

GROWING RESPONSIBLE CITIES:  
An Ecological Design Approach to Bellingham's Waterfront District

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A thesis  
submitted in partial fulfillment of the  
requirements for the degree of  
Master of Architecture

University of Washington  
2017

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Program Authorized to Offer Degree:  
Architecture

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# ABSTRACT

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The city of Bellingham, WA is in the midst of redeveloping its waterfront from a former industrial pulp mill into a sustainable, mixed-use hub, reconnecting the city to its waterfront. This thesis focuses on the 37 acre Downtown Waterfront Sub-District of the 2013 Master Plan adjacent to the city's Central Business District that will help form the downtown core of the city for decades to come. The framework for the project builds off of Alan Organschi's *Timber City* "instruction manual for transforming the 21st century city from CO2 source to carbon sink." The thesis looks to expand the benefits of mass timber by focusing

on early design opportunities that maximize the potential service life of buildings and thus maximize the sustainable gains inherent in mass timber. The project is realized through carbon footprint calculations comparing a similar concrete and mass timber structure. The mass timber structure is a framework capable of handling the programmatic extremes of both residential and office without the need for structural revisions. The design serves as a sustainable, structural prototype, that can be modified and repeated over the site, forming the bases of the new waterfront district.

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## 9. REFLECTION

# 1. INTRODUCTION

This thesis advocates for a shift from steel and concrete as the dominate structural systems in urban building typologies to one of mass timber as argued by Alan Organschi's *Timber City*. In addition, the thesis looks to expand on the benefits of mass timber by focusing on early design decisions that have the potential to increase the service life of the building and maximize the ecological benefits inherent in mass timber construction.

## 2. GLOBAL ISSUES

### CLIMATE CHANGE & POPULATION GROWTH

Carbon dioxide (CO<sub>2</sub>), a heat-trapping greenhouse gas caused by “human activities such as deforestation and burning fossil fuels, as well as natural processes such as respiration and volcanic eruptions” is 100+ parts per million higher than at any point over the last 400 thousand years with no sighs of decreasing.<sup>1</sup> In addition, the United Nations projects the global population will reach 9.7 billion people by 2050 and 11.2 billion by 2100.<sup>2</sup>

Currently, the population stands at 7.6 billion people meaning the population is projected to grow by 3.6 billion, that's 1 billion more people than the current populations of China and India combined (the worlds two most populated countries), or equal to the total population of the planet in 1970. Combined, these two issues have far reaching and potentially negative effects for the planet and its inhabitants. The two issues are also very much intertwined. CO<sub>2</sub> is a key contributor to climate change which, at the very least, will bring rising

1 NASA. Global Climate Change: Vital Signs of the Planet. 2017.

2 United Nations Department of Economic and Social Affairs/Population Division . World Population Prospects: The 2017 Revision, Key Findings and Advance Tables. 2017.

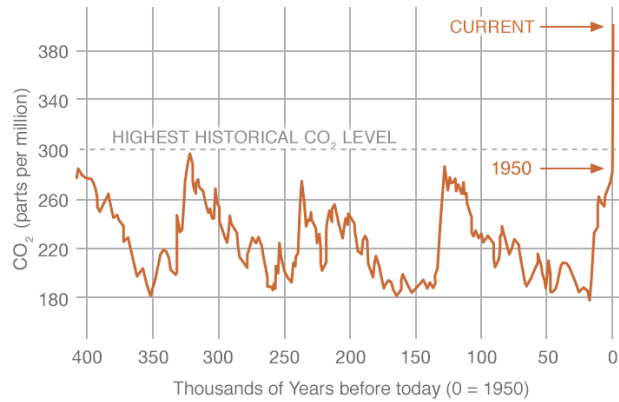


Fig. 2-1 Historic CO<sub>2</sub> Levels Reconstruction from Ice Cores. Source: NOAA

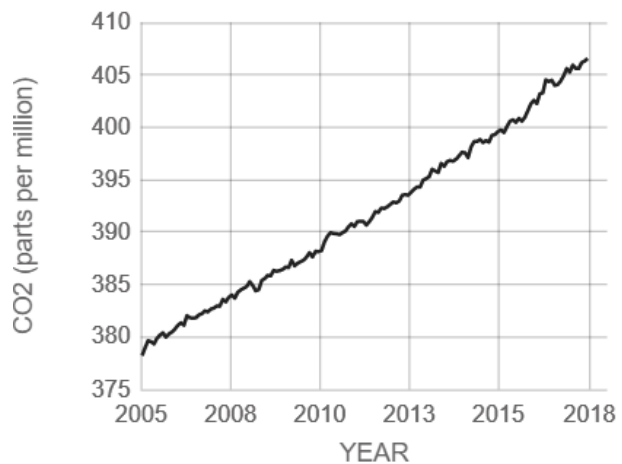


Fig. 2-2 Direct CO<sub>2</sub> Measurements Source: NOAA

tides and unpredictable, more severe, weather patterns. Unpredictable weather patterns can cause crops to fail, leading to food shortages and famine, while a rising population will only further increase the demand for more food.

Rising tides threaten to displace low-lying waterfront populations, increasing the demand for new housing and infrastructure in addition to the already forecasted demand due to population increases. How the world responds now to these challenges will shape the future of this planet for many generations to come. There are potential solutions to these challenges, some tested, some not, and some still yet to be conceived. For this to occur, there must be a will for them to be tried, modified and tried again across all disciplines, from policy to

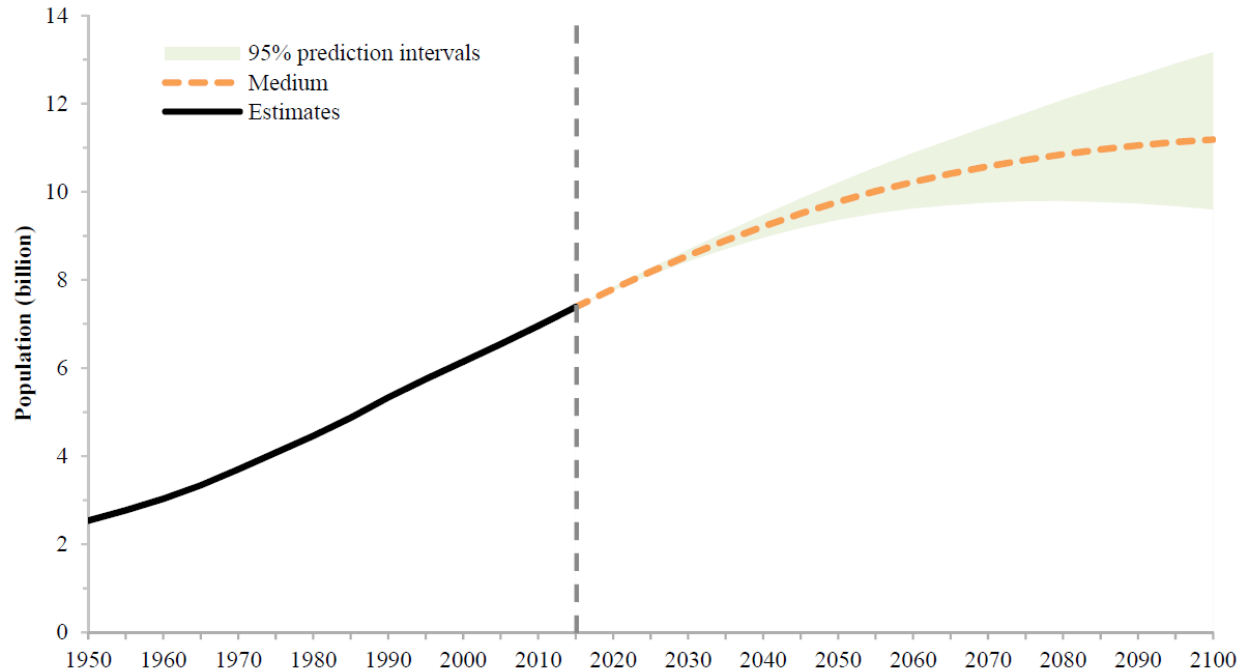


Fig. 2-3 Estimated Population Growth

Source: United Nations, Department of Economic and Social Affairs, Population Division (2017).

design, both locally and globally, with every effort a part of the whole solution.

