There are many different ways to connect materials and certain methods destroy both the material and the connector in the process. A few questions to consider when designing for disassembly would be: Does this process or method damage the material? Is the connector easily accessible so that it can be taken apart? How many tools will I need on site in order to take this apart? Is this adhesive reversible or dissolvable?

Having a series of common connections and methods for assembly and disassembly established in a project is vital to the success of both construction and deconstruction but also goes a long way in retaining the value of the material ultimately increasing its useful life.

Figure 10: DfD Strategies
Source: Jensen, K. G., & Sommer, J. (2016). Building a Circular Future. Kobenhavn: GXN Innovation. - Reinterpretations of originals owned by the Ellen MacArthur Foundation

Nails Damage the Material	 	 	Use Screws, Pins, Nuts and Bolts
Portland cement is impossible to disassemble	 	 	Use lime mortar instead
Avoid glue and sealants	 	 	Use easily dissolvable binders
Fasteners can be found in all shapes and sizes	 	 	Use Common and Similar Fasteners

PART 2: DESIGN FOR DISASSEMBLY: A SMARTER WAY TO BUILD

CONSIDERATIONS

Today the most preferred method of deconstruction is demolition. Recyclable and salvageable materials do get extracted from a building during deconstruction but in most cases, total demolition is more preferable because it is less costly and the material inside the buildings are of low re-use value. GXN has outlined current practices such as selective demolition, blasting, and down-cycling as common practices if certain valuable materials exist on site and are to be reclaimed in any manner. These three strategies then change to dismantling, relocation, and recycling in their proposed disassembly plan.¹⁰

It is a necessary part of the design for disassembly strategy to have a plan for deconstruction. As much as we often think about how buildings go together, we also need to consider how they are taken apart and in what order. It is also necessary to evaluate the materials removed from the disassembly process to establish their current value. Materials intended for direct re-use can be saved in entirety, they can be stored or sold as available building products. Materials that have value for up-cycling can be sold to

manufacturers to be made into new building products. Materials that have been damaged can be recycled.

Factors to consider when creating a deconstruction plan;

1. Establishing an order of operations, a sequence for the removal of materials.
2. Using a database of materials used when the building was constructed to evaluate the materials conditions while they are removed.
3. Having a place to store and sort materials as they are removed from the building site.
4. Maintain structural stability and a safe work environment throughout all phases of disassembly.

It can be also be valuable to list the project, its material database, and proposed date of deconstruction online as a source for builders looking to buy material for a new project.¹⁰
(Building A Circular Future)

PART 2: DESIGN FOR DISASSEMBLY: A SMARTER WAY TO BUILD

BENEFITS

'Design for Disassembly' lends itself to a multitude of benefits. The innate attention to a composition of parts that are removable, changeable, and fit to be adjusted over time lends itself to other benefits such as adaptability, allowing a built project to retain value because it can be used and reused, added on to, downsized, or taken apart and relocated.

“Almost no buildings adapt well. They're designed not to adapt; also budgeted and financed not to, constructed not to, administered not to, maintained not to, regulated and taxed not to, even remodeled not to. But all buildings (except monuments) adapt anyway, however poorly, because the usages in and around them are changing constantly.”¹¹
(Stewart Brand).

By designing buildings to grow and change, to be taken apart and adjusted, huge value is added to the materials used. Now, the building can be sold to other owners for parts and a plan for simple adaptation could be made easily. If the materials are not sold to be reused directly they can be taken apart and the material value can be invested into other construction projects.

Ultimately DfD is about planning for the future. We do not know how the building industry will change, but we do know that we are not going to stop needing buildings anytime soon. And as a result, DfD makes a lot of sense. It is better for the environment as it would reduce waste and relieve pressure on our landfills. Instead of contributing to a culture of waste DfD as a design strategy can create new opportunities for re-modelers, disassemblers, and material salvage. DfD is about the longevity of our material stock, it is about a conscious attempt to design better buildings that allow our cities to grow, change, preserving their value and usefulness for a very long time.

Quicker and simpler construction processes. Not using welds or nails or toxic binders as methods of attachment makes assembly easier and in some cases faster.

Optimized operation and maintenance. Because systems are arranged in a way to be taken apart, their access and use is optimized making repair and renovation a simple process.

Less Waste. Closed loop material streams allow materials to hold their value so they are much less likely to end up in a landfill.

Optimized up-cycling, recycling and reuse. Rather than being seen as garbage a materials are used in a way that make it optimal for them to be re used or recycled in new ways.

Released Pressure on Resource Scarcity. Instead of needing to harvest new material from our planet we can be constantly using and re-using the ones we already have.

Buildings as Material Banks. By designing buildings to be disassemblable we are investing material stock into our cities allowing this material to be harvested if the building needs to be removed.

Source: Jensen, K. G., & Sommer, J. (2016). Building a Circular Future. Kobenhavn: GXN Innovation. - Reinterpretations of originals owned by the Ellen MacArthur Foundation

PART 2: DESIGN FOR DISASSEMBLY: A SMARTER WAY TO BUILD

PRECEDENTS

'Design for disassembly' strategies have a strong correlation to prefabrication in the way that both design processes look very closely at the assembly process and its organization. Workflows and methods of prefabrication have a number of benefits in the construction industry today. Prefabrication is booming in popularity because of claims towards cost savings, labor and production efficiencies, a reduction in construction time and a higher level of quality control and efficient material use.¹⁵ These benefits are also shared with a DfD approach. The difference is that prefabrication does not currently anticipate disassembly as part of the design process. I have looked at a number of prefabrication strategies to see how they are assembled and in what capacity they might be applied to a DfD approach.

Five layers broken down by assembly method.

Structure

- Volumetric (modules)
- Panelized
- Components (Kit of Parts)

Skin

- Stacking
- Suspending
- Clipping
- Fastening

Services

- Integrated
- Segregated

Stuff

- Adjustable
- Fixed

Access

- Internal
- External

PART 2: DESIGN FOR DISASSEMBLY: A SMARTER WAY TO BUILD

STRUCTURE

Volumetric (modules):

Parts of a building with high density of pre-assembled services.

Pros:

Efficient construction time line

High quality control

Integration of services

Less coordination on site

Cons:

Shipping constraints

Lower degree of flexibility after assembly process



Figure 11: My Micro NY by nArchitects
Source: <https://www.dezeen.com/2015/11/26/five-most-popular-us-projects-dezeen-architecture-design/>



Figure 12: Pop-up Homes by Heijmans
Source: <https://www.dezeen.com/2015/01/23/heijmans-one-prefabricated-wooden-houses-move-between-sites>

PART 2: DESIGN FOR DISASSEMBLY: A SMARTER WAY TO BUILD

STRUCTURE

Panelized:

Structurally integrated wall, floor, and roof systems.

Pros:

Simple construction methods
High degree of flexibility
Services integrated with panels

Cons:

Longer site time for assembly



Figure 13: SIPS Residence by Kieron Gait Architects
Source: http://www.kierongait.com.au/portfolio_page/sips-residence/



Figure 14: CLT House by AtelierJones LLC
Source: <https://www.atelierjones.com/clthouse>

PART 2: DESIGN FOR DISASSEMBLY: A SMARTER WAY TO BUILD

STRUCTURE

Kit of Parts:

Modular, uniform assembly of components. Prefabricated parts and assembled on site.

Pros:

Simple construction methods

High degree of flexibility

Easy to deliver on site

Easy to remove from site

Cons:

More complex quality control.



Figure 15: SLU Discovery Center
Source: <https://www.mutualmaterials.com/projects/south-lake-union-discovery-center/>

PART 2: DESIGN FOR DISASSEMBLY: A SMARTER WAY TO BUILD

SKIN

The different ways to assemble the facade of the building will have an impact on the level of complexity for its assembly and disassembly. The facade can be comprised of many pieces that are assembled on-site, or designed as panelized components that are preassembled off-site.

The following page show facade options that are assembled in the following ways, each with their own set of design considerations.

Stacking

Suspending

Clipping

Fastening

Some questions to consider when designing the facade might be how many unique panel shapes are involved when using a panelized system? How many individual parts are used to assemble it? The more unique shapes and pieces that are integrated with the design will, in turn, make certain parts less likely to be ready for reuse.

The most important concern, when designing the facade will be to maintain a demountable system of parts. This way regardless of the variety of ways in which the facade might be designed, you still want to ensure that all of the parts can be broken down back to their individual parts, ready to be reused or recycled.

As we will see later in the case study projects, the skin of a building can be a great place to incorporate up-cycled waste. Waste that is difficult to break down, is also durable. This makes certain types of waste, plastics, for example, good materials to use as cladding.



Stacking

Stacking methods rely on gravity or a mortar in order to support the material. Lime mortar is reversible.

Figure 16: Clay Brick Facade
Kroyers Plads by COBE Architects



Suspending

Suspended building skins hang from the building structure by means of additional supports mounted to the facade.

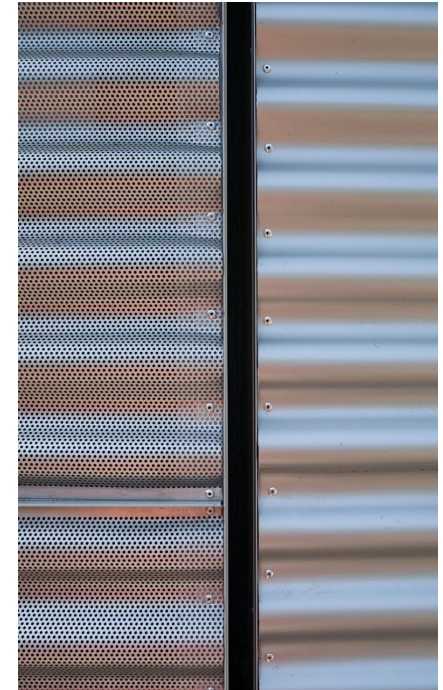
PFigure 17: Perforated Metal
Screen
Source: <https://www.stylepark.com/en/news/perforated-embossed-refined>



Clipping

Facade systems that clip together are easy to assemble and disassemble. They can have either visible or concealed connection methods.

Figure 18: Ceramic Facade with
visible clamps
Mosa.



Fastening

Fastening methods are less preferable in DfD because they involve mounting the material directly to a substrate which can damage the material.

Figure 19: Corrugated Metal
Facade
Hendel Residence by SaaB
architects



Figure 20: Circle house demonstrator by GXN innovation

PART 3: CASE STUDIES

CIRCLE HOUSE - GXN INNOVATION

PROJECT DESCRIPTION

Circle House is a social housing development that tests the possibilities of Circular Economy and challenges the ways in which we currently build housing. The project involved over 30 partnerships with industry leaders in Denmark to create a housing solution that was designed to be disassembled as well as include materials that were made from waste products. Some of the partnerships created throughout the building industry allowed for leasing and share economy principals to be tested.¹⁶

FABRICATION / ASSEMBLY

The major structural elements are comprised of prefabricated concrete components. These pieces have steel connectors cast within them so that they can then be bolted together. The mechanical systems are coordinated through vertical circulation elements so that maintenance is easy and systems are easily accessible. Another notable feature is the use of a floating floor system that provides access to other parts and can be easily repaired or replaced when needed.



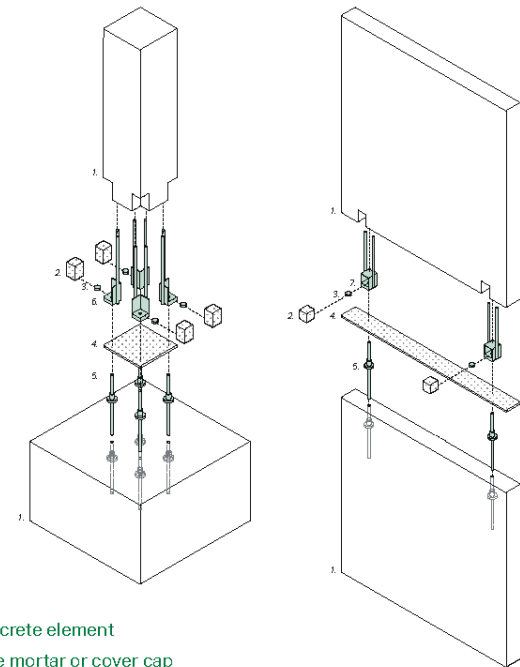
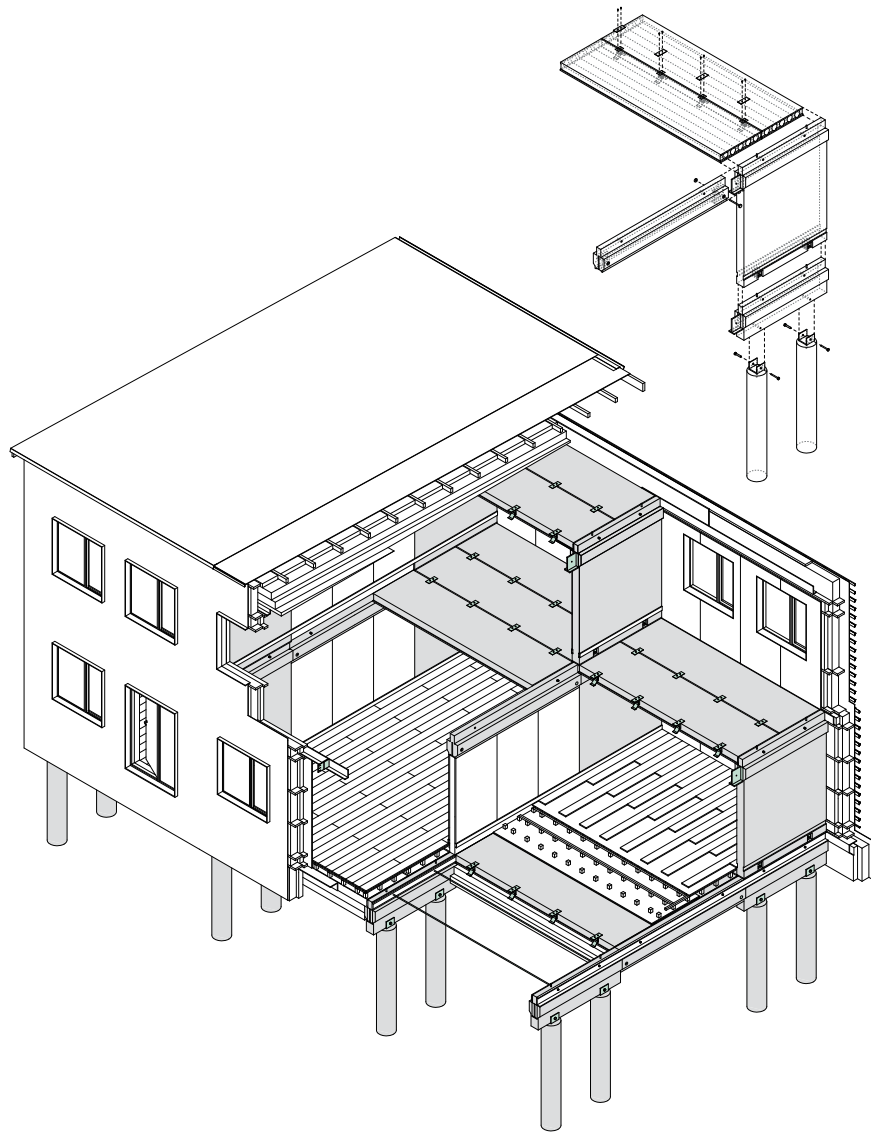
Figure 21: Exterior, Circle House Demonstrator

This project is Denmark's first social housing development that is constructed according to the principals of circular economy.

The circular approach created a housing built to a higher standard.

90% of building materials are intended to be reusable.¹⁶

Source: All Circle House Documents provided by GXN Innovation.



1. Concrete element
2. Lime mortar or cover cap
3. Nut
4. Undercutting mortar
5. Anchor bolt with thread
6. Peikko pillar shoes
7. Peikko wall shoes

Figure 22: Left, Diagram showing the assemblage of parts for the Circle House 2 Story Unit.

Figure 23: Above, Detail of the prefabricated concrete column and wall panel designed to be disassembled.

Source: All Circle House Documents provided by GXN Innovation.

PART 3: CASE STUDIES

CIRCLE HOUSE - GXN INNOVATION



Figure 24: Interior, Circle House Demonstrator
Source: All Circle House Documents and images provided by GXN Innovation.

The housing development consists of 60 housing units

- 5 Single room studio units - 325 - 375 sqft
- 5 Two room units - 754 sqft
- 10 Four room units - 1,184 sqft
- 40 Three room units - 970 sqft

A demonstrator (full scale unit) was built in order to;

Educate the visitors in circular economy principles.

Promote the companies circular products and sustainable solutions to a larger audience.

Provide product descriptions, contact informations and links to the sponsors website.

Debate how products can be developed and become more circular. ¹⁶



Figure 25: Circle House Demonstrator under construction



Figure 26: Circle House Facade Construction



Figure 27: Concrete Detail, Circle House

Source: All Circle House Documents and images provided by GXN Innovation.