#### MATERIAL USE & URBANIZATION

As the world population grows, it is rapidly becoming more urbanized, meaning a higher and higher percentage of the population is living in more dense, urban areas. By 2050, it is estimated that 65% of the world's population will live in cities, having only surpassed the 50/50 threshold in 2007.<sup>3</sup>

In countries considered to be more developed, resource consumption has remained relatively stable but in developing countries such as Brazil, Russia, India, China, and South Africa (BRICS), demand has rapidly expanded over the last 30 years from 2.75 metric tons per capita in 1980 to 9.75 metric tons per capita in 2010.<sup>4</sup>

Which materials are in demand has also shifted during the same period with demand for concrete increasing by 600% while demand for wood has slightly decreased. The implications for this shift in building material choice has a massive impact on the environment with steel and concrete having a much higher embodied energy and a destructive extraction process in comparison to wood.<sup>5</sup>

Alan Organschi's *Timber City* proposes an outline to flip the script on these seemingly overwhelming issues by turning them into opportunities. In proposing a switch away from concrete and steel to wood and mass timber as the major structural material from which cities are built, the new urban environments required to meet the growing population demands will also become the same carbon sequestration stores required to fight global climate change and environmental degradation. With more population concentrated in denser timber built urban centers, it leaves more room for undisturbed

3 Organschi, Alan. *Timber City Prospectus*. 2016.

4 Ibid.

5 Ibid.

forests as natural carbon sequestration banks while also decreasing newly generated CO2 emissions and sequestering CO2 in the very urban centers that generate them.

### 3. SUSTAINABILITY IN ARCHITECTURE

#### KEY METRICS

Sustainability in architecture is usually measured in energy: how much is used vs how much is generated and specifically how the energy is generated. Much of the early sustainability pursuits focused on how to decrease energy use through passive design principles, advances in material technology and tighter building envelopes. When alternative renewable energy technologies such as solar or wind power began to come down in price, the use of on-site renewable energy made it possible to bring these buildings down to net-zero or even energy positive buildings.

#### LIFE CYCLE ANALYSIS (LCA)

The materials, their extraction and processing, and the construction process itself also consume energy, some more than others. To compare these differences in materials, Life Cycle Analysis (LCA) has become a common tool in determining which materials are more sustainable than others. A LCA examines the total environmental impact of a material or product through every step of its life, from extraction, to disposal and/or recycling. It is a flexible figure specific to location due to changes in transportation distances and modes.<sup>6</sup> Reducing travel distance between each stage of the process along with increased efficiencies in the processing or material selection, can greatly affect the same buildings LCA from region to region.

6 Milne, Geoff, and Chris Reardon. Your Home: Australia's Guide to Environmentally Sustainable Homes. N.p.: Australian Government, 2013.

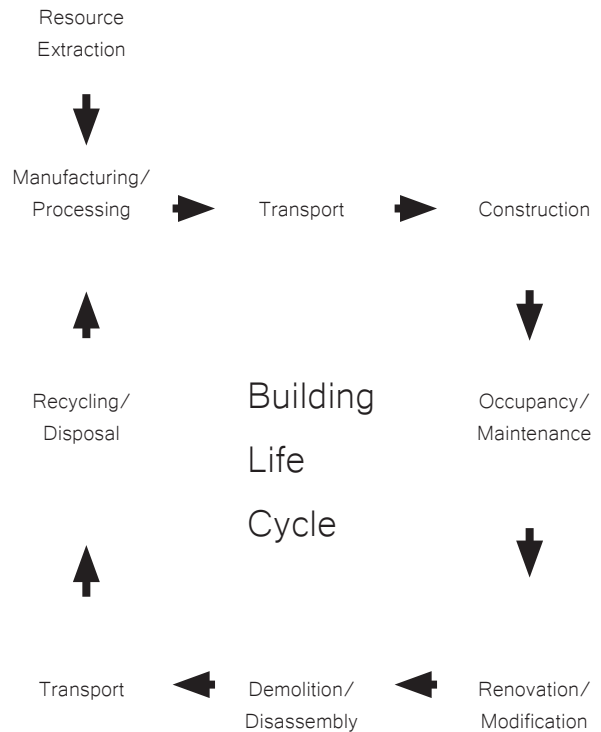


Fig. 4-1 Building Life Cycle

While great strides have been made in pursuit of reducing or decreasing the operational energy side of a building, for example Bullitt Center and other Living Building Projects, the embodied energy side has been less pursued. This thesis aims to focus on the aspects that impact and reduce the embodied energy side of the sustainability equation.

### 4. BUILDING LIFE CYCLE

Every building has a life cycle, from conception to demolition and beyond. Understanding this cycle has important consequences for the sustainability of the building and the process as a whole. Each stage in the cycle requires energy and as so, also represents a potential opportunity to reduce the energy consumed by the building.

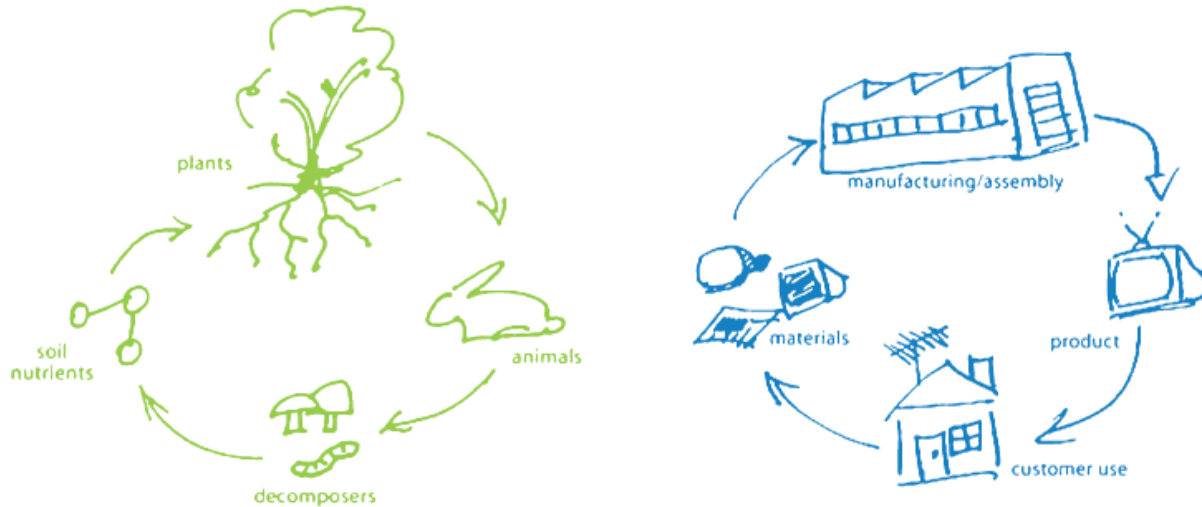


Fig. 4-2 Cradle-to-Cradle Biological and Technical Nutrient Cycles  
Source: McDonough Braungart Design Chemistry (MBDC)

## WASTE

In 2012, construction and demolition debris, i.e. concrete, asphalt, gypsum, roofing, lumber, metals, plastics, pipe, cardboard, carpet, etc. from the construction, renovation, repair and demolition of houses, large buildings and infrastructure including roads, bridges, piers, and dams accounted for 35% of the total waste generated in Washington State.<sup>7</sup> The reduction, reuse and elimination of this waste is of massive importance in reducing the harmful effects of the built environment on the overall health of the planet.

## CRADLE-TO-CRADLE

The best way to deal with waste is to prevent it. William McDonough and Michael Braungart's seminal book, *Cradle to Cradle: Remaking the Way We Make Things*, argues for a production cycle that does not include the concept of waste. Two metabolisms or nutrient cycles, the biological and the technical are introduced as vital to the no waste process. Historically, only the biological nutrient cycle existed with everything produced by

nature consumed and recycled by nature. In the biological nutrient cycle everything is essentially composted and available as micro-nutrients for the cycle to reboot. Examples of products in the biological nutrient cycle include natural textiles such as cotton or wool, plant based packaging, and wood products.

Human activity, especially after the advent of the Industrial Revolution, created the need for the technical nutrient cycle. The technical nutrient cycle like the biological nutrient cycle is a closed loop, designed to keep the products made within it, stay in it. This is necessary in order to maintain the products maximum value instead of being forced to down cycle the product which reduces the value of the product with each change of the cycle and eventually becoming waste. Chemicals, metals, and polymers are all examples of technical nutrients.

Separation of biological and technical nutrients is essential to eliminating waste as the mixing of the two will lead to a product neither compostable nor recyclable. It is however, possible and often desirable, to use both biological and technical materials in the same product. If the design allows for the after life processing to separate the different nutrients, each can retain its full value. A construction example could be the use of a

<sup>7</sup> Department of Ecology Washington State. State Solid & Hazardous Waste Plan: Progress Report - Construction and Demolition Debris. 2013.

mechanical connection in place of an adhesive. By choosing a bolt or screw assembly instead of glue and allowing the connection to be accessible after completion, two other benefits occur: one in making the members more easily replaceable for maintenance and two, making it easier for the whole system to be disassembled and reused in an alternative location.

If waste cannot be prevented it becomes an endless energy sink. Not only does the waste have to be transported somewhere, consuming more energy but it also has to be stored or incinerated. Incineration consumes yet again, more energy, and releases harmful toxins. If it is not incinerated then it must be stored, requiring massive landfills unfit for other uses long after reaching capacity, entrusting the self-depleting process is doomed to repeat itself.

## SUSTAINABLE DEVELOPMENT

Sustainable Development looks for integrative solutions to offset, rework, and eliminate the negative consequence caused by human development on the natural environment and is often referred to as consisting of three main points:

1. Integrated cycle management: the closing of the material cycle from raw material to waste material and emissions.
2. Reducing energy consumption and the use of sustainable natural energy sources.
3. Quality improvement: Raising the quality of the products, the fabrication process, minimizing waste production and negative impacts on environment all aiming for a longer use of our available natural resources.<sup>8</sup>

This thesis proposes that all three of these sustainable development principles can be accomplished through the use of mass timber construction in conjunction with sustainable forestry

practices and the incorporation of design principles common amongst buildings with long service lives.

Much of the work in the pursuit of sustainability in architecture has focused on the occupancy stage of a building's life cycle, as it accounts for the largest portion of the total energy used throughout the life of the building. It is however, closely tied to the users and therefore, is highly volatile. This thesis looks at additional opportunities available in the other building life cycle stages by proposing:

1. Decreasing the energy consumed in the resources extraction, manufacturing & processing, transport, and construction stages through the use of mass timber in conjunction with sustainable forestry practices local to where these products are extracted and manufactured.
2. Mass timber is highly recyclable and can be reused after disassembly, further reducing its impact. In addition, wood has a much lower embodied energy when compared to steel or concrete.
3. Increasing the overall service life of a building through the integration of design decisions consistent amongst buildings with historically long service lives. The increase in service life, reduces the energy consumed during demolition, construction, and the harmful material extraction process when building turnover is decreased.

## 5. BUILDING DEMOLITION SURVEY

### TOP REASONS FOR DEMOLITION

Understanding why buildings are demolished is integral to developing design principles for maximizing the service life of a building. One of the most prominent studies on the subject of demolition was carried out by the Athena Sustainable Materials Institute titled "Minnesota Demolition Survey" and published in 2004. The survey included 227 commercial and residential properties demolished between 2000–2003 and collected data on the

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<sup>8</sup> Blok, R, F.V. Herwijnen, A Kozlowski, and S Wołinski. Service Life and Life Cycles of Building Structures.

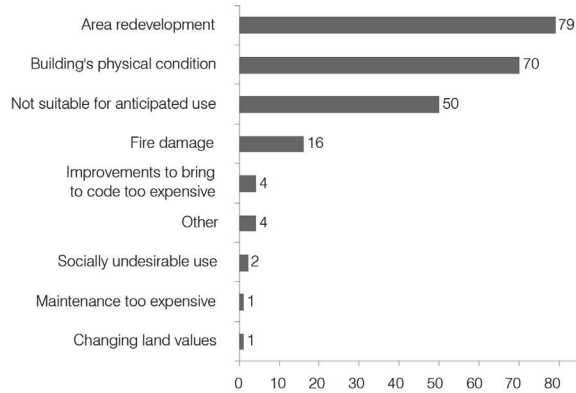


Fig. 5-1 Number of Demolished Buildings by Reason for Demolition

Source: Athena Institute, Minnesota Demolition Survey.

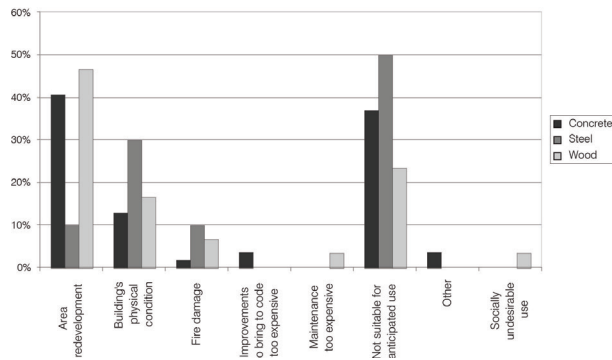


Fig. 5-2 Comparison of Percentage of Demolished Commercial Buildings by Structural Material Related to Reason for Demolition

Source: Athena Institute, Minnesota Demolition Survey.

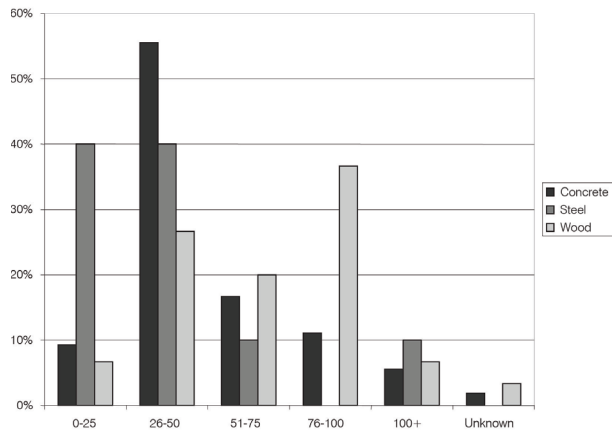


Fig. 5-3 Comparison of Percentage of Demolished Commercial Buildings in Each Age Group by Structural Material

Source: Athena Institute, Minnesota Demolition Survey.

age of the building, the main structural material and reason for demolition.