PART 3: CASE STUDIES

PEOPLES PAVILION - BUREAU SLA

PROJECT DESCRIPTION

This project was developed as a temporary structure for Dutch Design Week by Bureau SLA. The colorful shingle facade is comprised of up-cycled plastic and the structure is built from borrowed timber.¹⁷

FABRICATION / ASSEMBLY

The plastic shingles were developed by sorting plastic waste by color and is suspended on a welded wire mesh. The wooden framework utilizes 19 different components that are all intended to be returned after its use. The construction technique explores assembly methods that do not use glue, screws or nails according to the designer. The system instead uses tie-down straps, tension belts, and cable ties and required extensive testing because it is not common.¹⁷



Figure 28: Exterior, People's Pavilion

Source:<http://www.aboutdesignworld.com/pavilion/peoples-pavilion-bureau-sla-overtredersw/>

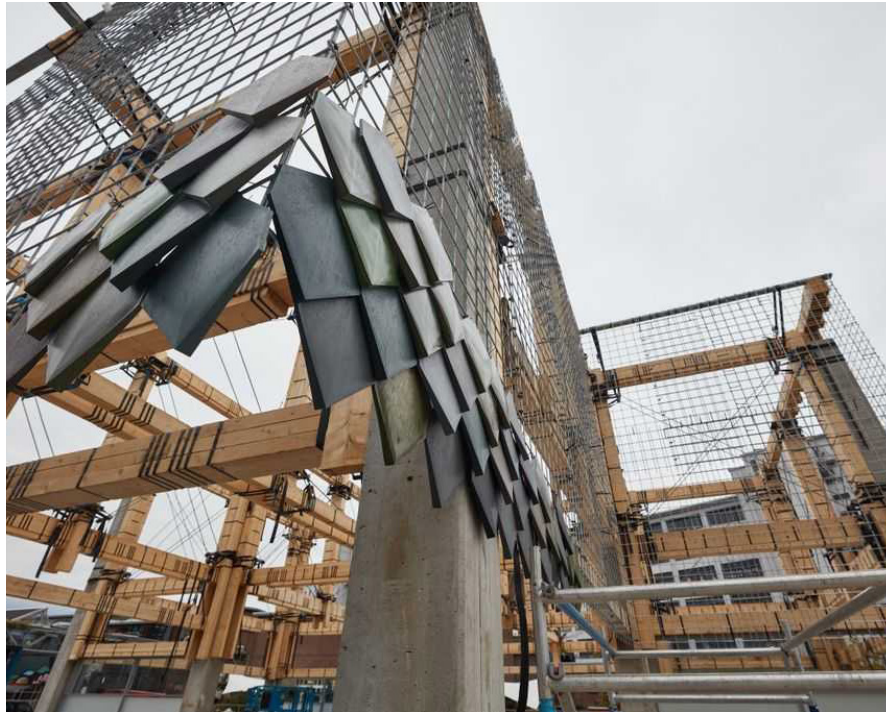


Figure 29: Facade Assembly, People's Pavilion
Source: <http://www.aboutdesignworld.com/pavilion/peoples-pavilion-bureau-sla-overtredersw/>

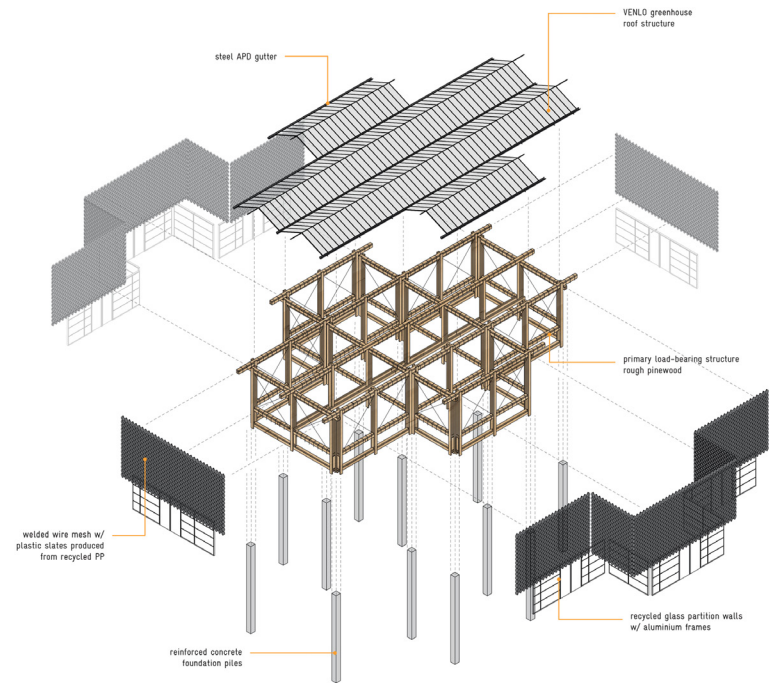


Figure 30: Kit of Parts Diagram, People's Pavilion
Source: <http://www.aboutdesignworld.com/pavilion/peoples-pavilion-bureau-sla-overtredersw/>

PART 3: CASE STUDIES

LOBLOLLY HOUSE - KIERAN TIMBERLAKE

PROJECT DESCRIPTION

This project boasts a simplicity of fabrication that is achieved through a high degree of planning and digital modeling to ensure a perfect fit of all parts which are pre-fabricated off-site. The approach reduces the number of parts used in the traditional assembly of a house from thousands down to much more manageable, pre-assembled components that are fastened together on site with simple hand tools.¹⁸

FABRICATION / ASSEMBLY

The system consolidates parts into components and establishes them into four different categories; scaffold, cartridge, block, and equipment. The scaffold is made of an aluminum framework that supports the other components. Each component comes with pre-integrated systems.¹⁸

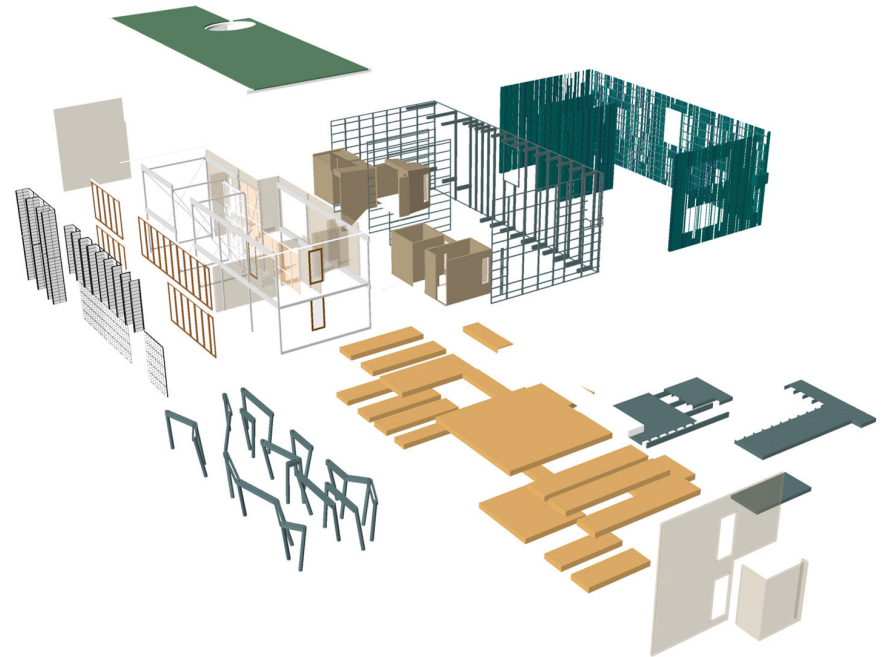


Figure 31: Kit of Parts Diagram, Loblolly House
Source: <https://kierantimberlake.com/post/view/145>

PART 3: CASE STUDIES



Figure 32: Exterior, Loblolly House
Source: <https://kierantimberlake.com/pages/view/20/loblolly-house/parent:3>



Figure 33: Exterior, Loblolly House
Source: <https://kierantimberlake.com/pages/view/20/loblolly-house/parent:3>



Figure 34: Interior, Loblolly House
Source: <https://kierantimberlake.com/pages/view/20/loblolly-house/parent:3>

PART 3: CASE STUDIES

CELLOPHANE HOUSE - KIERAN TIMBERLAKE

PROJECT DESCRIPTION

This project took ideas learned from the Loblolly house and pushed them further by exploring ideas of disassembly. It was constructed as a temporary experiment to test the potentials of prefabricated architecture for exhibition at The Museum of Modern Art. The project was a five-story house with two bedrooms, two bathrooms, a living and dining space, a roof terrace, and a carport.¹⁹

FABRICATION / ASSEMBLY

The structural system used in the Loblolly house was scaled up here. The aluminum framework was reinforced with custom steel components. The structure was then enclosed using a thin “SmartWrap” energy-gathering envelope comprised of plastics, hence the name Cellophane House. Eighty percent of the construction was completed in six days. The entire structure was disassembled and parts were removed from the site with zero waste generated.¹⁹

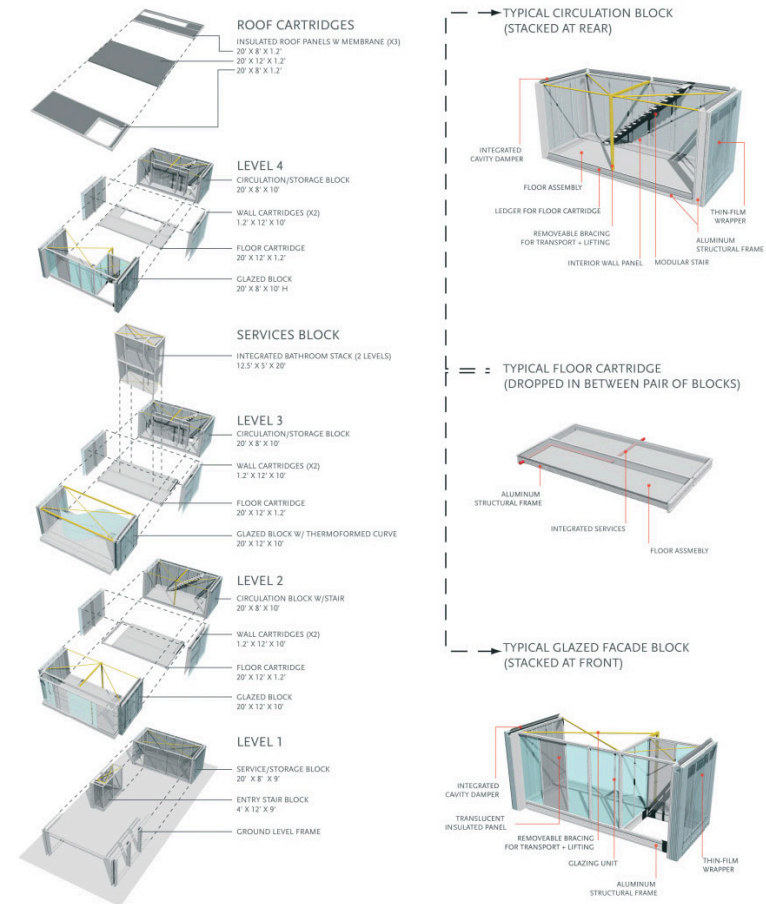


Figure 35: Kit of Parts Diagram, Cellophane House
Source: Kieran, C., & Timberlake, J. (2009). Cellophane House. Architectural Design, 79(2), 58-61.

PART 3: CASE STUDIES

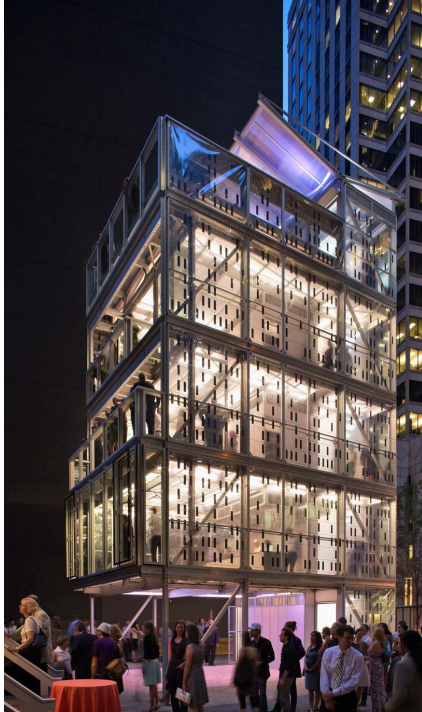


Figure 36: Exterior, Cellophane House
Source: <https://kierantimberlake.com/pages/view/14/>



Figure 37: Interior, Cellophane House
Source: <https://kierantimberlake.com/pages/view/14/>



Figure 38: Interior, Cellophane House
Source: <https://kierantimberlake.com/pages/view/14/>

PART 3: HOUSING



Figure 39: Rowhouses, Wallingford
Source: <https://www.theurbanist.org/2017/08/09/broadening-seattles-growth/>

PART 3: HOUSING

CURRENT TRENDS

“Housing crisis is a predictable, consistent outcome of a basic characteristic of capitalist spatial development: housing is not produced and distributed for the purposes of dwelling for all; it is produced and distributed as a commodity to enrich the few”²⁰
(In Defense of Housing)

In the United States, housing is a crisis that can not be fixed. The term crisis implies that something was once working and is now broken, but that crisis is a state which housing has always been in for the working-class and impoverished. Housing is a commodity and it is not given to people as a human right. It is bought and sold for the profit of others. This thesis does not address this issue. This thesis accepts that housing is and will continue to be a commodity and suggests that we take a closer look at how we are using land and materials within our cities in order to alleviate some of the pressures our cities face in regard to housing growth.

As previously stated in the introduction more and more people are moving to cities every single day. Yet our housing production is struggling to meet those demands. The first major reason our cities are struggling to produce more housing is that there is not

a lot of available land to build the quantity and variety of housing types that we need. According to Dr. Arthur C. Nelson as cited by Opticos Design “90% of available housing in the U.S. is located in a conventional neighborhood of single-family homes, adding up to a 35 million unit housing shortage.”⁸ Why the shortage? It has a lot to do with restrictions on land use. Single-family zoning restricts development to one type of housing that does not meet the needs of a growing population. Limiting the development capacity of our land to one type of housing is simultaneously reducing the supply of housing and increasing the cost of housing. According to Freddie Mac “robust demand but weak supply has driven up housing prices rapidly.”⁷ In addition to increased housing costs, the average size of a single-family home has doubled since 1960 while at the same time household size is decreasing.²¹ Because of the restrictions on land use coupled with the cost of building a home, families that can afford to are maximizing the buildable area that they are allowed. However, family sizes are smaller due to the increased cost associated with having a child and likely the increased cost of owning a home.

PART 3: HOUSING

CURRENT TRENDS

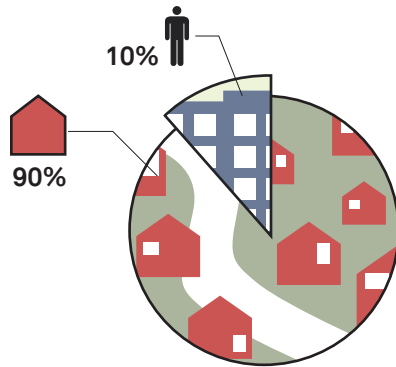


Figure 40: 90% of available housing in the U.S. is located in conventional neighborhoods of single family homes. Reinterpretation of diagram from <https://missingmiddlehousing.com/about/market>

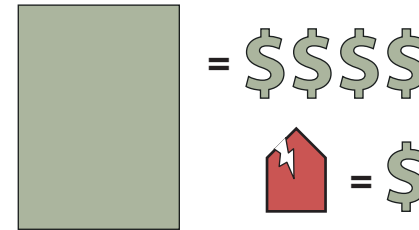


Figure 41: "In some markets . . . land can cost upward of 70 percent the cost of building a home. Laws and regulations such as local zoning restrictions on lot sizes and building height and open space designations also increase the cost of building a home, in turn reducing the supply of new homes." (Freddie Mac, 2018)



Figure 42: "Robust demand but weak supply has driven up housing prices rapidly." (Freddie Mac, 2018)

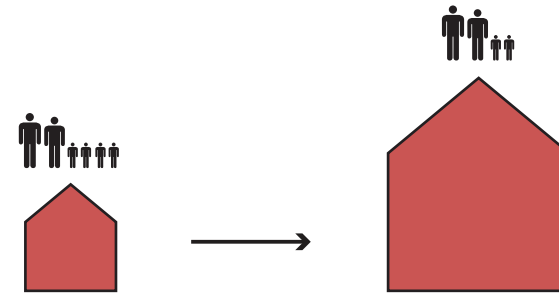


Figure 43: The average size of a new house in the U.S. has doubled since 1960. At the same time the average family size is decreasing. (Darrin Qualman, 2018)

PART 3: HOUSING

CURRENT TRENDS

“In the United States today, nearly one in three American households spend more than 30 percent of their income on housing.”²² Due to the increased costs associated with owning or renting a home more and more people are now seeking shared living arrangements. At the same time young adults that are looking to form households of their own are looking for smaller homes. They want to live close to the city without the high cost of rent associated with living in the city. They are looking for a home that is in a walkable neighborhood that is in close proximity to entertainment, services, and work.⁸ Young adults aren’t the only people looking for new homes. There are in fact many reasons that people seek new living arrangements. According to the Census Bureau as cited by CHalmer, “an American may move 11.4 times during their lifetime.”²³ The different reasons that people move will vary. They could be transitioning from renting to owning, relocating for a new job, finding a bigger or a smaller home due to changes in family size or income. The reasons might be less predictable, however, our homes aren’t the objects that are not designed to change or move with us.