The four biggest reasons cited for demolition included “Area Redevelopment” (35%), “Building’s Physical Condition” (31%), “Not Suitable for Anticipated Use” (22%), and “Fire Damage” (7%).<sup>9</sup>

Of the four reasons, “Area Redevelopment” and “Not Suitable for Anticipated Use” are the most likely categories where early design decisions could make a positive influence on the longterm service life of the building. By prioritizing flexibility in the design, it is inferred the building would be more likely to be remodeled and reused if the structure and other design elements were not constraining to programmatic uses beyond the original intent. “Building’s Physical Condition” as a reason for demolition was largely due to a lack of maintenance with 54 of the 70 buildings citing it as the main contributing factor.

Only eight cases specifically stated a problem with the structure or other material systems failing.<sup>10</sup> Of the eight, all had foundational problems in addition to other concerns, giving little reason to believe structural material choice is a major contributing factor to the demolition of buildings under the “physical condition” category. It also flies contrary to a common held idea that wood structural systems are less durable than steel or concrete systems. In fact, wood buildings accounted for two-thirds of the buildings surveyed with 85% in the 51 years and over category, 47% of which were in the 76-100 year category and 18% in the more than 100 year old category.<sup>11</sup>

On the other side, 63% of the concrete buildings and 80% of the steel buildings were in the 50

9 Athena Sustainable Materials Institute, Minnesota Demolition Survey. 2004.

10 Ibid.

11 Ibid.

years and under category and “totally dominated the ‘Area Redevelopment’ and ‘Not suitable for Anticipated Use’ categories.”<sup>12</sup>

This suggests steel and concrete buildings, despite their reputation as more durable than wood, are more likely to be demolished at a younger age. The reasons for their demolition seem to suggest their designs failed to accommodate programs beyond the first use. The failure of these buildings to accommodate use beyond 50 years is compounded by concrete having five times and steel twenty-four times as much embodied energy as wood.<sup>13</sup>

## EMBODIED ENERGY

Embodied energy is the amount of energy consumed by all of the preprocessing associated with the production of a material from extraction through manufacturing, transportation and final delivery of the product.<sup>14</sup> It is a “front-end” energy measurement, measuring the energy required to take a product from “cradle-to-gate” or from extraction to delivery for use on-site. It does not include the operational and disposal energy costs associated with the material as a life cycle assessment (LCA) would.<sup>15</sup> It is however, a very important measurement to use when making early material design decisions as it can contribute to a large total of the over all energy consumed in a building’s life.

More importantly perhaps, is the building’s ability to adapt and be flexible enough for future uses beyond its initial program/use. In the Athena Institutes’ Minnesota Demolition Survey, the researchers concluded durability is more than a

function of structural material. Urban and site planning, along with building construction and maintenance play a major role in a building’s longevity. The study takes the stance that more should be done to “develop building systems that are flexible and that can be readily deconstructed for reuse in different locations if future land use is in question for economic or other reasons.”<sup>16</sup>

## 6. RESEARCH AND THEORY

The development of building systems that are flexible and readily deconstructed for reuse is a common sentiment found in research on the topics of embodied energy, Life Cycle Assessment, and ecological design. This section will attempt to establish design principles for increasing a building’s service life by looking at past examples, and work on the subject.

In his book, *How Buildings Learn*, Stewart Brand explores what happens to buildings after they are built and the common connections that lead to some buildings lasting hundreds of years while others do not.

## SIX S’S SHEARING LAYERS OF CHANGE

Buildings are not homogeneous but rather a layered set of components and systems working in concert. As separate layers with different functions, they age and change at different rates. Brand identifies 6 such layers starting with the most permanent—Site, and working their way to least permanent—Stuff. Site is the “geographic setting”, or “legally defined lot, whose boundaries and context outlast generations of ephemeral buildings. Site is eternal”<sup>17</sup> Structure consists of the foundation and load-

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12 Athena Institute, Demolition Survey.

13 Van Der Ryn, Sim, and Stuart Cowen. *Ecological Design*. N.p.: Island Press, 2007.

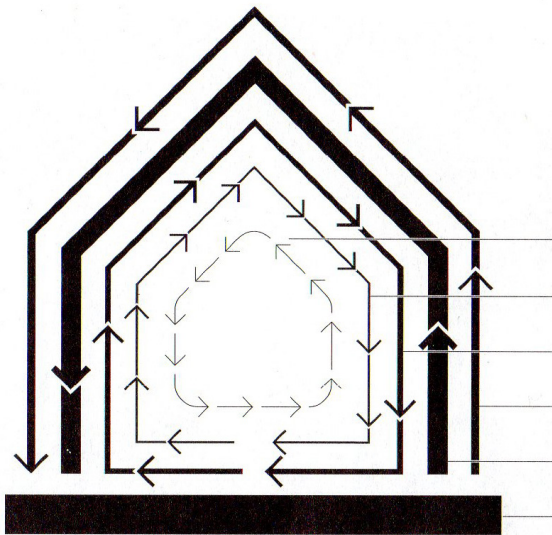
14 Milne, Geoff, and Chris Reardon. *Your Home: Australia’s Guide to Environmentally Sustainable Homes*. N.p.: Australian Government, 2013.

15 Ibid

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16 Athena Institute, Demolition Survey.

17 Brand, Stewart. *How Buildings Learn: What Happens After They’re Built*. N.p.: Penguin, 1994.



Stuff	Constantly
Space	3-30 yr
Services	7-15 yr
Skin	20-50 yr
Structure	30-300 yr
Site	"Site is eternal"

Fig. 6-1 Six S's Shearing Layers of Change  
 Source: Stewart Brand, *How Buildings Learn*

bearing elements. Brand calls the structure *the building* because it is "perilous and expensive to change, so people don't." It can last between 30 and 300 years. The Skin makes up the exterior surface and is "changed every 20 years or so to keep up with fashion or technology, or for wholesale repair." Services are the "working guts of a building: Communications wiring, electrical wiring, plumbing, sprinkler system, HVAC (heating, ventilating, and air conditioning), and moving parts like elevators and escalators." Their life span is usually between 7 and 15 years. Space plan is the interior layout of the building consisting of non-bearing, partition walls, ceilings, and floors. Commercial spaces can be changed as frequently as every three years while private homes may not be changed for 30. Stuff encompasses all the non-permanent elements found in a building, including: furniture, appliances, and electronics.

Acknowledging different parts of the building age at different rates, has important design consequences for a building keen on being as adaptable and maintainable as possible towards maximizing service life. Not only should the materials be durable but they should also be separated into their layers making them easily removed, repaired and replaced. Embedding any layer into another without designing

an access point hinders the ability of that layer to be maintained. Burying pipe and electrical wiring in walls is common but a pipe embedded in a concrete wall is very different, from an accessibility standpoint, to a pipe in a stud wall cavity. The pipe in the stud cavity can be more easily and cheaply accessed, repaired, or replaced. Perhaps even more importantly the stud cavity provides a space for additional pipes and systems compared to a solid concrete wall.

#### BUILDINGS THAT LAST

Buildings that are "easily loved" are buildings that come to last. Brand identifies two routes that a building can become "easily loved" and categorizes them as those on the "Low Road" or those on the "High Road."

#### The Low Road

Garages, warehouses, and "temporary" buildings epitomize the low road. They often feature open space plans that allow for a variety of different programs and uses. If it does not accommodate a use, the user is empowered to make the changes necessary, freed from the perception found in other buildings as being "too precious" to alter. It



ca. 1955 - Jules Barsotti's garage at 770 North Point in San Francisco had endearingly succinct ornament to go with its wide door and factory windows. Every building should feature its date of origin this way. A bas relief and spiffy roof trim is gravy.



1990 - A perfect general-purpose space, the old auto shop was an upscale retail outlet for Patagonia in the 1980s and 1990s, peddling high quality outdoor apparel.

May 1990. Brand.



1925 - It was no doubt sometimes too cold and sometimes too hot, but the big clear-span space of the garage had the early-20th-century daylighting that is more appreciated now that it is rare. The metal roof was cheap and effective and still sounds wonderful in the rain.



1993 - The 1924 Structure and Skin of the building was so simple and separated from everything else that it remains unchanged seventy years and many tenants later. With its abundant windows and airy steel truss overhead, it makes a cheery shop.

July 1993. Brand.

Fig. 6-2 The Low Road

Source: Stewart Brand, *How Buildings Learn*

is their personal connection, formed from a sense of ownership over the space, that allows people to easily love an otherwise unremarkable building. When freed from the sense of ruining the building by making a change, it is possible to quickly adapt the building to the users temporary needs. This process is relived over and over again, making the temporary, permanent.

### The High Road

Low road buildings are loved because of their quick adaptability and “can’t mess it up” charm. The high road exemplifies the opposite, it is the time and capital consuming “labor of love”. They are the biographical buildings, telling the story of the inhabitants who lived, worked or administered the building over the generations. These buildings are often expanded in good financial times and a burden in poor times. Sprawling private mansions,

religious, governmental, and institutional buildings make up the bulk of high road because they often require massive fortunes and time to build, expand and maintain. People come to love these buildings for varied reasons, some for their significance in comparison to the other buildings around them, while others seem to love them simply because of their expanded longevity. Their lasting power is made possible by the champions with the means and drive to maintain them long enough to be seen as “always having been there.” By lasting so long they become a part of living history which people value and maintain in its own right.

Fewer buildings can take the high road to longevity because of the massive resource and particular situations needed to do so. If buildings are to follow the high road then they need to have “structure built to last... and some areas of very high finish... particularly with the skin and at least



Boston Athenaeum. Neg. no. A.BAZ-18 | 1895 a.s.

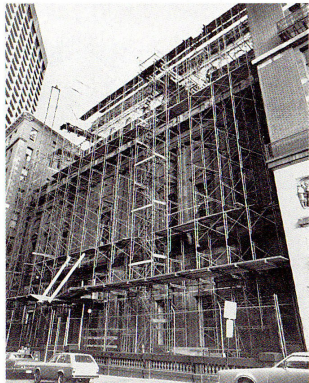
1895 - Already two renovations had reorganized the interior—the books invaded the top and bottom floors, and an extravagant staircase was removed to make room.



Boston Athenaeum. Neg. no. A.BAZ-18 | 1902.

1902 - With tall new buildings on each side, the north (street) side of the Athenaeum was declared too dark inside for reading, so the stacks were moved to that side, and reading rooms were developed on the south side, looking over the historic Granary burying ground.

1976 - A quiet facelift for the Brahmin of Beacon Street brightened the dark stone, but not too much, and repaired window and roof problems.



Boston Athenaeum. Neg. no. A.BAZ-160 | 1976.d.

1990 - The spots of light on the Athenaeum are sunlight reflected from the windows of surrounding skyscrapers. The last time I talked to the director of the Athenaeum, he said the trustees were trying to figure out where to expand the library next—perhaps out into the setback space in front of the top two floors.



20 November 1990. Brand.

1990 - Though from the street the Athenaeum still appears to be two stories high, a look down the stairwell reveals ten levels—including two basements and the mezzanine levels for stacks in the high-ceilinged main floors.



20 November 1990. Brand.

Fig. 6-3 The High Road

Source: Stewart Brand, *How Buildings Learn*

some interiors, to set a high standard for future work.”<sup>18</sup> These lessons along with lessons from the low road however are readily adaptable into new building designs.

#### ATTRIBUTES OF HISTORICALLY FLEXIBLE BUILDINGS

A building’s relationship to its users and the people in contact with it is a vital component to why some buildings have staying power while others do not. Looking to the past can also help shed some light on what design elements or attributes are common

in buildings with long service lives. McDonough and Braungart, in *Cradle-to-Cradle*, highlight the SoHo and TriBeCa neighborhoods of New York City as examples of areas that have thrived due to their building’s typologies. High ceilings, large, high windows, and thick thermal walls permeate the neighborhood. The same buildings have been used “as warehouses, showrooms, and workshops, then storage and distribution centers, then artists’ lofts and, more recently, offices, galleries, and apartments”.<sup>19</sup>

18 Brand, *How Buildings Learn*

19 McDonough, William, and Michael Braungart. *Cradle to Cradle: Remaking the Way We Make Things*. N.p.: North Point Press, 2002.



Fig. 6-4 TriBeCa Neighborhood Loft  
Source: ODA Architects



Fig. 6-5 Typical TriBeCa Neighborhood Block  
Source: The Square Foot

The tall ceilings, combined with the large, high windows allow natural daylight to penetrate deep into the space while providing ample flexible space for storage, a mezzanine level, or mechanical systems. The thick thermal walls provide not only a durable structural system but also help cool the building during the warm days and release heat during the cool nights.

Geometry and space planning play an important role in dictating a building's ability to easily adapt to new uses. Brand, in *How Buildings Learn* advocates for square or rectangular plans as a starting point because of the geometry's ability to grow or subdivide with ease. "If you start boxy and simple,

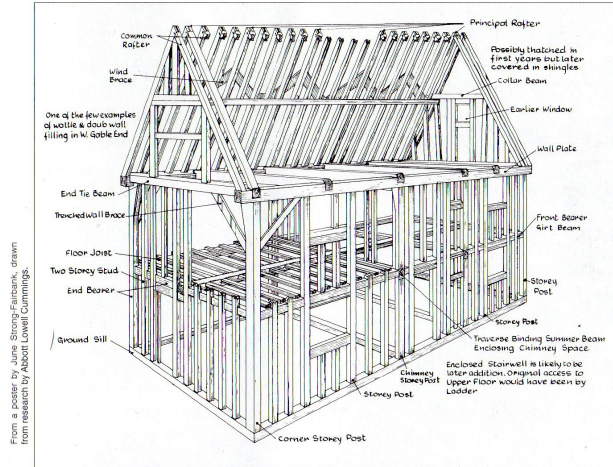


Fig. 6-6 Timber-Frame construction, well known for its longevity, is the predecessor to and is closely related to mass timber construction. Timber-frame construction uses solid timber and wood-to-wood joinery in place of mass timber's engineered wood products and mechanical fasteners. Above is the timber-frame skeleton of the oldest wood-frame building in America, the Fairbanks House of Dedham, Massachusetts built in 1636.

Source: Stewart Brand, *How Buildings Learn*

outside and in, then you can let complications develop with time, responsive to use.”<sup>20</sup>

Anna Vernez Moudon's *Built for Change* highlights San Francisco's Victorian row houses with their six foot wide halls running the entire length of the rectangular floor plan and acting as a “support core” providing services beyond circulation. The generous hall's width allows daylight deeper into the other spaces and even provides enough room to subdivide into storage or bathrooms. This “relieves the rest of the box of clutter.”<sup>21</sup> The “Victorian Box” also features unspecialized rooms, each separately day-lit and ventilated with their own operable windows, access to the corridor and the capability to open to adjoining rooms.