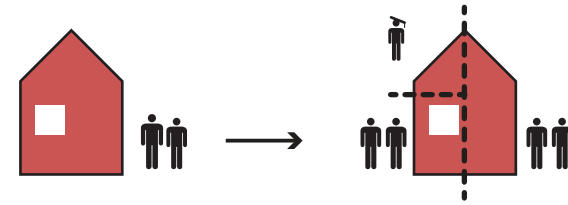


Figure 44: “Facing higher home prices and rents, many young people are doubling up in shared living arrangements or living at home with their parents.” (Freddie Mac, 2018)



Figure 45: More and more, consumers are choosing smaller homes within walking distances of entertainment, services, and work. (National Association of Realtors, National Community Preference Survey, October 2013)

PART 3: HOUSING

CURRENT TRENDS

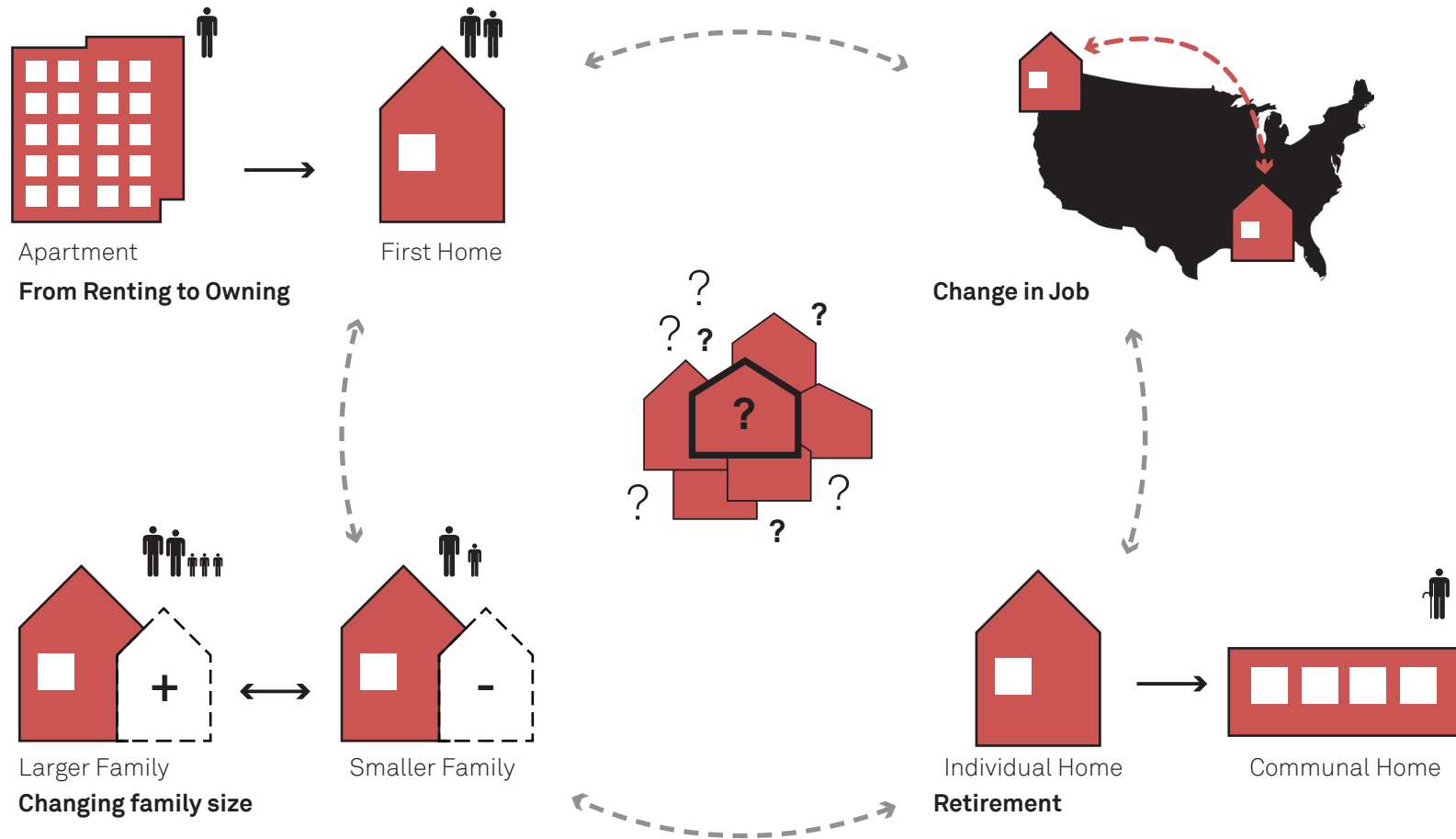


Figure 46: The reasons people change homes vary but our housing is not designed to adapt to changing lifestyles, income, or family size.

PART 3: HOUSING

LOCAL CONTEXT

Seattle will be the location for this thesis project because, as a fast-growing metropolis, it is being forced to address many challenges associated with housing growth. The majority of these challenges are due to several reasons, outlined by the Seattle Planning Commission, however, this thesis will focus on two.

Firstly, the population is increasing rapidly, however, the housing supply is struggling to keep up. Growth is transforming the city but due to skyrocketing housing costs, people are being forced out of the city. This has a negative impact on both cultural diversity and the quality of life that is accessible to the cities new and existing inhabitants.

“Since 2010, Seattle has added more than 105,000 residents, surpassing 700,000 in 2017, making [Seattle] one of the fastest growing U.S. cities”⁹
(Seattle Planning Commission).

Secondly, out of all the land that housing is allowed to be built, this excludes industrial areas and street right of ways, only 25% is zoned for multifamily housing. The other 75% of that land is zoned

for single-family housing only.

“Seattle has a changing population with a wide range of housing needs, yet almost half of Seattle’s land is reserved for one housing type.”⁹
(Seattle Planning Commission)

The city of Seattle is very aware of the issues associated with single-family zoning and is currently implementing new zoning changes as a way to increase the variety of housing types allowed. Seattle has just recently passed citywide Mandatory Housing Affordability legislation in March of 2019 as a means to implement affordable housing requirements in 27 urban villages throughout Seattle. This legislation also includes development capacity increases within these urban villages in order to allow a greater density and mix of housing types.²⁴

We need more housing and we need more types of housing if we want to reduce these pressures on the housing market.

PART 3: HOUSING

LOCAL CONTEXT

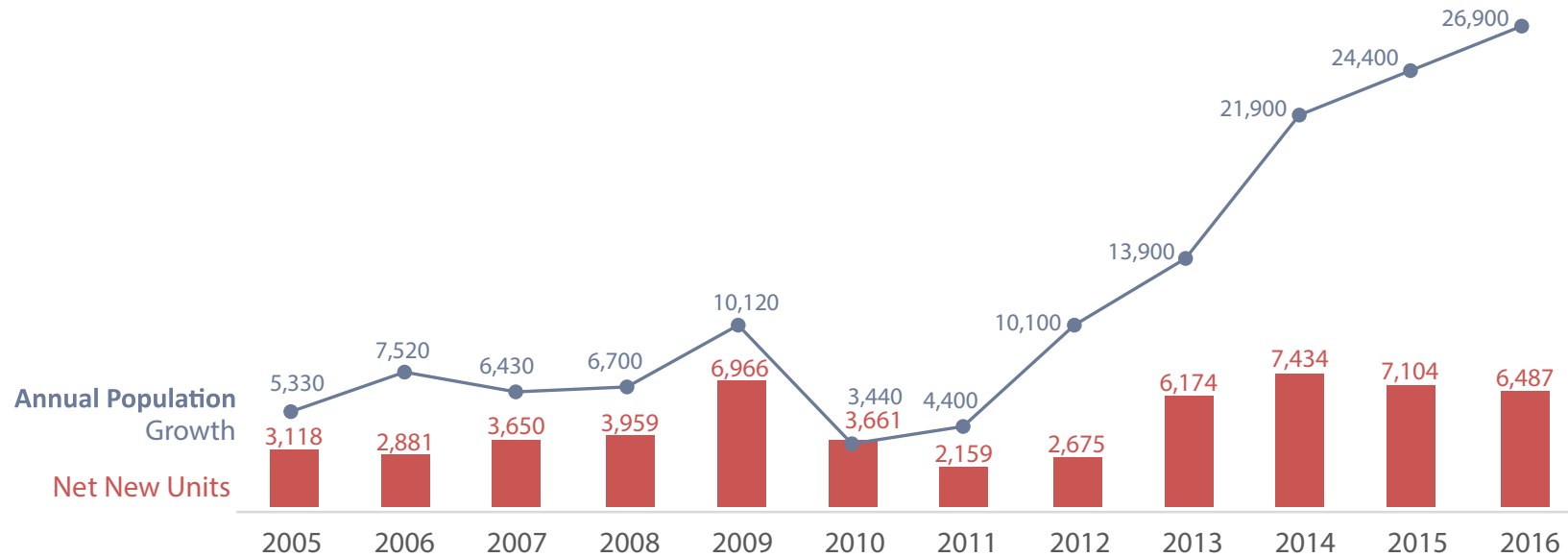


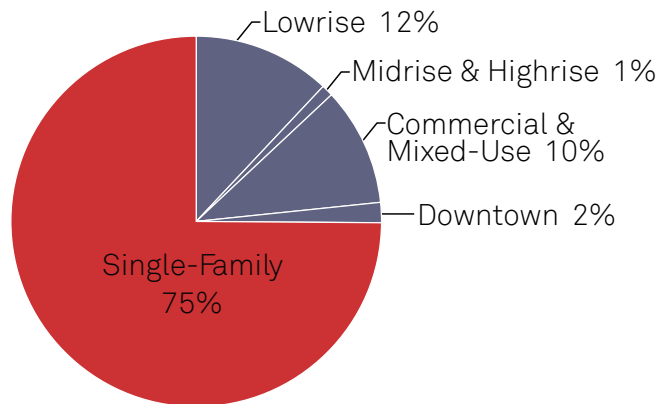
Figure 47: Since 2010, Seattle has added more than 105,000 residents surpassing 700,000 in 2017, making [Seattle] on of the fastest growing US cities.

City of Seattle Data as cited by the Seattle Planning Commission

LOCAL CONTEXT

Distribution of Zoning that Allows Residential Uses

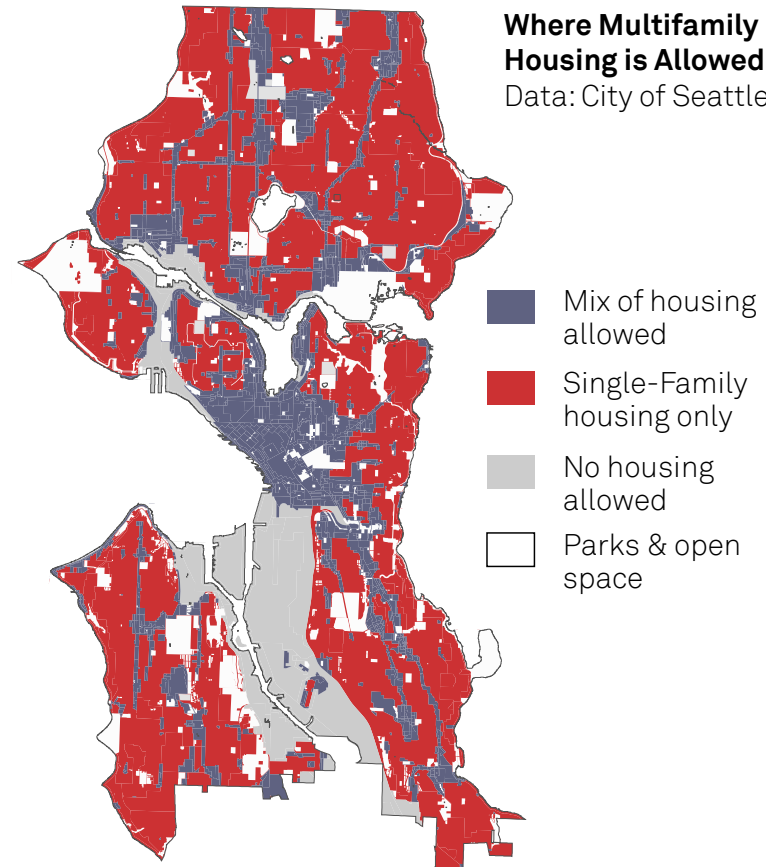
Data: City of Seattle



Three-quarters of all the land that Seattleites can live on is zoned for single-family.

Where Multifamily Housing is Allowed

Data: City of Seattle



Households who cannot afford, or want a more affordable option are limited to the areas of the city shaded blue—those zoned for a mix of housing, including multifamily housing.

Figure 48: City of Seattle Data as cited by the Seattle Planning Commission

PART 3: HOUSING

LOCAL CONTEXT

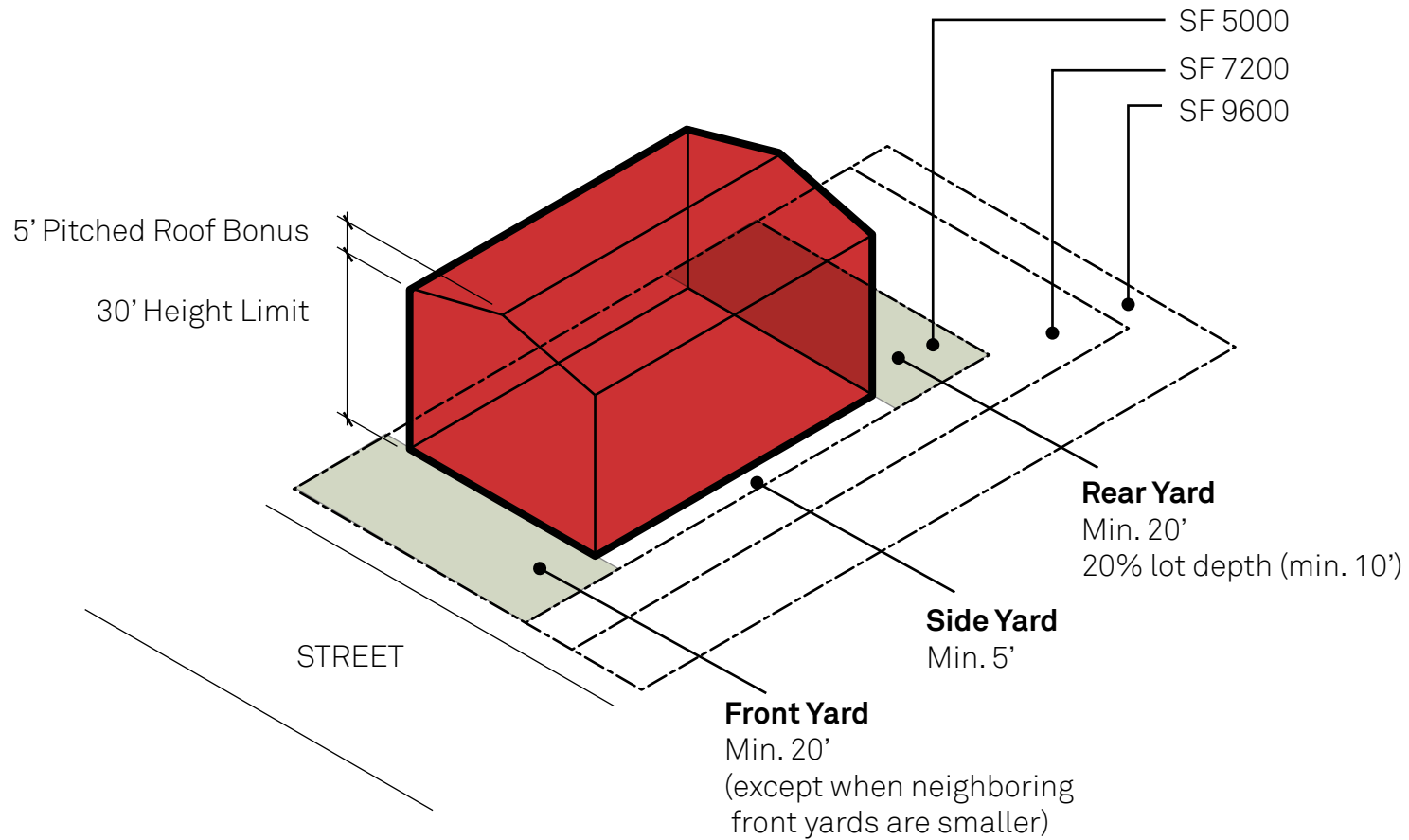


Figure 49: Current zoning regulations allow a house of up to 5,250 square feet to be built on a 5,000 square foot lot.

City of Seattle Data as cited by the Seattle Planning Commission

PART 5: THE PROJECT



Figure 50: Concept Rendering of Tower Scheme, by Author

PART 5: THE PROJECT

THESIS STATEMENT

We can increase the useful life of the buildings we design and ensure that the materials we use can be reused or ‘up-cycled’ in the future. With ‘design for disassembly’ as an integral part of how we think about and develop new housing, we can build homes that are more readily adaptable and use materials more effectively and purposefully, ultimately reducing waste, labor, and cost over the lifespan of the building.

THESIS GOALS AND OBJECTIVES

This thesis project explores ways in which design for reassembly can alleviate some of the pressures on the current housing market in Seattle, Washington while also reducing construction waste by promoting disassembly and reassembly as opposed to demolition or destructive renovation.

The project goal is to design a kit of parts for the production of adaptable housing and to test a range of possible housing typologies that can be built using the same system. Because reassembly is the primary focus, a method of assembly and

disassembly needs to be part of the design thinking from the beginning. This kit of parts will be developed according to the insights learned from DfD principals and then tested on a neighborhood block consisting of single-family homes.

Among the major factors which will contribute to the design of the system are the existing zoning requirements of the neighborhood, assumptions around future growth and expansion, and shipping constraints required for increased mobility and constructibility of the system.

The following pages will introduce the site and existing context followed by the design of the system. Then the system is put to the test and arranged in a variety of possible outcomes on the site. The project concludes with a closer look at three of the various options suggesting a wide range of possibilities that design for reassembly could provide Seattle and other growing cities in the future.

PART 5: THE PROJECT

THE SITE



This site is particularly interesting because it is growing and will likely continue to grow over time. It currently consists of nineteen single family homes on a block that has just recently been up-zoned from a single family to a low rise zone.