“A return to the room-as-module for residential design is a necessary step toward creating resilient

20 Brand, *How Buildings Learn*

21 Vernez Moudon, Anna. *Built for Change*. N.p.: MIT, 1986.

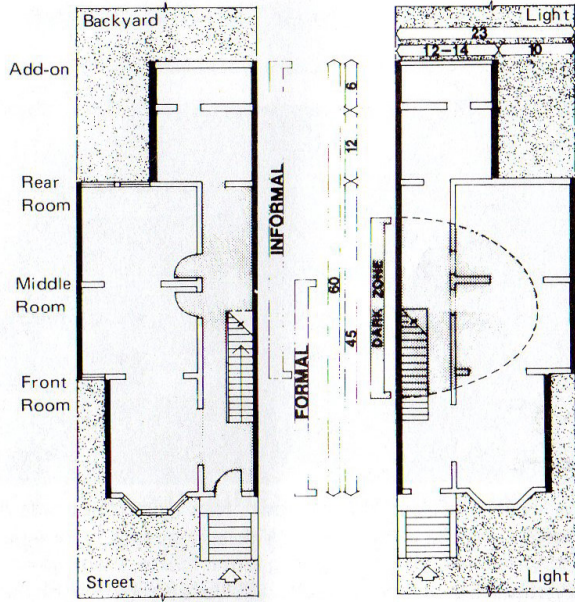
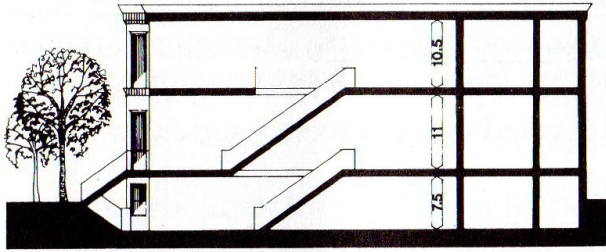


Fig. 6-7 Victorian Box, the near universal space plan behind San Francisco's varied row house facades, features a wide hallway to one side that acts as a "support core" for the other autonomous rooms making it easy to adapt.

Source: Stewart Brand, *How Buildings Learn* & Anne Vernez Moudon, *Built to Last*

space. We must abandon the use of dwellings as modules of spatial organization."<sup>22</sup> Brand and Moudon argue when a dwelling-as-module is used as the basic design element, rooms become too specialized, restricting the reorganization of and re-specialization of space by a future inhabitant. This is compared to an autonomous room layout, where each room is specialized by the user themselves as the need arises.

These simple design features allowed a singular building typology to flourish over multiple generations of users by providing a basic structure and floor

plan from which to adapt and make unique. While facades change, and single family homes become split into two or three different apartments and then back again, it is the simplicity of the space plan with its "support core" and autonomous rooms, individually day-lit with operable windows that make it possible for these buildings to become easily adaptable and loved.

#### IFD BUILDING

Industrial, Flexible, and Demountable Building is an engineering approach to increasing a building's potential service life. Covered in the *Service Life and Life Cycle of Building Structures*, it advocates for increasing efficiencies in the building's process in order to decrease the waste and ecological degradation caused by the construction process.

Industrial is used synonymously with prefabricated, meaning the preference is to "preform in the factory what was originally done on the building site" in an effort to make the process more efficient by controlling for more variables.<sup>23</sup> Examples of industrial building components include prestressed floor plates, Structurally Insulated Panels (SIPs), and unitized curtain walls.

Flexibility is defined as "the quality of a building or building component which allows adjustments according to the demands and wishes of the users."<sup>24</sup> In the design stage, flexibility means "variability in the composition and the use of material" while in the user or occupancy stage flexibility relates to the user's ability "to adjust the composition and the applied building components to the changing demands and/or wishes of the same or varying users while in use."<sup>25</sup> In other words, can the structure and layout provide for

22 Vernez Moudon, *Built for Change*.

23 Blok, R, F.V. Herwijnen, A Kozlowski, and S Wo-linski. *Service Life and Life Cycles of Building Structures*.

24 Millard, W.R., and M.J. Robinson. *The Life of Structures*. N.p.: Elsevier, 1989

25 Blok, *Service Life and Life Cycles of Building Structures*.



*Fig. 7-1 Bellingham Bay to Mount Baker*  
 Source: City of Bellingham

added working loads as use changes? Can it accommodate additional stairwells, elevator shafts or pipes? Perhaps another floor or mezzanine level is required. Does the structure allow for such drastic changes or additions? A truly flexible building structure would be able to answer “yes” to these questions.

Demountable allows for the building components to be removed, re-used, or recycled without being soiled by other materials or damaging the surrounding components upon removal/exchange.<sup>26</sup> The same assembly methods that help make the components flexible, help make them demountable. Combining this knowledge with Brand’s six shearing layers makes it possible to design connections and componentry not in conflict with differing maintenance schedules or creating accessibility issues that hinder the user’s ability to modify or adapt the space.

All of these principles are designed to remove the barriers that make it harder for a user to make changes to a building. By removing these barriers it decreases the building’s odds of becoming obsolete and demolished. It also provides the opportunity for the user to bond with the building during the process by making the space their own.



*Fig. 7-2 Waterfront Demolition*  
 Source: Bellingham Business Journal

It is perhaps this bond, more than anything else, that is most influential in increasing the lifespan of the building, and in doing so, preventing the unnecessary and harmful waste of resources.

## 7. SITE

Bellingham, Washington is the chosen site for the implementation of a design proposal that builds off of the preceding research and theories coalescing in a mixed-use, mass timber, structure and core framework. The site offers a unique, “blank slate”, urban setting in a growing small city with a local timber industry. The location is a prime opportunity for realizing the maximum environmental benefits resulting from designing for an increased building’s service life and mass timber construction over an entire district.

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26 Millard, *The Life of Structures*.



Fig. 7-3 237 Acre Waterfront Redevelopment Site. Bellingham, WA  
Source: Base Image, Google Earth





Fig. 7-4 Downtown Waterfront District  
 Source: Base Photo, Port of Bellingham

## AREA

Bellingham, WA is located in the Pacific Northwest region of the United States 17 miles south of the Canadian border with easy access to the metropolitan areas of Vancouver, B.C. and Seattle, WA. As of April 1, 2017, the Washington State Office of Financial management estimated a growing population of 86,720 residence.

## HISTORY

Over the last century, Bellingham's waterfront has served as a vital cog in the economic growth of the city and has a major influence on its identity as a whole. The waterfront has served as both gateway and industrial center. Maritime activities have always centered around the area and in

1891, the Great Northern Railroad reached the area, connecting the waterfront overland through the nationwide rail network.<sup>27</sup>

In 1926, the first pulp mill was opened on the site south of Whatcom Waterway creating a new opportunity for the area's rich timber resources.<sup>28</sup> Other pulp mills followed expanding the area and providing major employment for the city. In the 1960's Georgia-Pacific acquired the waterfront mill site and continued to operate the site until 2001 when it closed the pulp operation, eventually closing the entire facility in 2007.<sup>29</sup>