- Neighborhood Commercial
- Low Rise 3
- Low Rise 1
- Low Rise 1
- Residential Small Lot
- Residential Urban Village Boundary

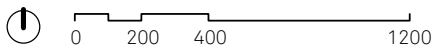


Figure 51: Wallingford Residential Urban Village

PART 5: THE PROJECT

THE SITE

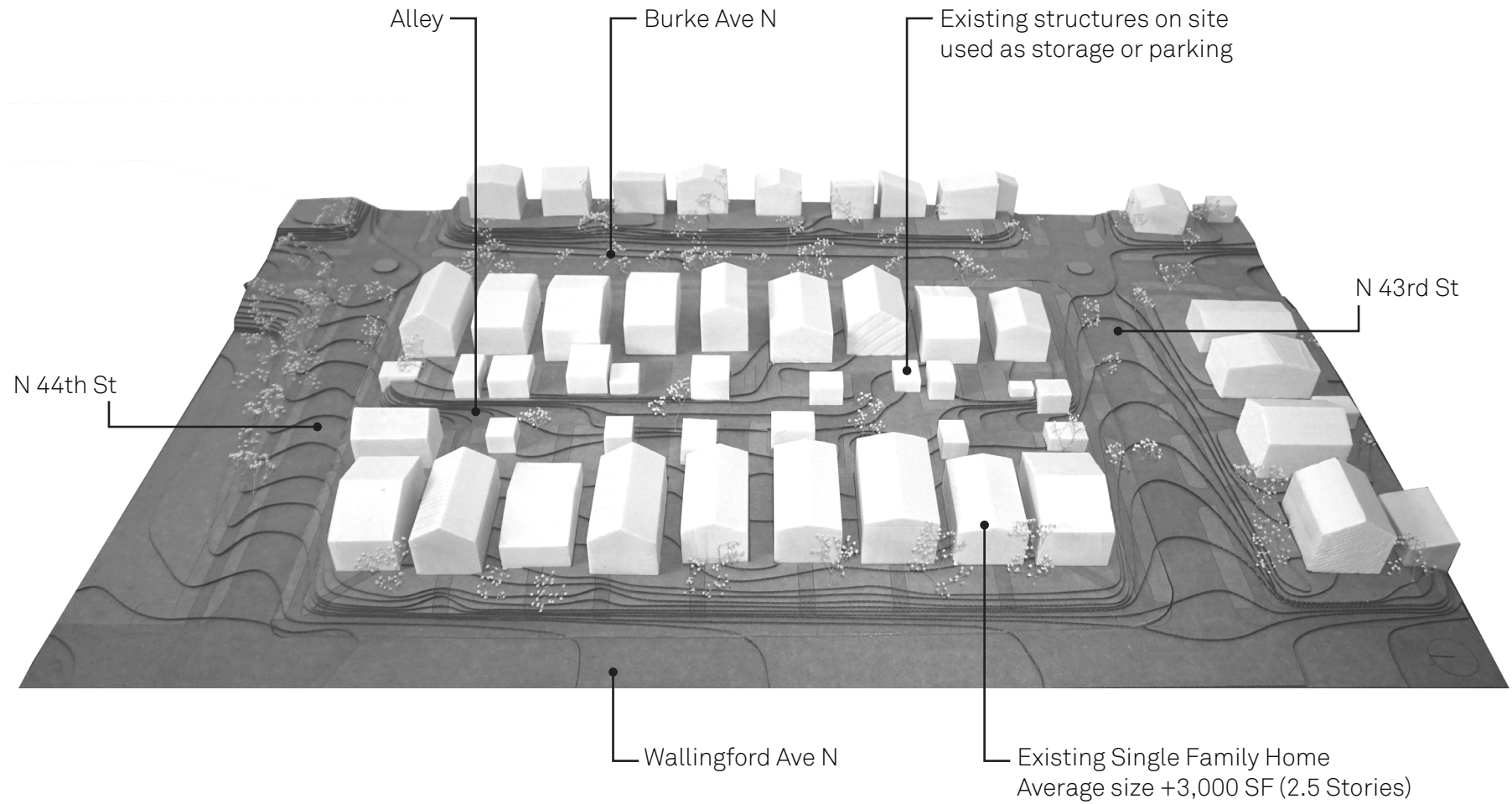


Figure 52: Site Model

PART 5: THE PROJECT

THE SITE

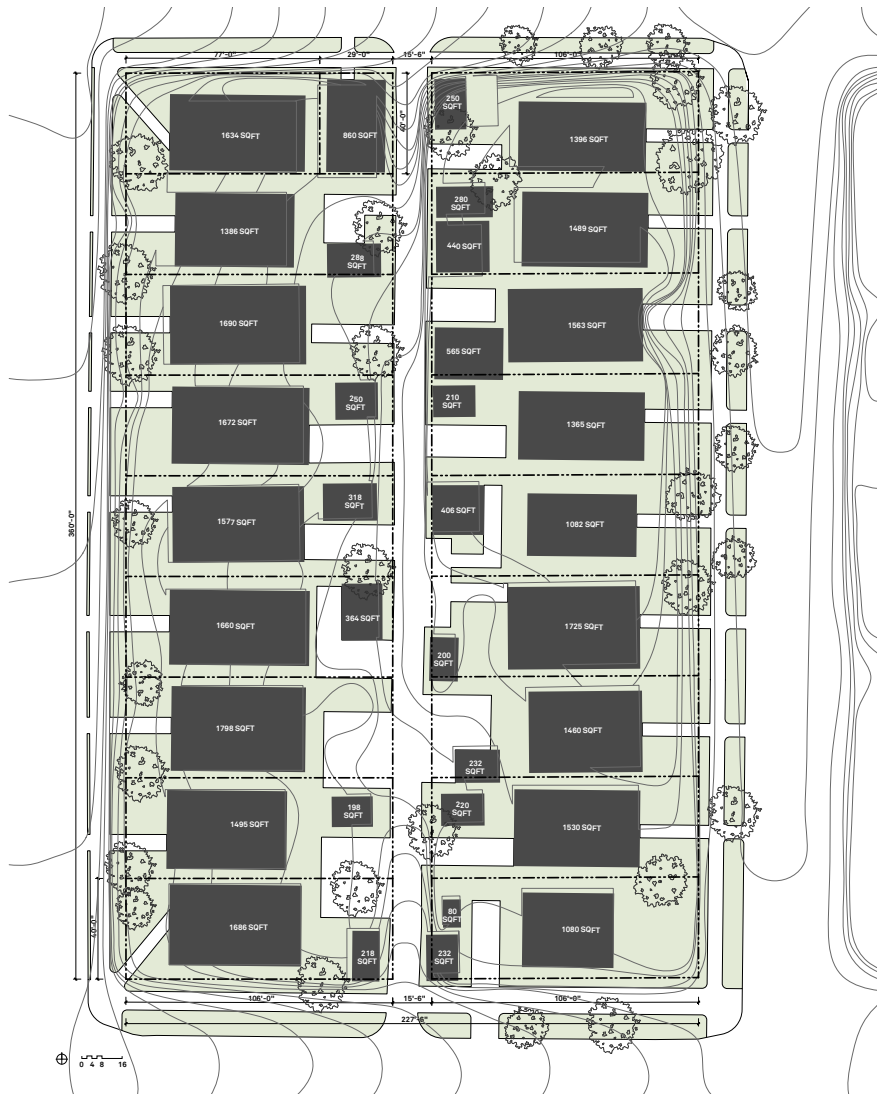


Figure 53: Site Plan



Figure 54: Alley



Figure 55: Alley

The existing footprint of these homes is quite large. Given the amount of built area, over 30,000 square feet, only 19 families can live here. The site also has an alley running through it, a characteristic not uncommon to many other blocks in Seattle. Similar areas of single-family zoning, like this one, are now facing the pressures of housing growth. (data obtained from City of Seattle Parcel Viewer)²⁵

Typical Lot Size:	= 40' x 106' = 4,240 SF Each
Total Coverage (Block):	
Lot area	= 81,900 SF
Coverage	= 31,900 SF or 40%
Number of units:	= 19

PART 5: THE PROJECT

THE SITE



Figure 56: Wallingford Ave N.



Figure 57: N 43rd St.

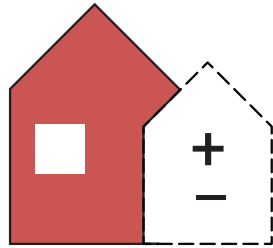


Figure 58: N 44th St.

PART 5: THE PROJECT

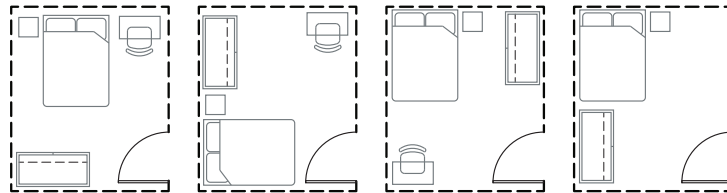
DESIGN CONSIDERATIONS

Add or Remove -

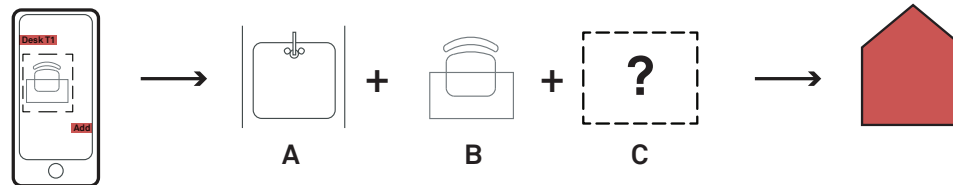


After considering the various reasons a household would buy or rent a home and how their spatial needs could change over time I have broken down a series of requirements for maximizing flexibility within the system. Knowing it is designed to be taken apart, it should also be able to grow, shrink, or relocated.

Ability to Re-arrange -



Customizable / Open Source -



Easy to Move -

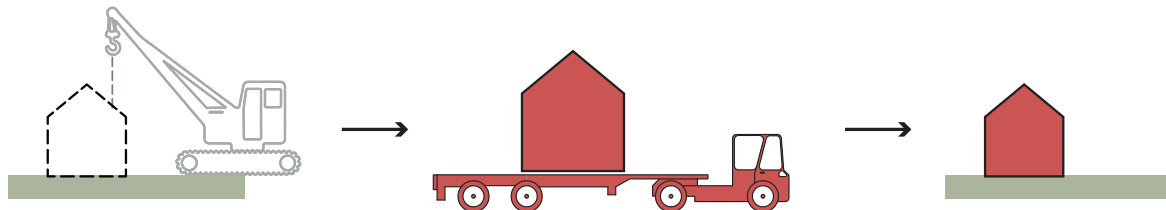


Figure 59: What makes a home flexible

PART 5: THE PROJECT

DESIGN CONSIDERATIONS

In order to begin designing a framework for the system, some restraints needed to be established in order to ensure its mobility and constructibility throughout the city.

Dimensions provided by other modular housing fabricators in the city were used to establish these constraints. An oversized shipment is limited to 16 feet wide by 13 feet high. The grid was then set at 15 feet on center in order to provide enough space for modules to be shipped prefabricated or as a flat pack kit of parts.

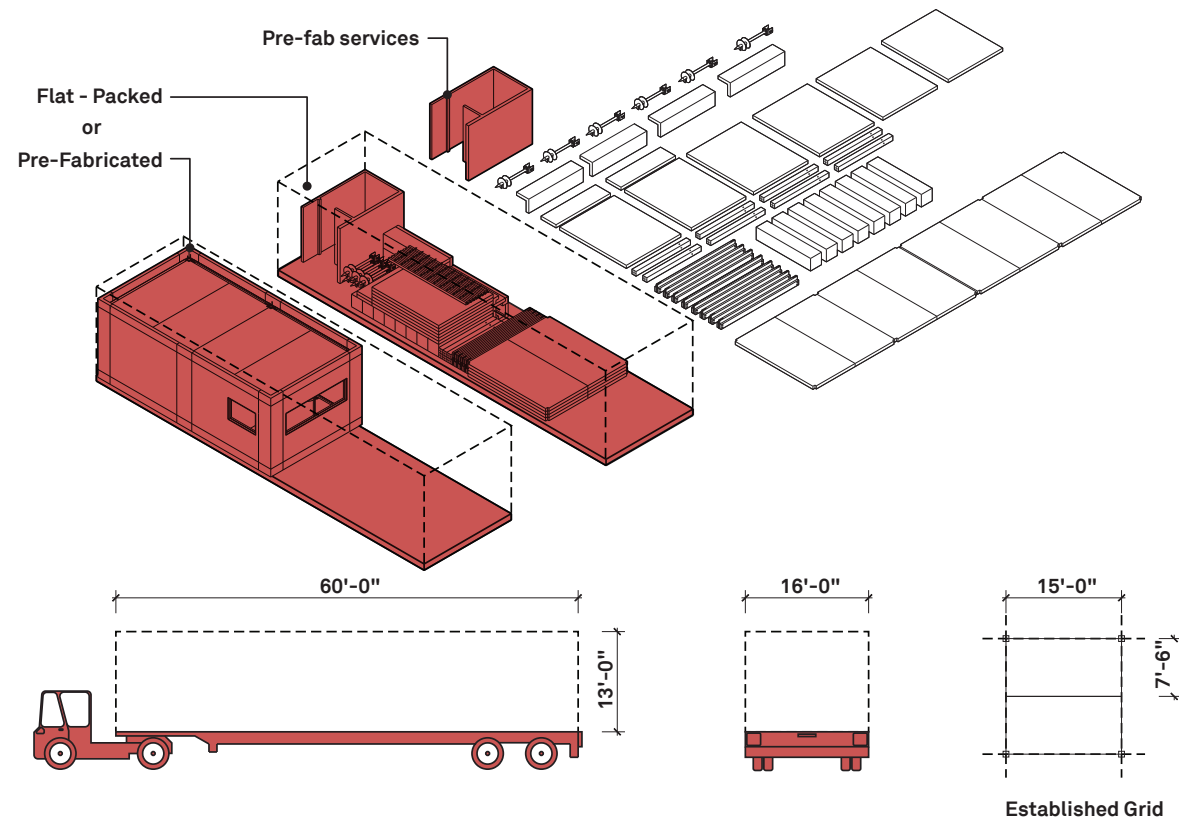


Figure 60: Shipping constraints

PART 5: THE PROJECT

THE SYSTEM

The system is designed as a kit of parts and each component of the system is organized by the five building layers that were described in the earlier chapters; Skin, Structure, Services, Stuff, Access.

A primary component of many multifamily and single family structures in Seattle is a concrete foundation. Also, site-cast concrete is preferred to pre-cast and as such, I decided to avoid using concrete altogether. What is growing in use, however, are mass timber products like CLT (cross laminated timber) or DLT (dowel laminated timber). These wood products are a good ecological choice because of the fact that wood sequesters carbon. And if sustainably forested wood products are used, these products can have a positive impact on the environment. Measuring these environmental impacts is outside of the scope of this thesis.

Knowing this, reversible screw piles were selected as footings. From there, a heavy timber structure established the framework and the module of the system. The heavy timber frame is held together with reversible steel components that are inspired by dismantlable

IKEA products. The timber beams are notched in order to support a dowel laminated floor panel. The intention behind notching the beams was to allow the system to stack on top of itself without the need for a duplicate floor, an unnecessary waste of extra material common in prefabricated modular construction.

Modular aluminum facade panels are suspended from the framework. The facade panels are intended to have only four unique shapes to minimize complexity and increase adaptability. There is an inside corner panel, and outside corner panel, a short middle segment and a full middle segment.

Service modules are prefabricated with plumbing and electrical requirements for bathrooms, washrooms, and kitchens. Later options explore the idea of incorporating prefabricated service cores.

The next few pages will break down each of the five building layers that comprise the entire system.

PART 5: THE PROJECT

THE SYSTEM: KIT OF PARTS

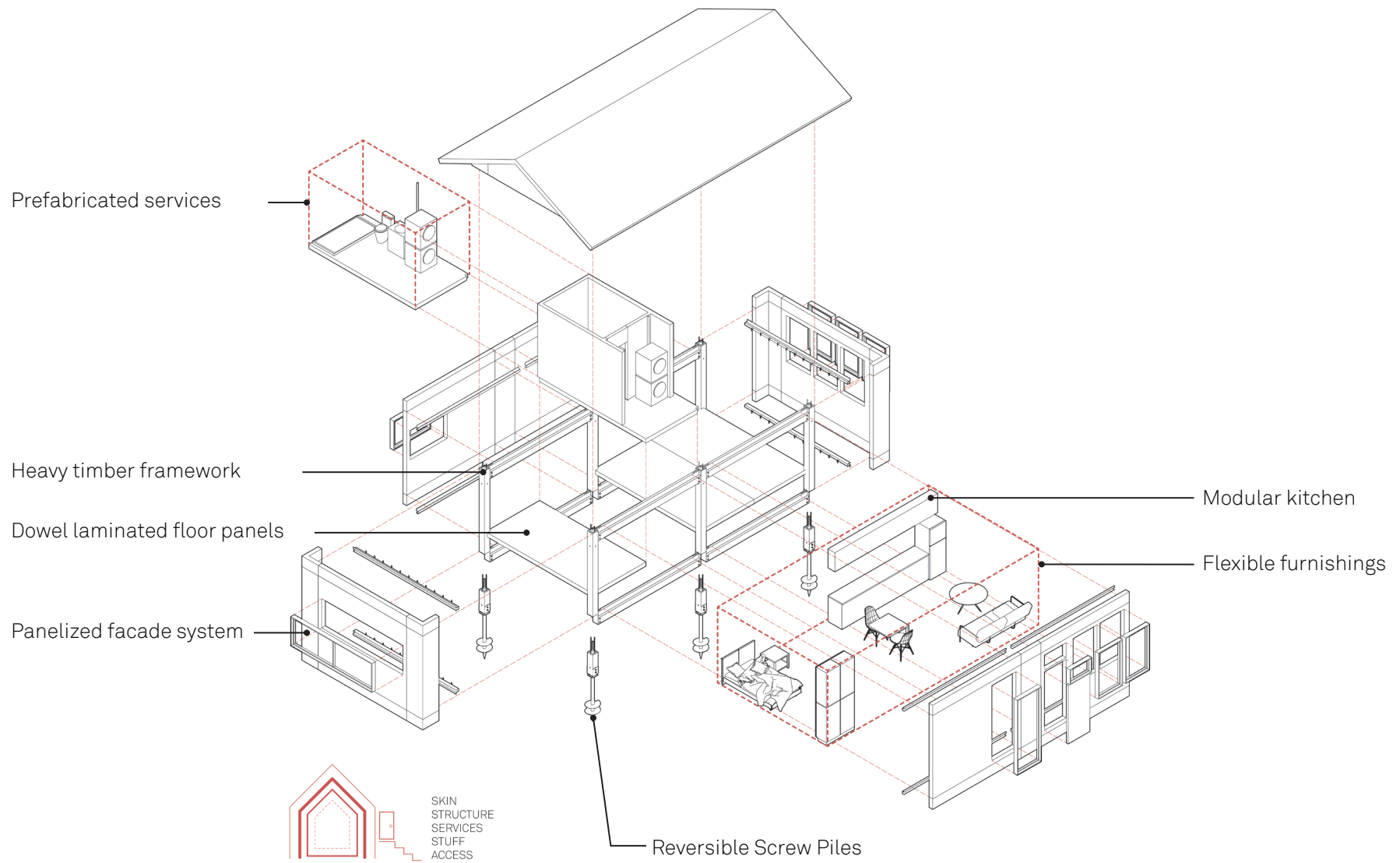
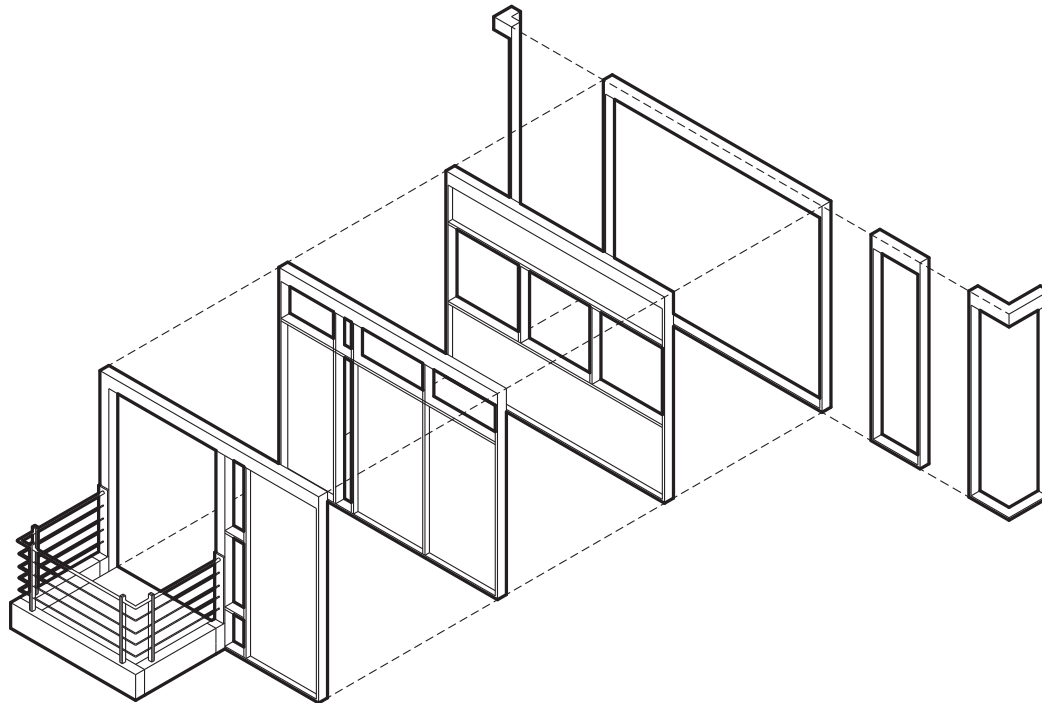


Figure 61: Kit of Parts

PART 5: THE PROJECT

THE SYSTEM: SKIN



Panelized Aluminum Facade

4 unique shapes attach together and are suspended from the structure to form the skin.

Variety of types

Panels can be customized to fit a variety of shapes and openings as well as include integrated components like balconies, doors, and shading devices. Each panel could be clad with a variety of materials as selected by the buyer.

High Re-use Value

The versatility of a panelized system allows users to select the modules and materials they wish to use. At the end of their desired use the panels can be directly re-used by another person or disassembled completely.



Figure 62: Kit of Parts, Skin

PART 5: THE PROJECT

THE SYSTEM: STRUCTURE

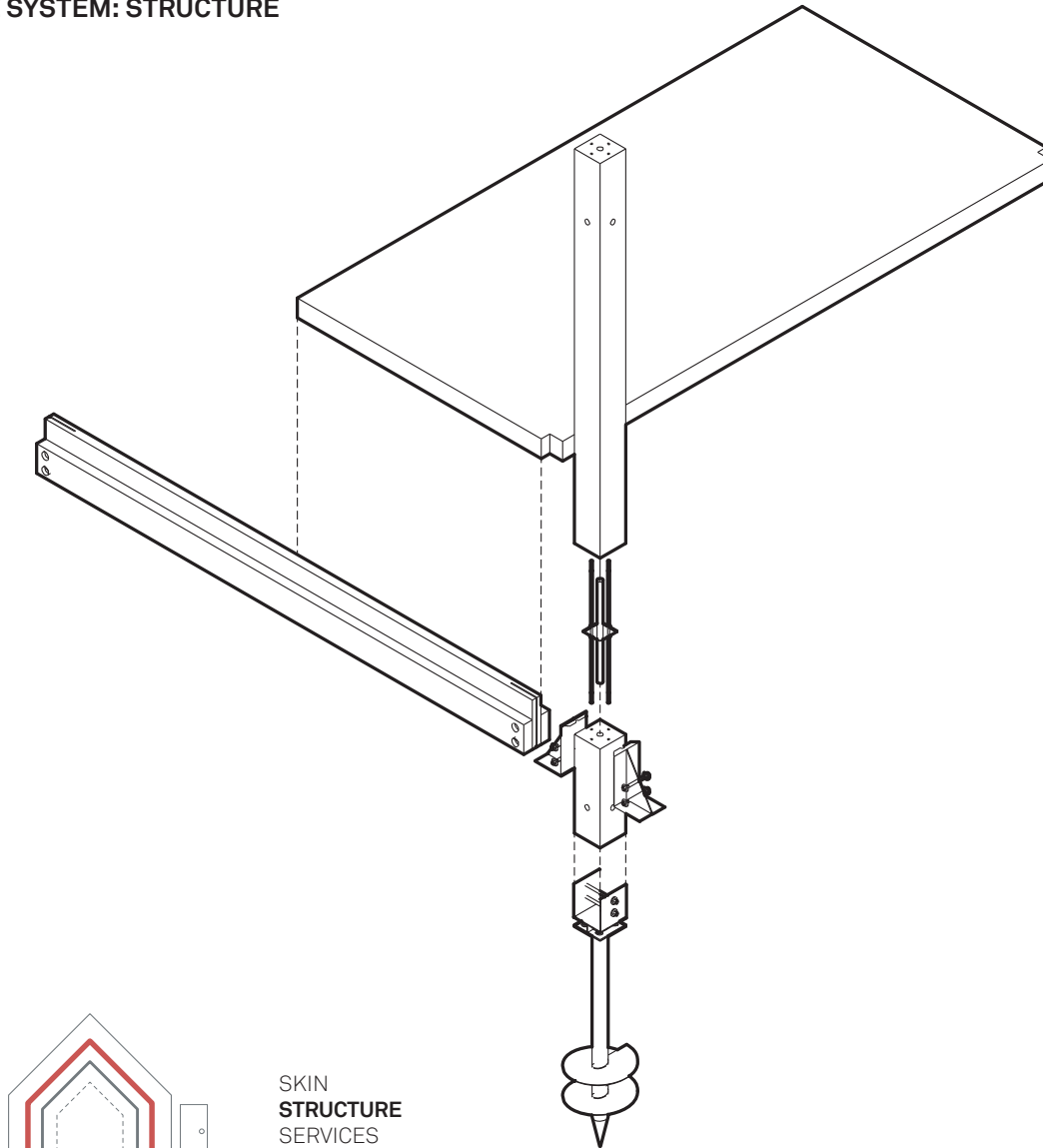


Figure 63: Kit of Parts, Structure

Heavy timber framework

A heavy timber framework is comprised of one beam and one column type. They are connected as needed with a small selection of steel components.

Dowel Laminated Floor Panel

Floor panels drop easily into place as supported by the T-shaped beams. Dowel Laminated Timber (DLT) can support integrated mechanical and electrical equipment as well as insulation.

High Flexibility Value

A simple structural system can be assembled, deconstructed, and reassembled fast with simple hand tools. This allows for easy expansion as well as recovery and reuse of individual elements.

PART 5: THE PROJECT

THE SYSTEM: STRUCTURE



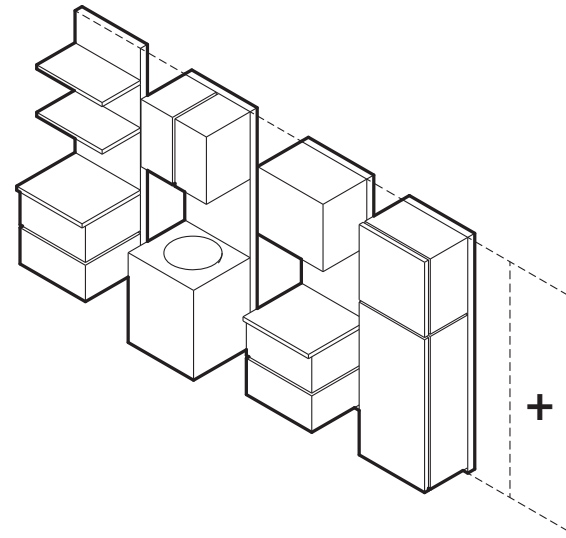
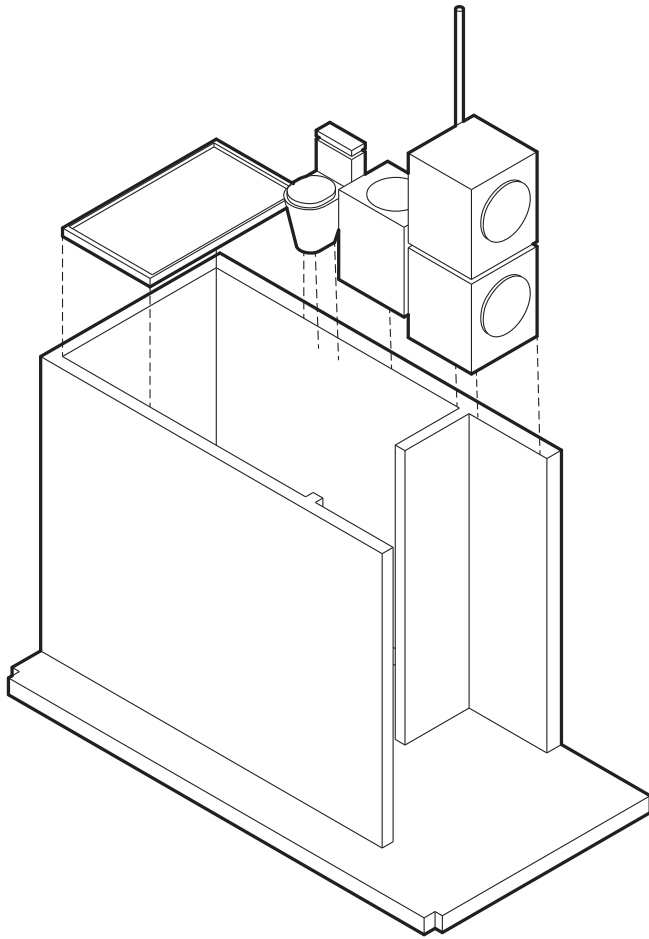
Figure 64: Prototype of the heavy timber connection.

Inspiration for the detail came from cam-lock fasteners commonly used in dismantlable ikea products.



PART 5: THE PROJECT

THE SYSTEM: SERVICES



Prefabricated Services

Service Modules that are prefabricated and include necessary plumbing requirements allow systems to plug into a variety of unit types as they are required.

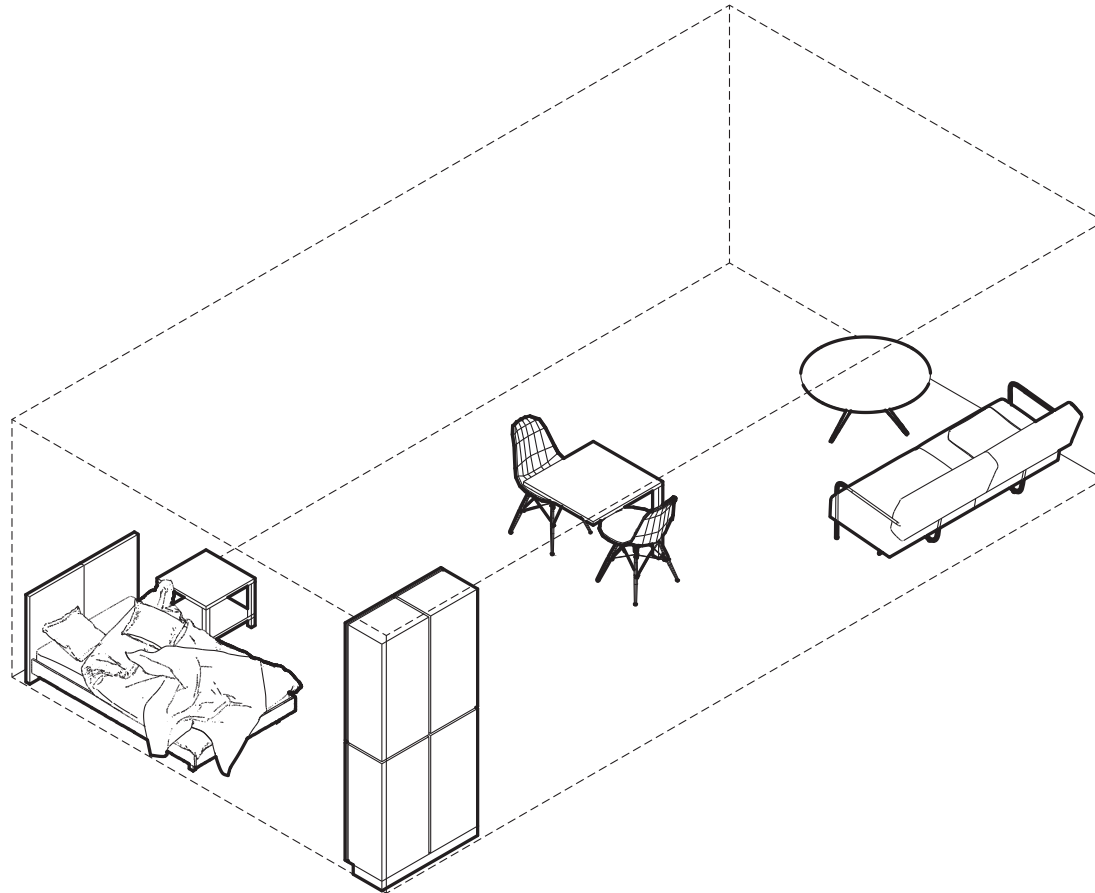
Modular Kitchen systems

A flexible / modular kitchen allows users to change or customize their own kitchens to meet their needs and aesthetic.

Figure 65: Kit of Parts, Services

PART 5: THE PROJECT

THE SYSTEM: STUFF



Flexible Space

Modules are well proportioned to allow a flexible and customizable arrangement of personal furnishings.

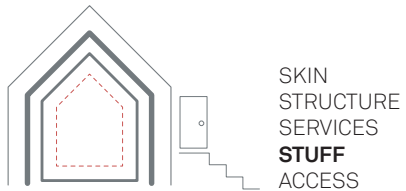
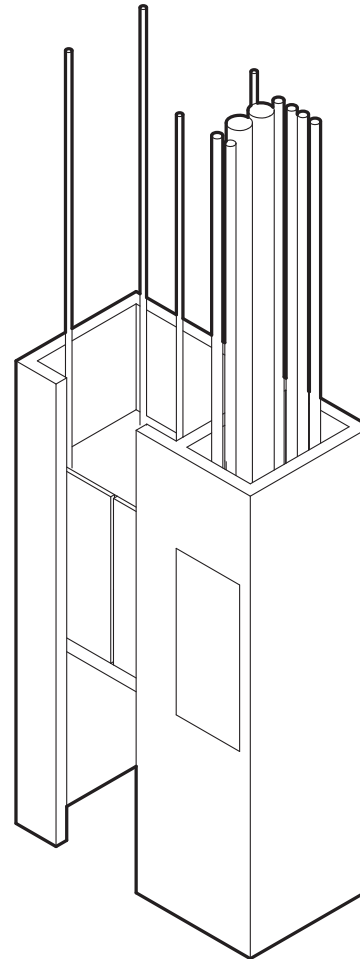
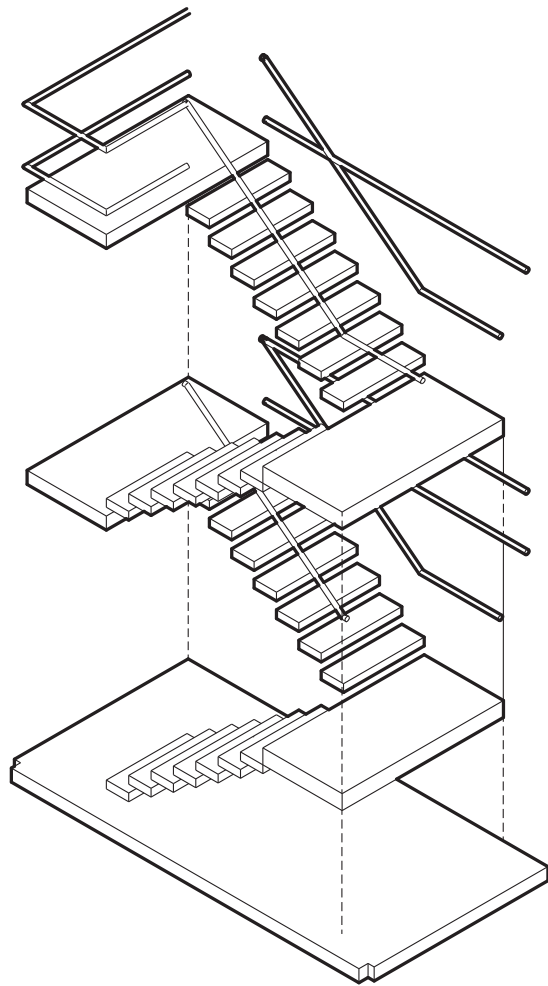


Figure 66: Kit of Parts, Stuff

PART 5: THE PROJECT

THE SYSTEM: ACCESS



Vertical Circulation

Stairs can be broken down into chunks and are sized according to the module so that they can be pre-assembled and attach to the system with very little effort.

Mechanical Shafts

For larger structures mechanical shafts can be combined with vertical circulation chunks. This allows for easy install and can make systems more accessible for repair.