27 Port of Bellingham/City of Bellingham. The Waterfront District Sub-Area Plan. 2013.

28 Ibid.

29 Ibid.

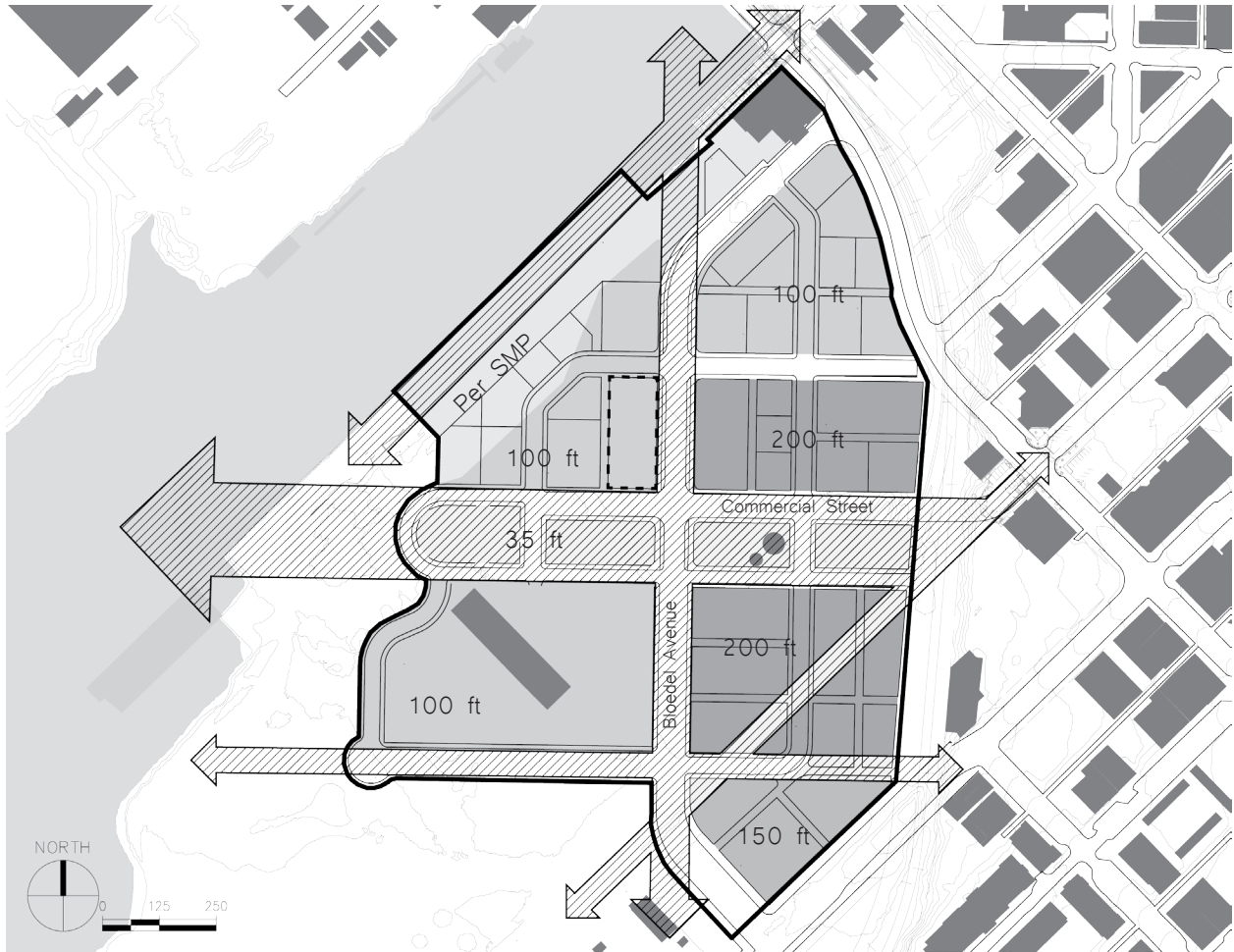


Fig. 7-5 Downtown Waterfront District Zoning Height Limits and View Corridors  
 Source: Waterfront District Development Regulations (2013)

## PLANNING

In 2005, the Port of Bellingham began to acquire the now 237 acre Waterfront District including the Georgia-Pacific Pulp Mill site. As part of the agreement, the Port agreed to pay for the extensive environmental cleanup necessary to restore the area from decades of industrial use, securing state and federal grants to help with the cleanup, habitat restoration and infrastructure design.<sup>30</sup> The city of Bellingham also agreed to provide utilities to the site, build new streets, waterfront parks, trails and provide the regulatory standards required to attract private development on the site.<sup>31</sup>

30 Port of Bellingham, Waterfront District

31 Ibid.

Extensive public involvement has been a key part of the entire conversion from private to public ownership and investment on the site. The Waterfront Advisory Group (WAG) was a citizen-led task force charged with holding public hearings, creating awareness and participating in the planning process itself. The process led to a framework developed into a master plan for the waterfront establishing view corridors and vistas, preferred land uses, buildings heights and design standards.<sup>32</sup>

## CURRENT CONDITIONS

The Waterfront District is bordered by the Columbia and Lettered Streets neighborhoods to the north,

32 Port of Bellingham, Waterfront District

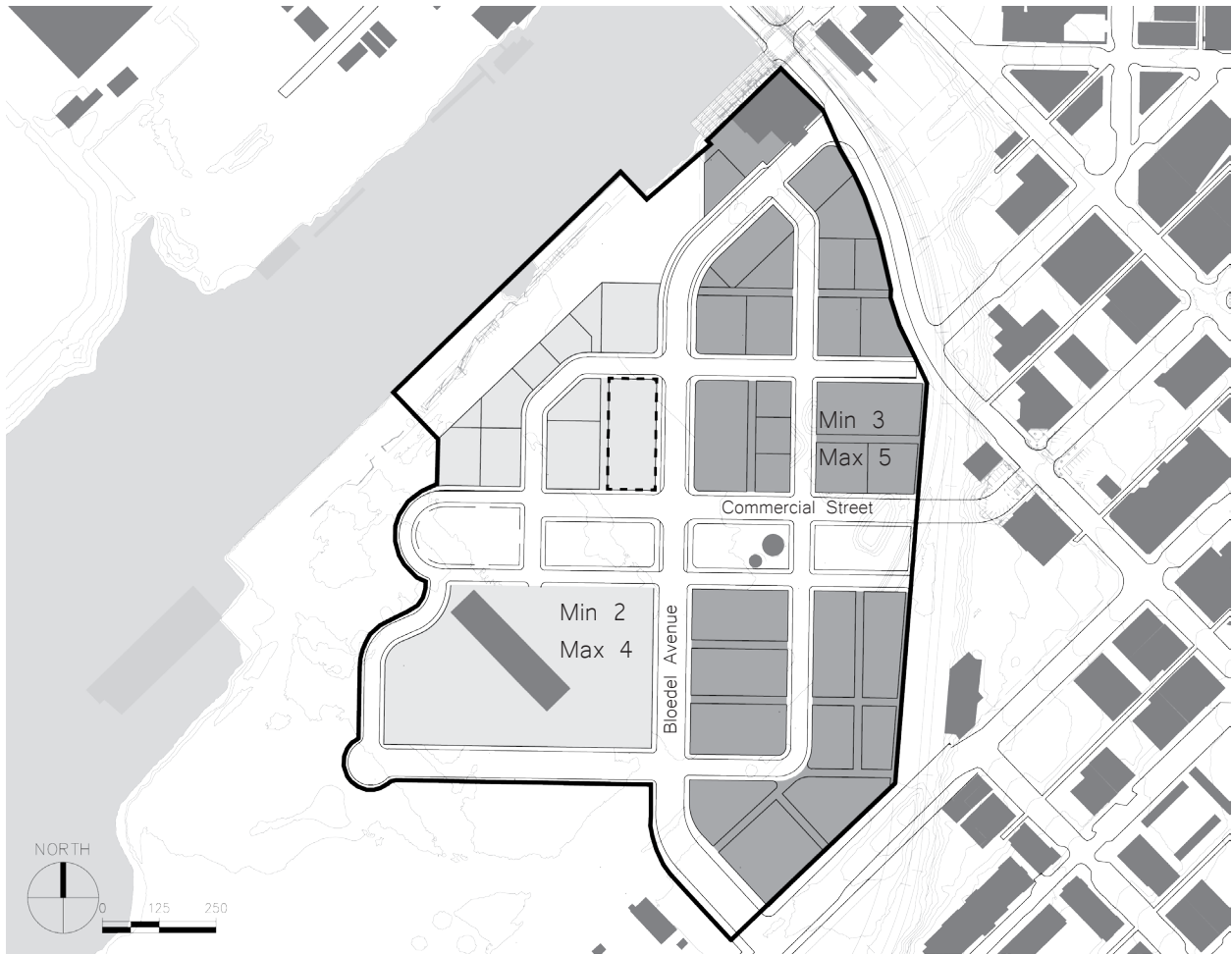


Fig. 7-6 Downtown Waterfront District Floor Area Ratio (FAR) Zoning  
 Source: Waterfront District Development Regulations (2013)

the Central Business District (CBD) and Old Town to the east, Sehome and South Hill to the south and Bellingham Bay to the west. Density in the Waterfront District is low with no residential population.<sup>33</sup> The site is occupied by a few remaining former industrial structures identified as possible adaptive-reuse projects including the Granary Building which is currently undergoing the transition from its agricultural roots to a mixed-use building providing retail and office space, as well as public access to the waterfront.<sup>34</sup> Over all, public access to the site is currently limited to a few dead-end streets with the only recreational area a

small pocket park. The shorelines are primarily hard wall industrial wharfs restricting water access and hindering marine habitat.