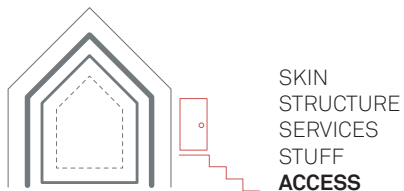
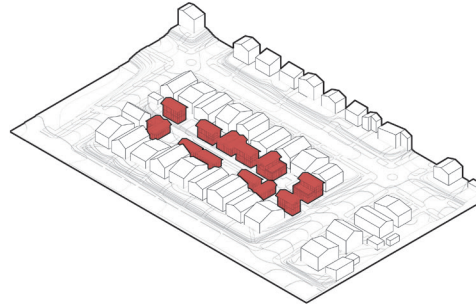
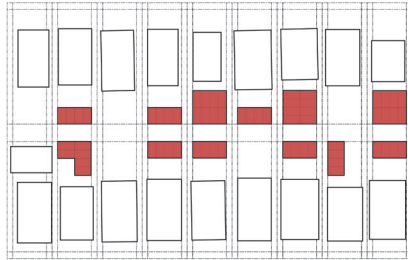
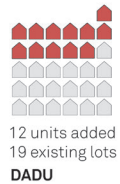


Figure 67: Kit of Parts, Access

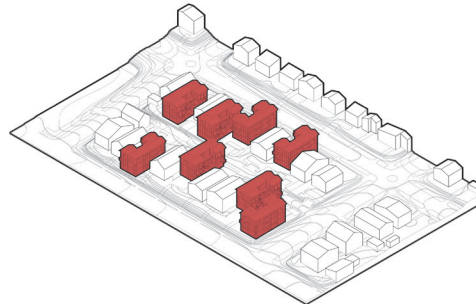
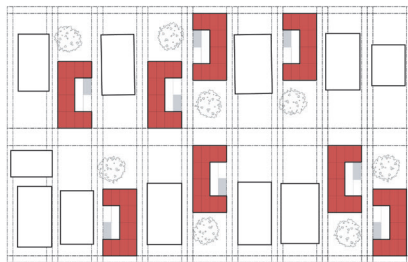
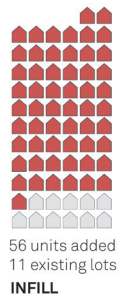
PART 5: THE PROJECT

POSSIBILITIES



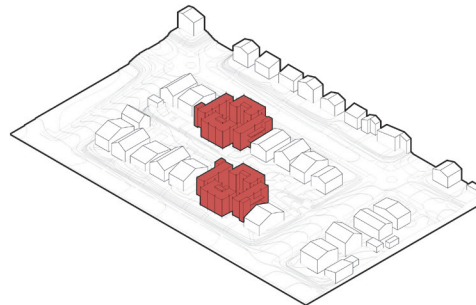
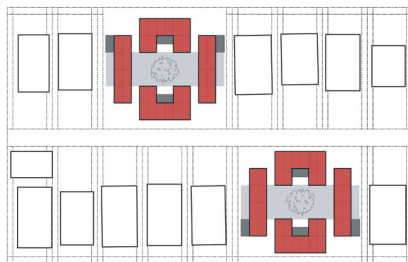
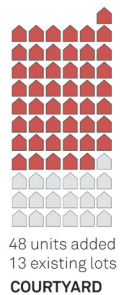
DADU

The Detached Accessory Dwelling Unit is designed for expansion. It allows for more bedrooms or shared living scenarios and still can fit in someones backyard with out taking up too much space.



INFILL

The Infill unit doesn't take up more coverage then that of a single family home, but it takes advantage of a little bit more height. With this size and scale you can add a maximum of 9 individual units on the existing lot.



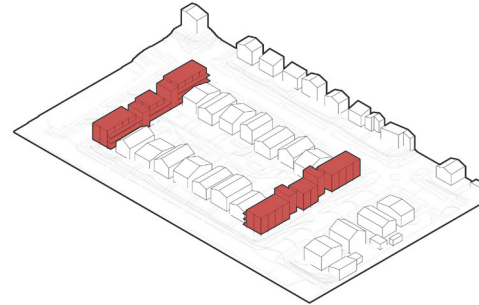
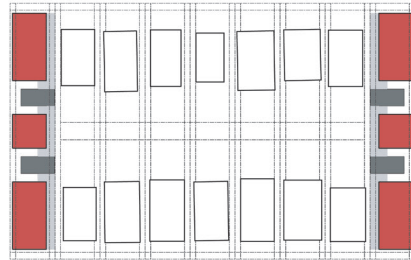
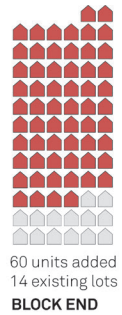
COURTYARD

Combining lots allows you to share green space between units. This option is still only reaching three stories in height and adds a maximum of 24 individual units per 3 typical lots.

Figure 68: Possibilities 1-3

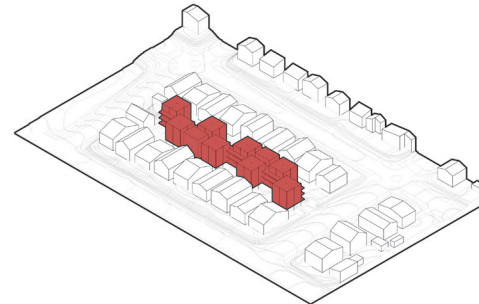
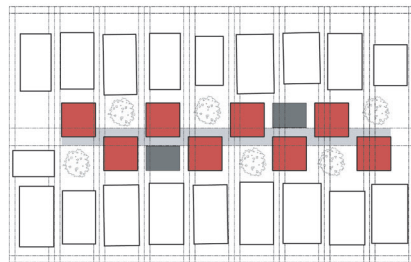
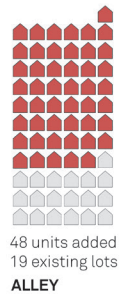
PART 5: THE PROJECT

POSSIBILITIES



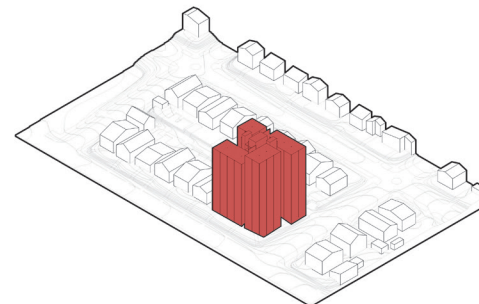
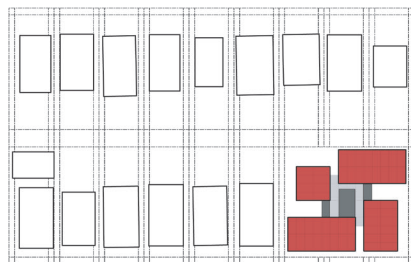
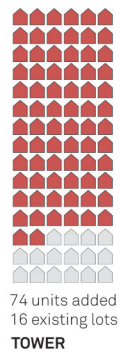
BLOCK END

By using the end of the block you can begin to create a blending of two different street typologies. One with single family homes, and the other with larger multifamily housing structures. This option is showing 3 stories high with about 30 units per building.



ALLEY

Seattle has a unique street type that occurs semi-frequently throughout single family neighborhoods. By creating a scheme along alley ways you can maintain all of the existing single family homes while adding approximately 48 units along the alley.



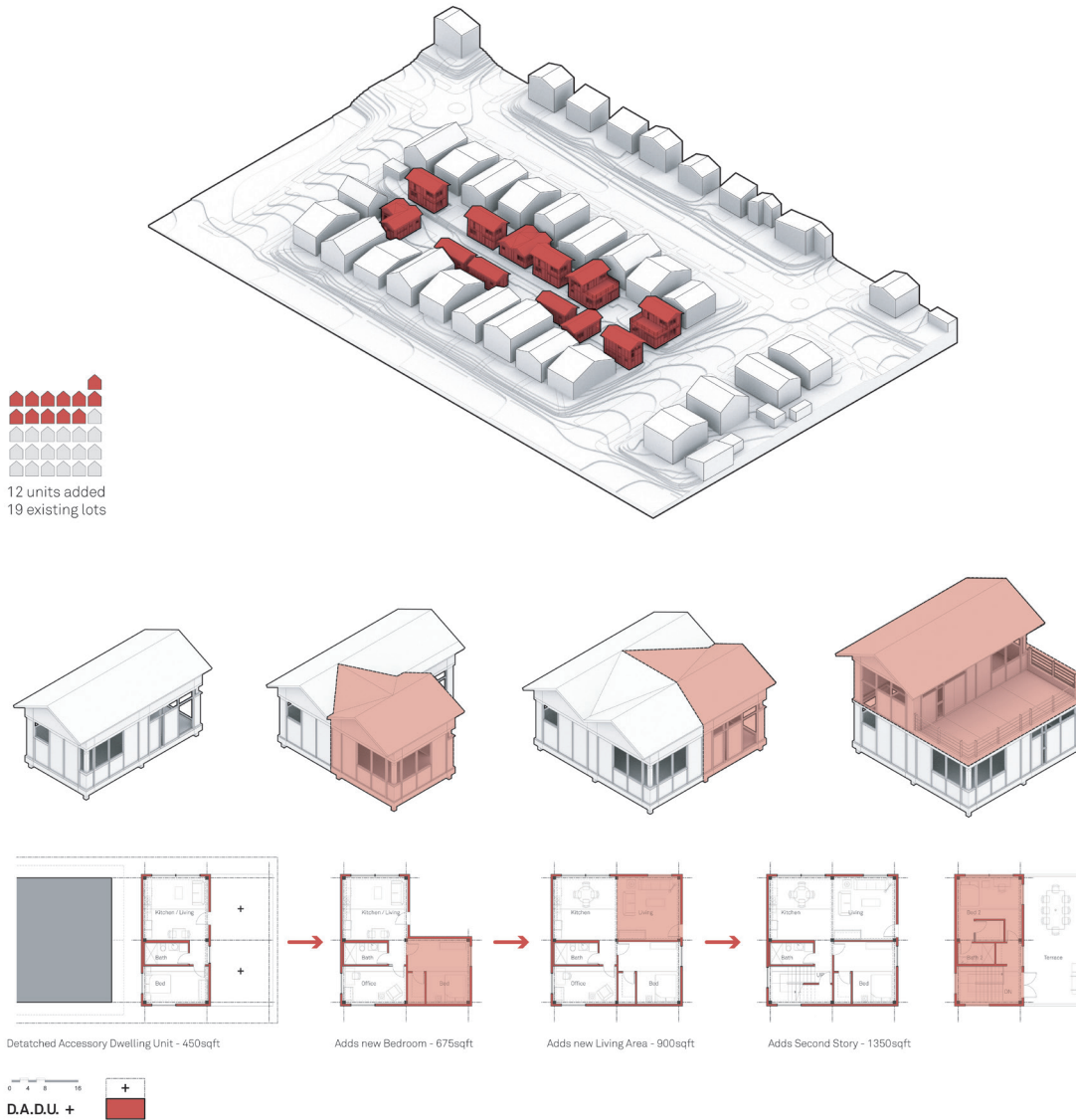
TOWER

It is likely that we will continue to see height limits increasing as the city expands. The tower option combines three existing lots and adds over 70 units to the site while also providing opportunities to include public amenities for the entire neighborhood.

Figure 69: Possibilities 4-6

PART 5: THE PROJECT

D.A.D.U.



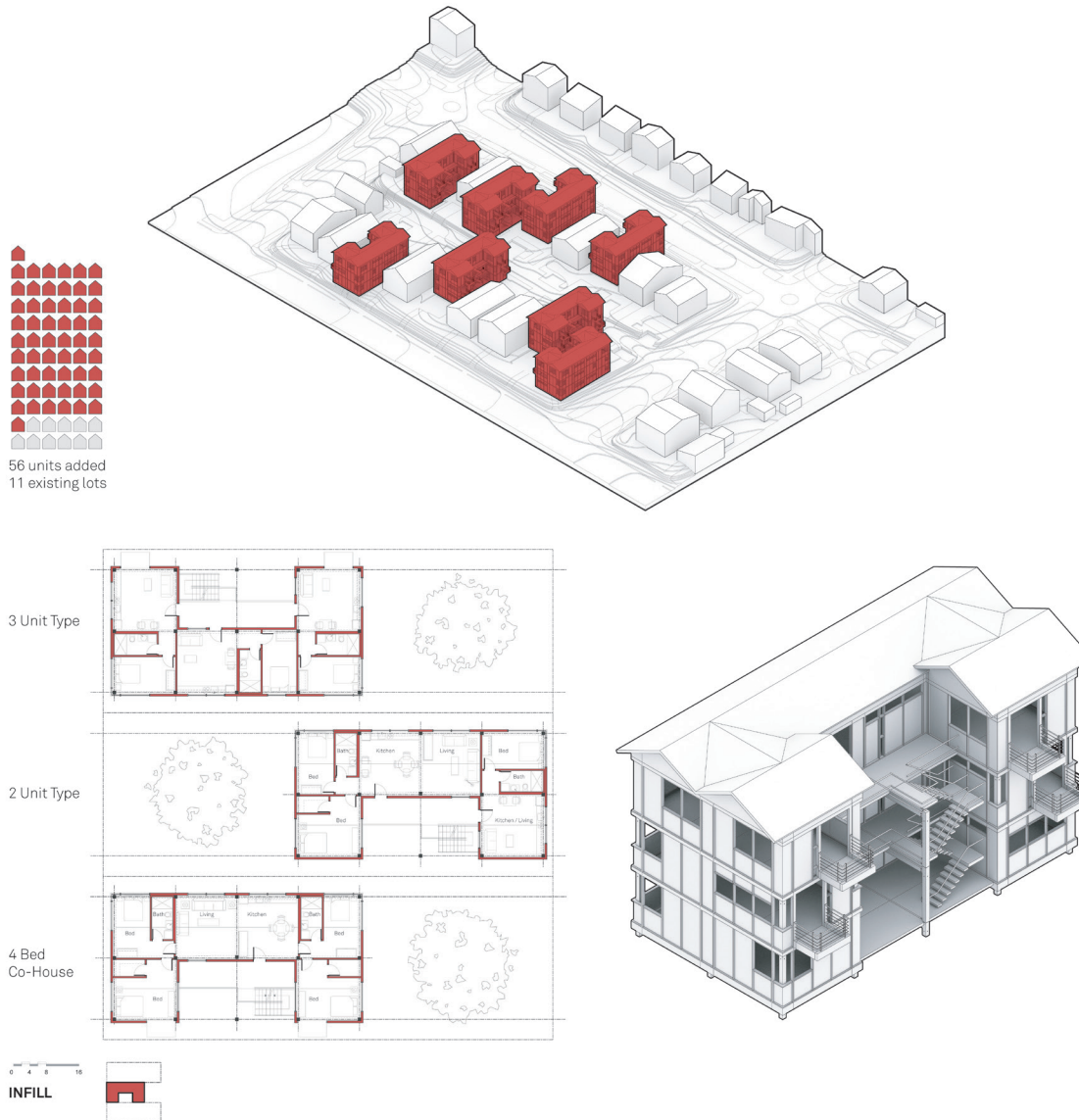
DADU

The Detached Accessory Dwelling Unit is designed for expansion. It allows for more bedrooms or shared living scenarios and still can fit in someones backyard with out taking up too much space.

Figure 70: Scheme 1, DADU

PART 5: THE PROJECT

INFILL



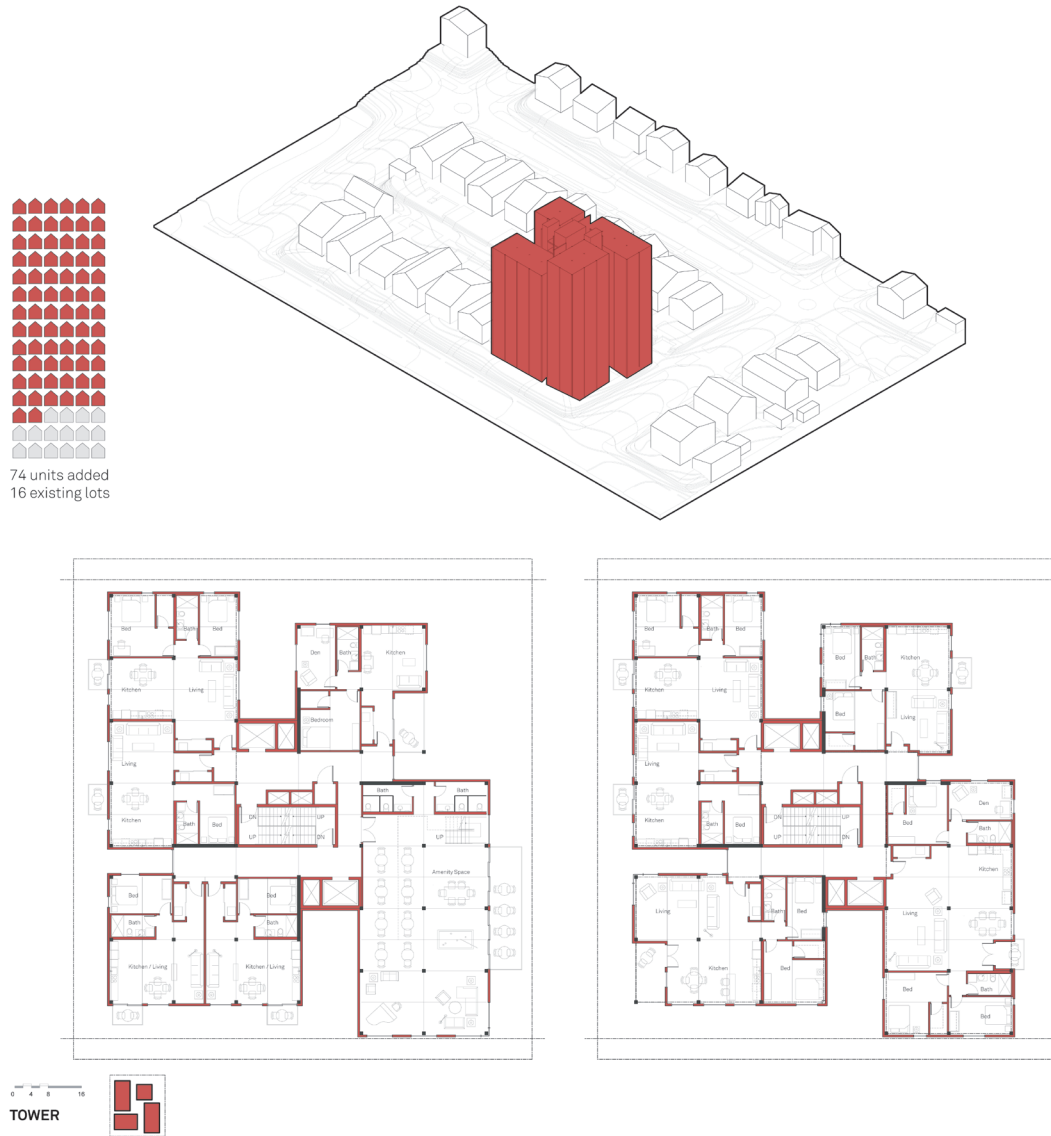
INFILL

The Infill unit doesn't take up more space than what is allowed of a single family home, but it takes advantage of a little bit more height. With this size and scale you can add a maximum of 9 individual units on the existing lot.

Figure 71: Scheme 2, INFILL

PART 5: THE PROJECT

TOWER



TOWER

It is likely that we will continue to see height limits increasing as the city expands. The tower option combines three existing lots and adds over 70 units to the site while also providing opportunities to include public amenities for the entire neighborhood.

Figure 72: Scheme 3, TOWER



Figure 73: Concept rendering, TOWER

PART 6: CONCLUSIONS AND RECOMMENDATIONS

“Waste and pollution are not accidents, but the consequences of decisions made at the design stage, where around 80% of environmental impacts are determined. By changing our mindset to view waste as a design flaw and harnessing new materials and technologies, we can ensure that waste and pollution are not created in the first place.”³

(Ellen Macarthur Foundation)

I believe that Design for Reassembly could be a very sustainable strategy to increase housing supply and ensure we can reuse materials in the future. As it is currently being demonstrated by GXN innovation, the Ellen Macarthur Foundation, and others, this approach to design thinking is possible, however, there are still many steps required to actually make systems of material reuse common practice. One of the biggest steps is collaboration. We need more professionals working together to solve larger issues, to develop new materials, to change the building code, and to adopt new policies on the ways in which we build our cities.

The biggest question brought up throughout the project was whether or not the system was designed to be the ‘only system’. Would this system prescribe that every house in the future look the

same? What happens as new materials and construction methods are advanced alongside new technologies, will the system become obsolete? My answer to this is no, the system is not a one size fits all solution, but rather it demonstrates how this kind of design thinking might work. Designing for disassembly and adaptability should be applied to other building types and systems at all scales. As construction methods and new technologies advance design thinking it is even more important to design this way. Any building, system, or product can become obsolete so it should still be designed so that it can be taken apart in its entirety so our raw materials do not end up as waste in a landfill.

In the very long term, say 300 years from now, these design strategies could change the way we envision our cities. If material reuse and adaptability were embedded into the structures of our society it is not so difficult to imagine our cities’ structures as the quarry of building materials from which we build the future.

I think global warming is a greater threat than terrorism. Climate change could kill millions . . . We are all time travelers, journeying together into the future. But let us work together to make that future a place we want to visit.

Remember to look up at the stars and not down on your feet. Try to make sense of what you see, and wonder about what makes the universe exist. Be curious. and however difficult life may seem, there is always something you can do, and succeed at. It matters that you don't just give up.

Stephen Hawking

PART 6: CONCLUSIONS AND RECOMENDATIONS

REFERENCES

1. Global Construction 2030. Retrieved from <http://www.globalconstruction2030.com/>
2. Advancing Sustainable Materials Management: Facts and Figures Report. (2019, June 12). Retrieved from <http://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/advancing-sustainable-materials-management>
3. What Is The Circular Economy? Retrieved from <https://www.ellenmacarthurfoundation.org/circular-economy/what-is-the-circular-economy>
4. Explore Deconstruction. Retrieved from <https://www.portlandoregon.gov/bps/68520>
5. McDonough, W., Braungart, M., & McDonough, W. (2009). *Cradle to cradle*. London: Vintage.
6. Brand, S. (2010). *Whole earth discipline: An ecopragmatist manifesto*. London: Atlantic Books.
7. The Major Challenge of Inadequate U.S. Housing Supply. Retrieved from https://freddiemac.gcs-web.com/news-releases/news-release-details/major-challenge-inadequate-us-housing-supply?_ga=2.85654160.823995960.1560450066-1783921431.1553121930
8. Market. Retrieved from <https://missingmiddlehousing.com/about/market>
9. Neighborhoods For All. Retrieved April 10, 2019, from <https://www.seattle.gov/planningcommission/our-work/neighborhoods-for-all>
10. Building a Circular Future. (2016). GXN Innovation (Byggecentrum).
11. Brand, S. (1994). *How buildings learn: And fail to learn*. New York, NY: Viking.
12. *The Re-Use Atlas*. (2017). London: RIBA Publishing.
13. Simonen, K. (2014). *Life cycle assessment*. London: Routledge.
14. Leupen, B. (2009). *Frame and generic space a study into the changable dwelling; proceeding from the permanent*. Rotterdam: 010.
15. Building Affordability by Building Affordably: The case for Off-site Multifamily Construction. Retrieved from <https://turnercenter.berkeley.edu/blog/offsite-construction>
16. Circle House Publication. Retrieved from <https://gxn.3xn.com/project/circle-house>
17. People's Pavilion | Bureau SLA & OvertredersW. (2018, November 17). Retrieved from <http://www.aboutdesignworld.com/pavilion/peoples-pavilion-bureau-sla-overtredersw/>
18. Loblolly House | Prefabricated Architecture Integrated with Nature. Retrieved from <https://kierantimberlake.com/pages/view/20/loblolly-house/parent:3>
19. Cellophane House | Prefabricated Architecture & Design for Disassembly. Retrieved from <https://kierantimberlake.com/pages/view/14/cellophane-house/parent:3>
20. Madden, D., & Marcuse, P. (2016). *In defense of housing: The politics of crisis*. London ; New York: Verso.
21. Darrin Qualman. (2018, September 22). Home grown: 67 years of US and Canadian house size data. Retrieved from <https://www.darrinqualman.com/house-size/>
22. March 15, 2017: Turner Center Releases New Paper on Benefits of Off-Site Multifamily Construction. Retrieved from <https://ced.berkeley.edu/events-media/news/turner-center-releases-new-paper-on-benefits-of-off-site-multifamily-constr>
23. CHamler. (2018, January 15). How Often Does the Average Person Move in a Lifetime and Why? Retrieved from <https://mortgage.info/often-average-person-move-lifetime/>
24. Mandatory Housing Affordability (MHA). Retrieved from [https://www.seattle.gov/hala/about/mandatory-housing-affordability-\(mha\)](https://www.seattle.gov/hala/about/mandatory-housing-affordability-(mha))
25. Retrieved from <http://web6.seattle.gov/dpd/parceldata/default.aspx>
26. Stechz, M. (2018, April 20). Stephen Hawking's last words to the humanity. Retrieved June 13, 2019, from <https://www.youtube.com/watch?v=P17GbICtNSw>
27. Kieran, S., & Timberlake, J. (2004). *Refabricating architecture: How manufacturing methodologies are poised to transform building construction*. New York, NY: McGraw-Hill.

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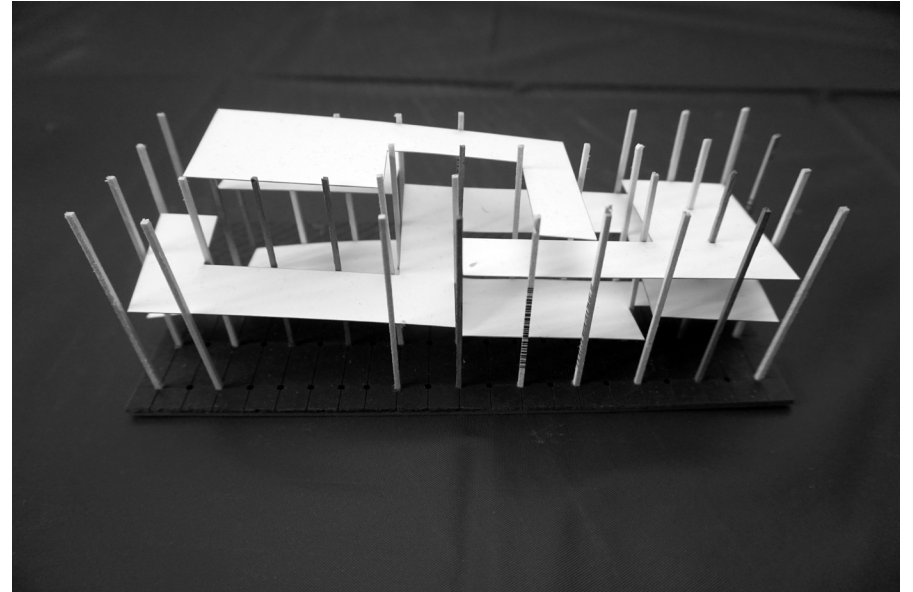
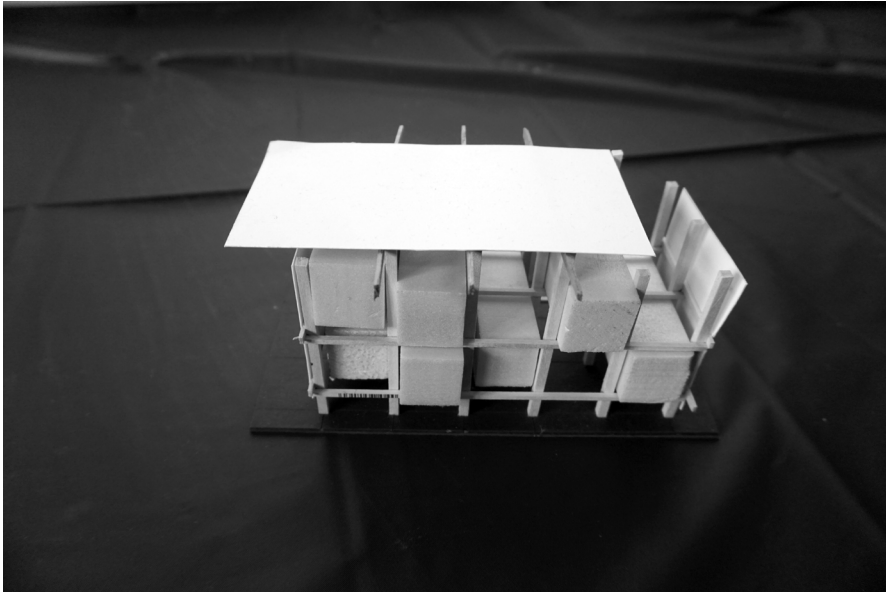
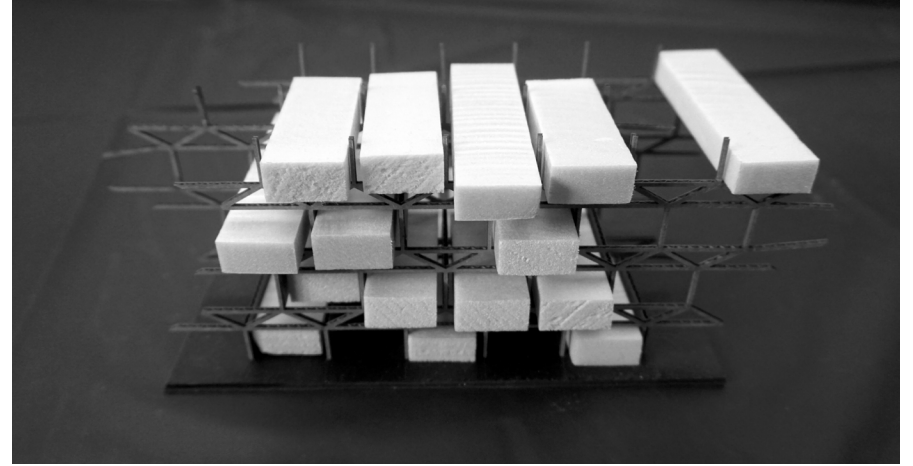
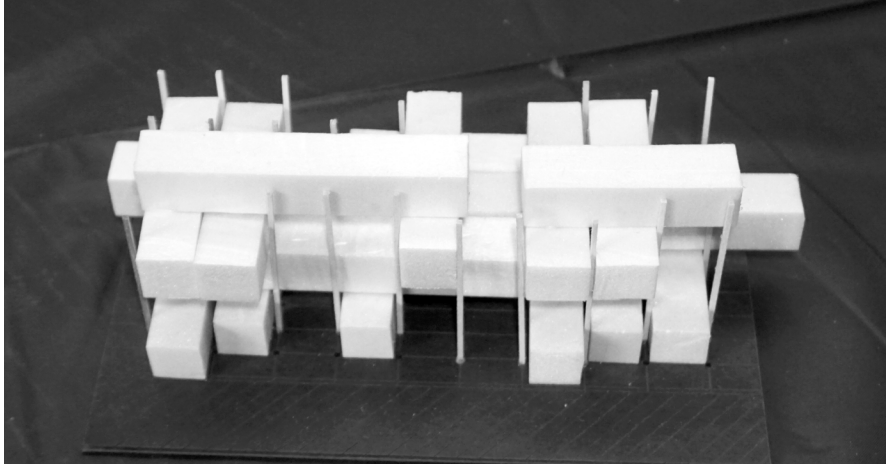
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Note: All Photographs, Diagrams, Images, and models are produced by the author except for those that are noted otherwise.

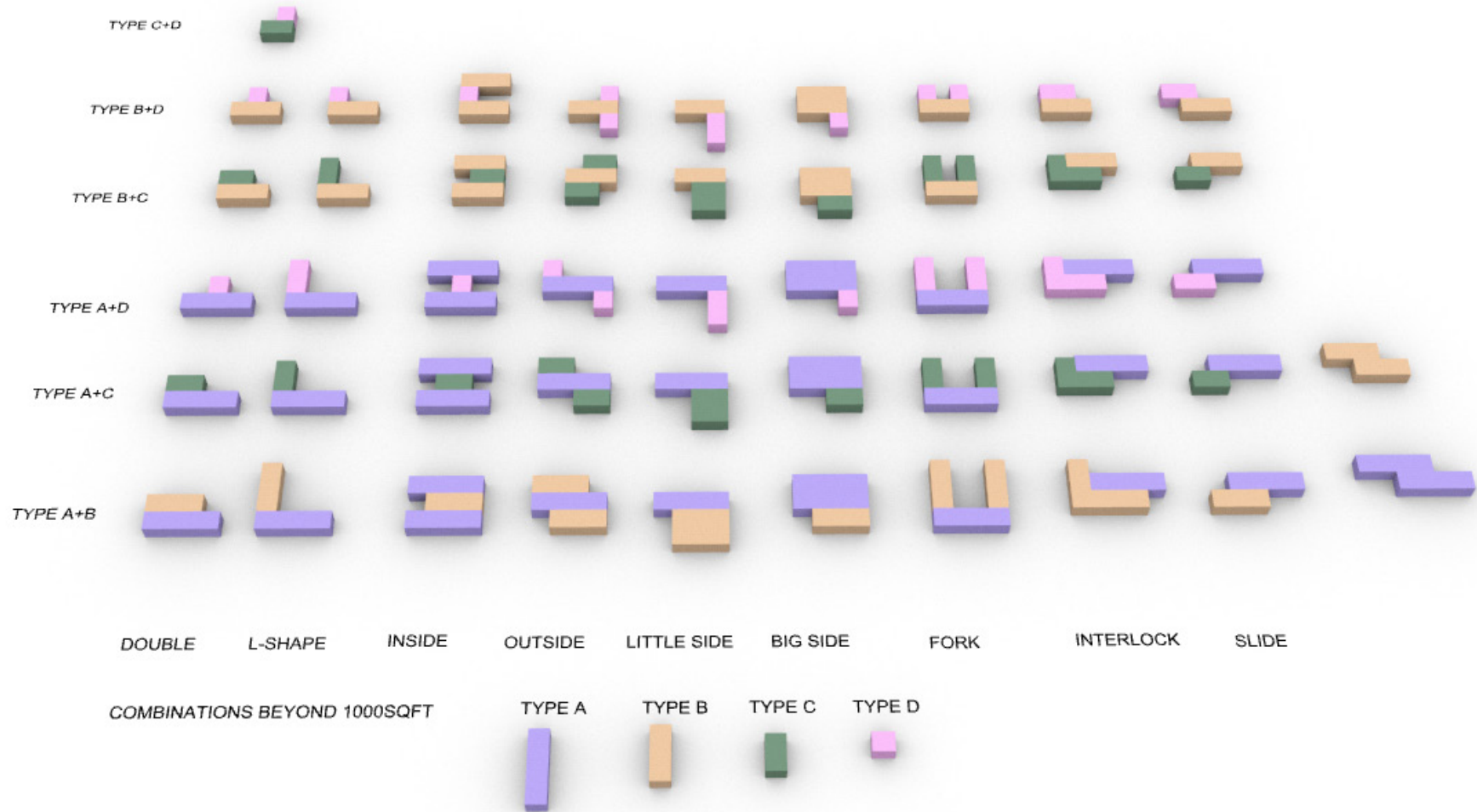
PART 6: CONCLUSIONS AND RECOMENDATIONS

DESIGN ITERATIONS



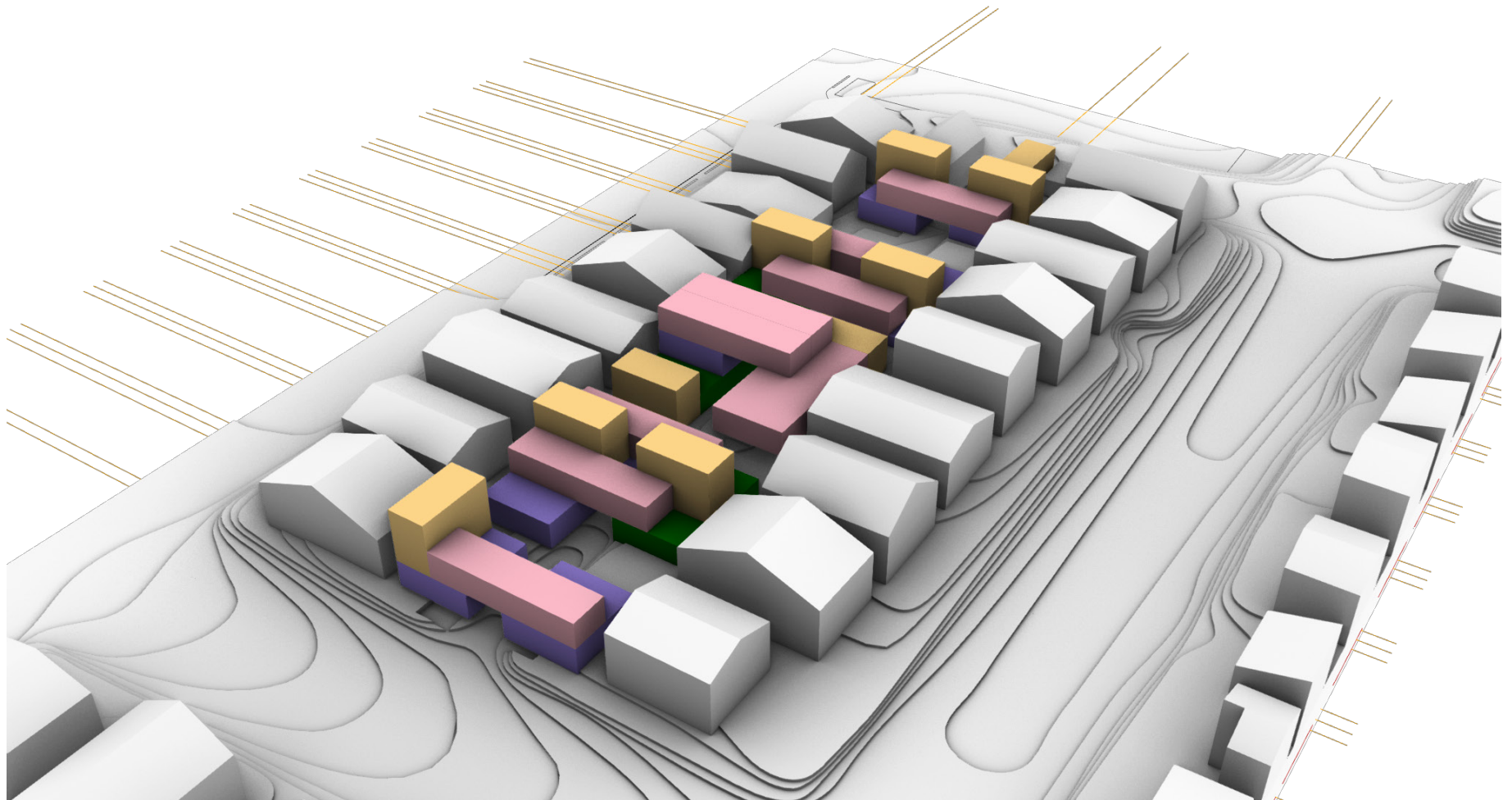
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DESIGN ITERATIONS



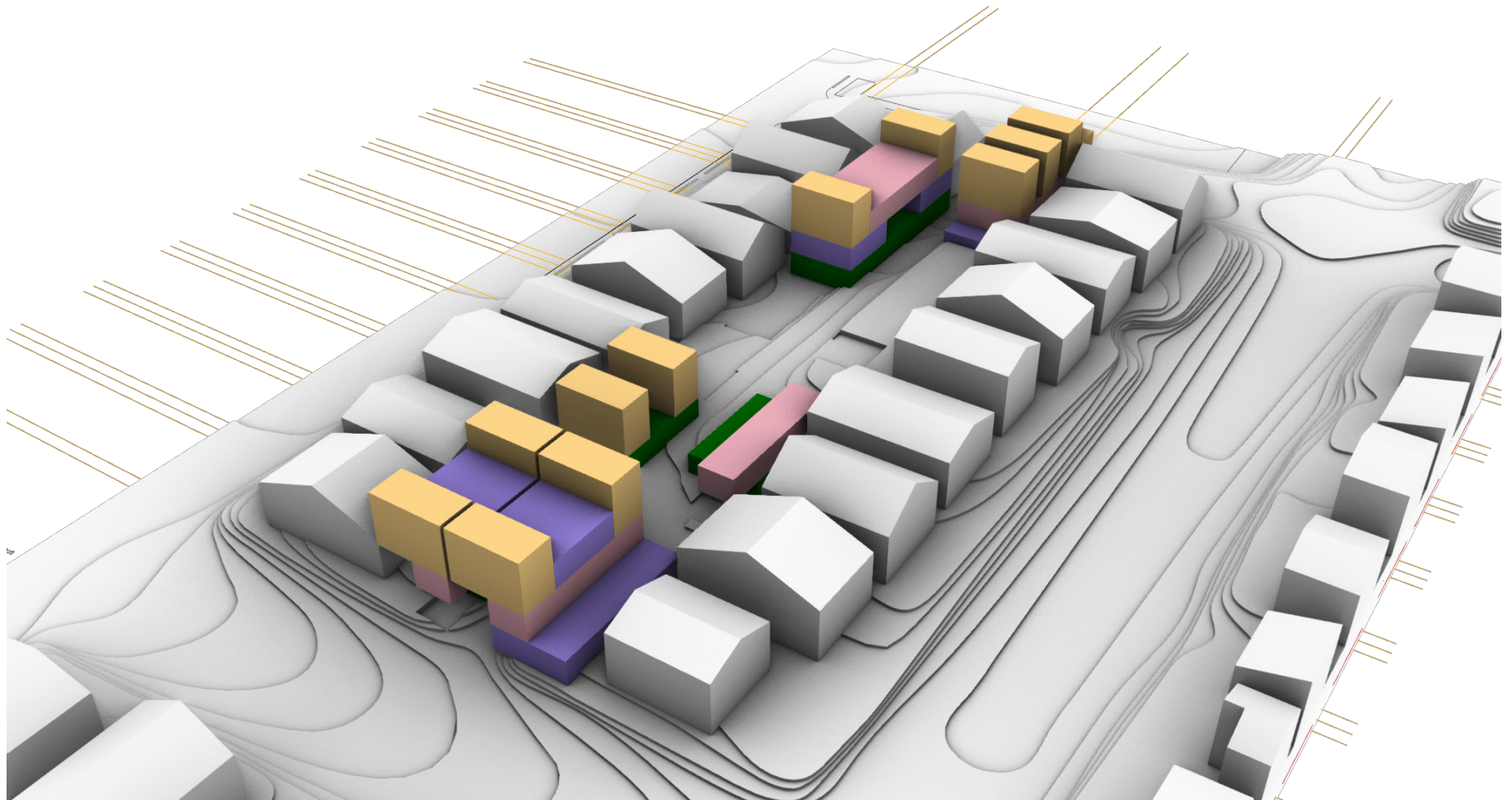
PART 6: CONCLUSIONS AND RECOMENDATIONS

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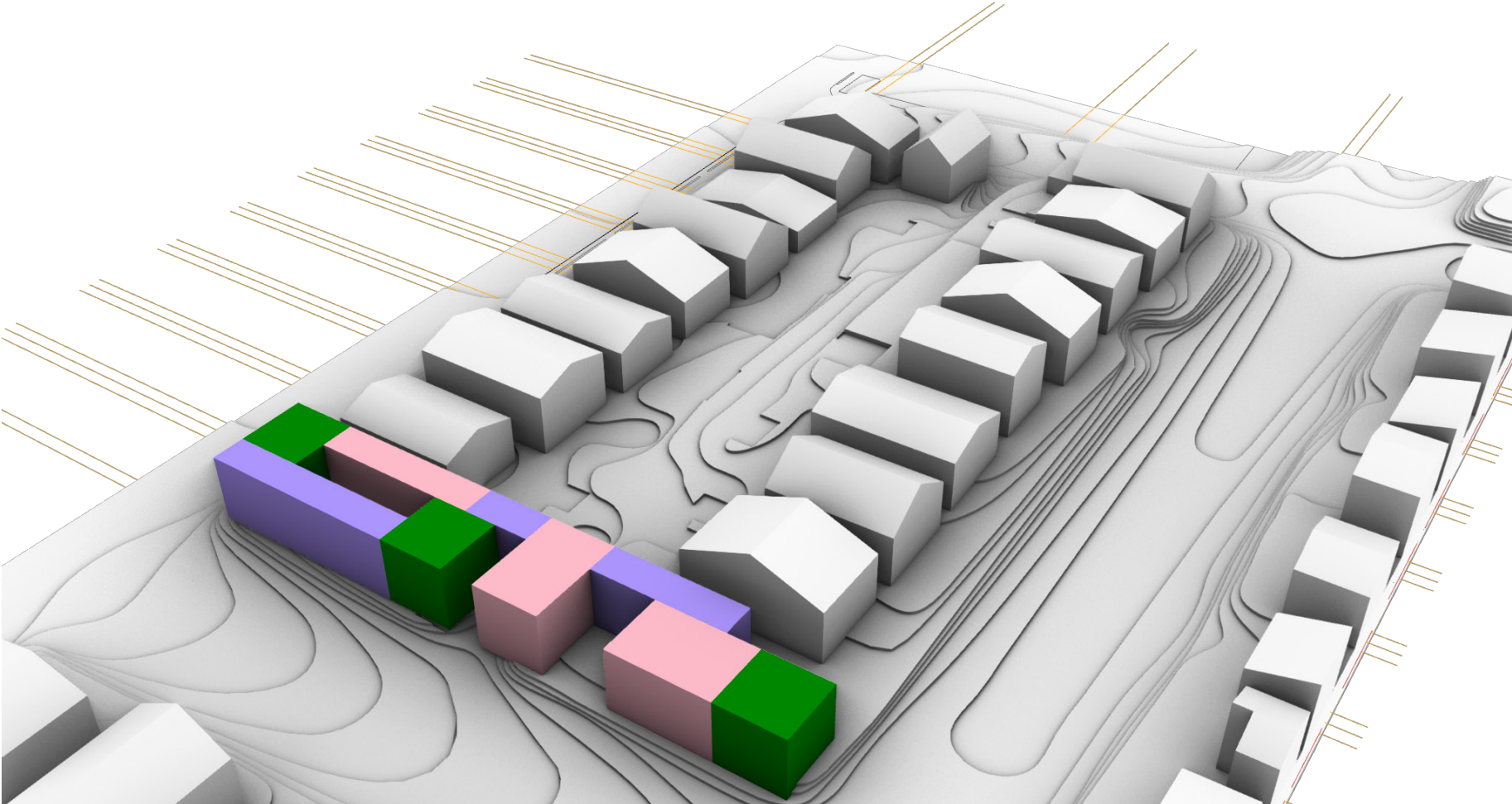
PART 6: CONCLUSIONS AND RECOMENDATIONS

DESIGN ITERATIONS



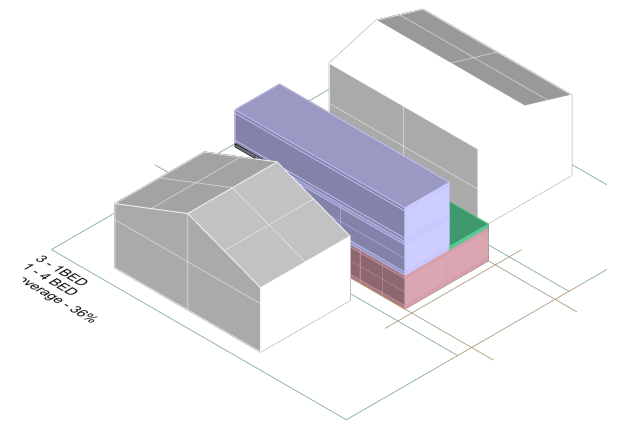
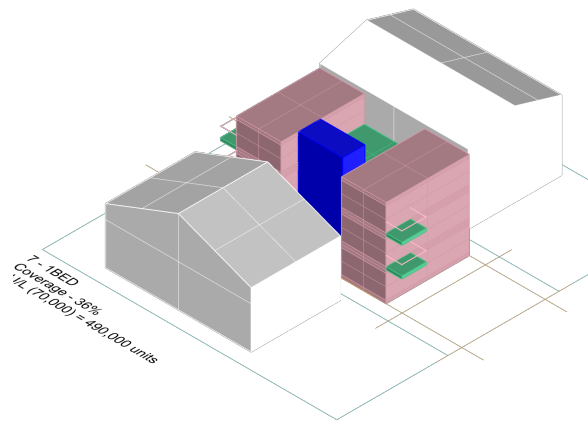
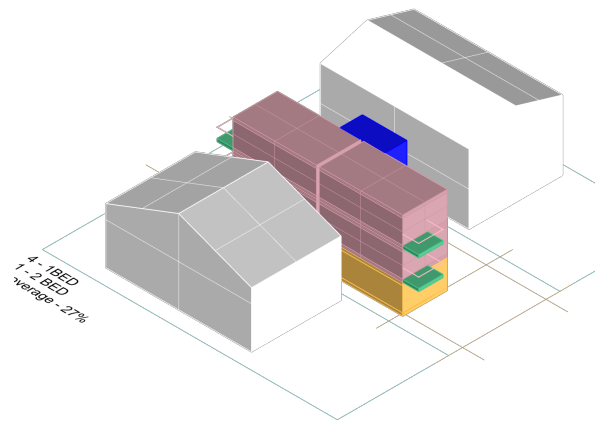
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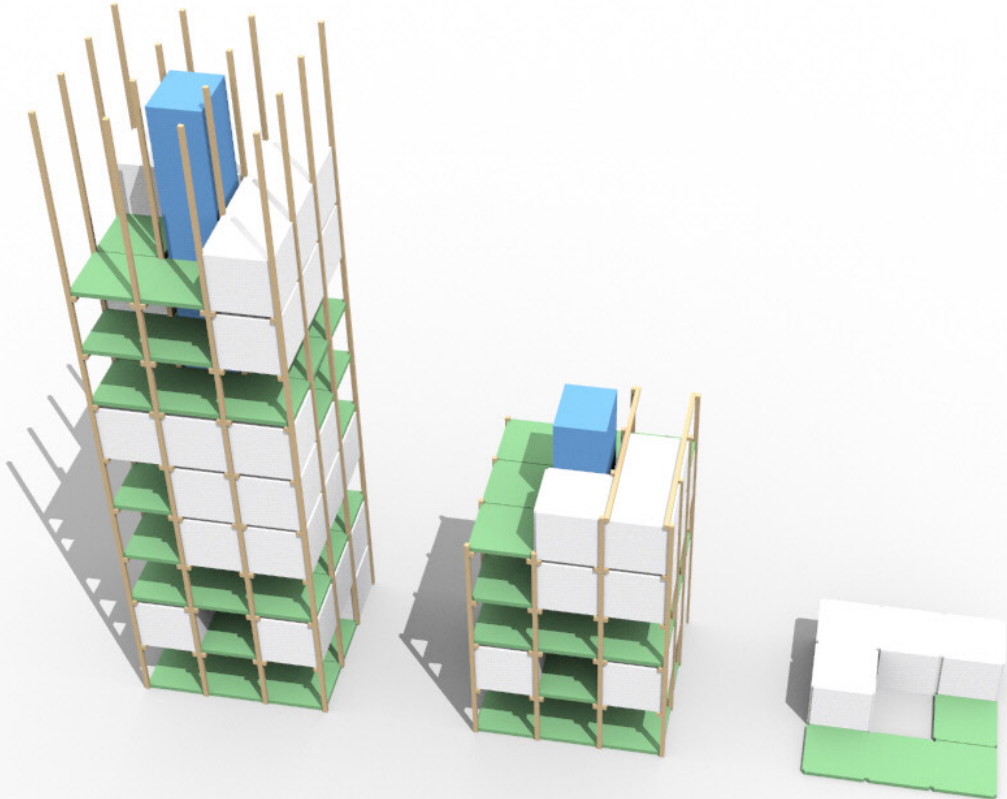
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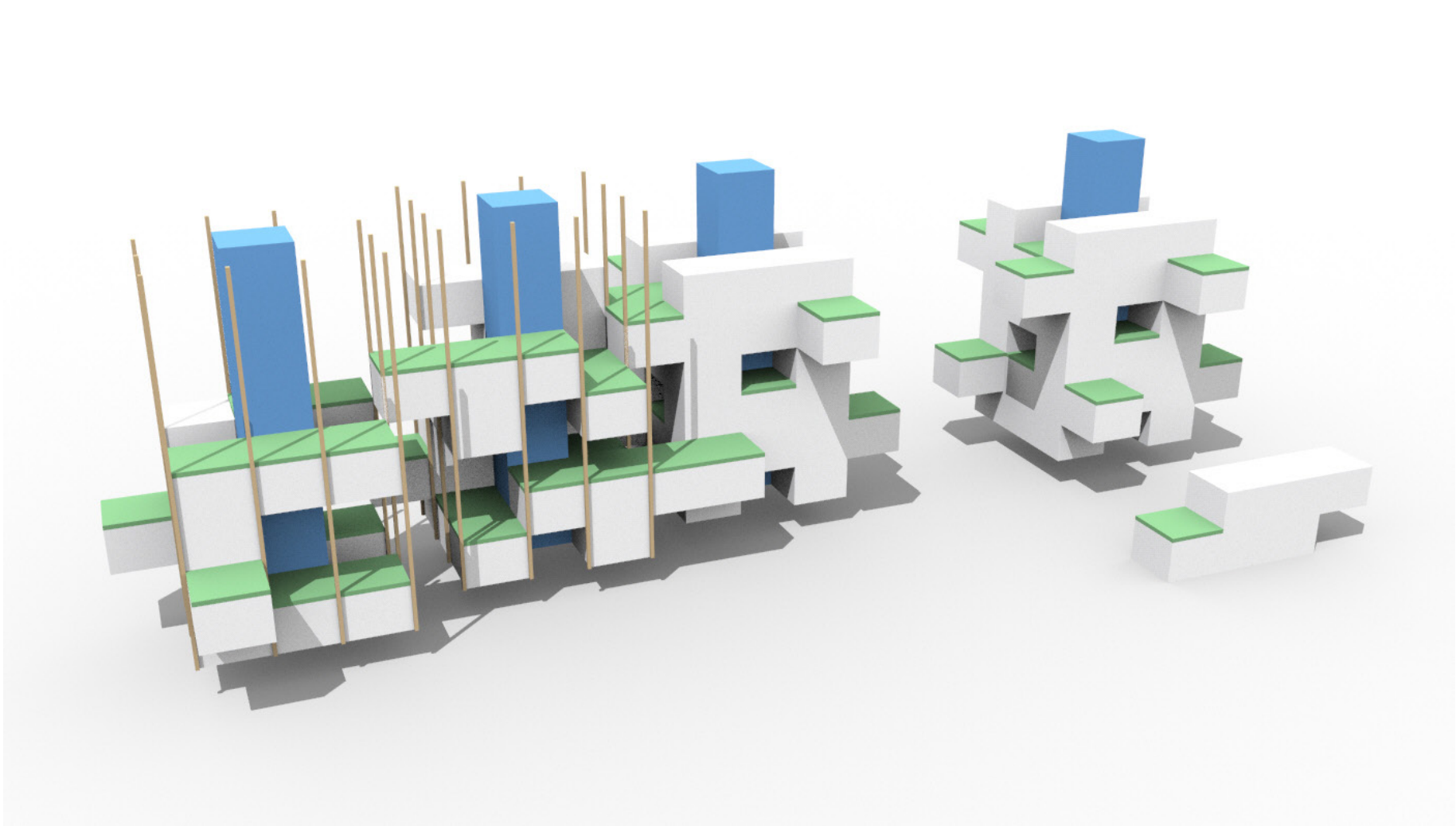
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