#### REDEVELOPMENT POTENTIAL

Potential for the district is immense and far reaching. The vision formed during the public design process seeks to turn the Waterfront District into a multifaceted district complete with a vibrant mixed-use extension of the Central Business District in the upland area, marine and light industry in the outlying areas and restored public access through recreational opportunities along the shoreline.<sup>35</sup> The Four Guiding Principles identified by the Waterfront

33 Port of Bellingham, Waterfront District

34 WOHLFEIL, SAMANTHA. "Construction on Bellingham Waterfront Granary Expected by Summer." The Bellingham Herald, April 30, 2016.

35 Port of Bellingham, Waterfront District

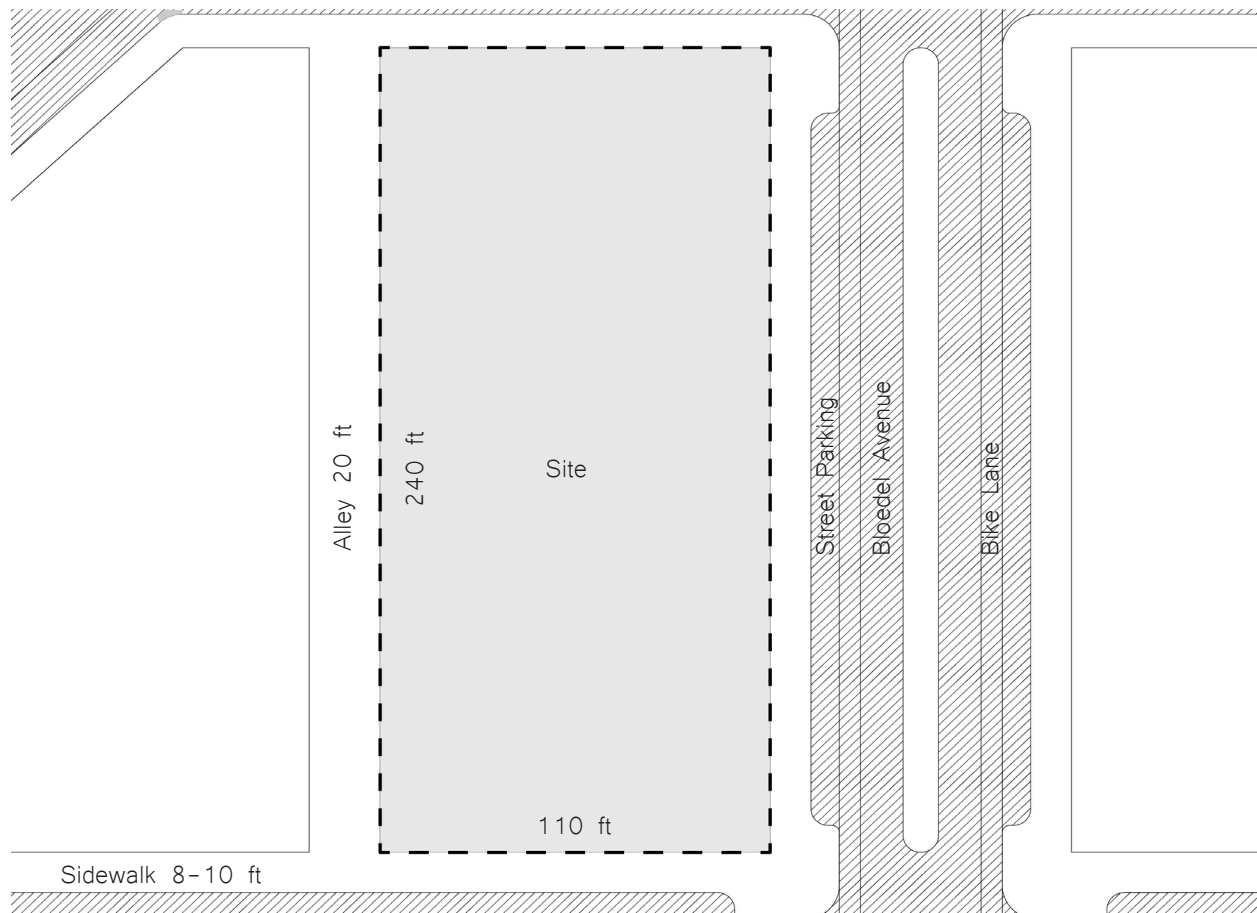


Fig. 7-7 Site Plan

Source: *Waterfront District Development Regulations (2013)*

Futures Group include:

1. Reinforce the Inherent qualities of Each Place on the Waterfront.
2. Restore the Health of the Land & Water.
3. Improve Waterfront Access.
4. Promote a Healthy and Dynamic Waterfront Economy.<sup>36</sup>

The Waterfront District is also set to handle a major portion of the expected population growth as part of the city's urban infill strategy. "The 2006 Bellingham Comprehensive Plan projects a demand for 1,225 infill housing unites in the Central Waterfront District Urban Center, and an additional 1,321 units in the Downtown Core Urban Center by the year 2025."<sup>37</sup>

36 Port of Bellingham, Waterfront District

37 Ibid.

To meet these demands, an increase in urban density is required in these areas with much of the new growth to occur in the now largely vacant Waterfront District. The 237 acre Waterfront District was subdivided to help meet the different demands outlined in the visioning process. The 37 acre Downtown Waterfront District closest to the Central Business District has been identified as the commercial and residential mixed-use area. As so, it is also the area with the highest zoned density with a Floor Area Ratio (FAR) ranging from a minimum of 2 to a maximum of 5.<sup>38</sup>

The redevelopment of this 37 acre mixed-use district makes it a prime location for the application of the findings from this thesis. The design proposal is a sustainable, mass timber, mid-rise, structural

38 Port of Bellingham, Waterfront District

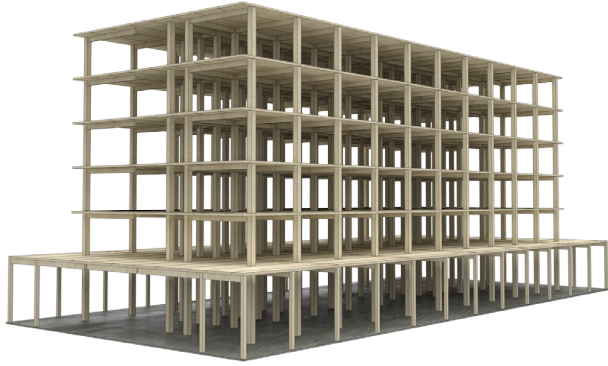


Fig. 7-8 Massing, six story mixed-use building with street edge podium and stepped back tower.

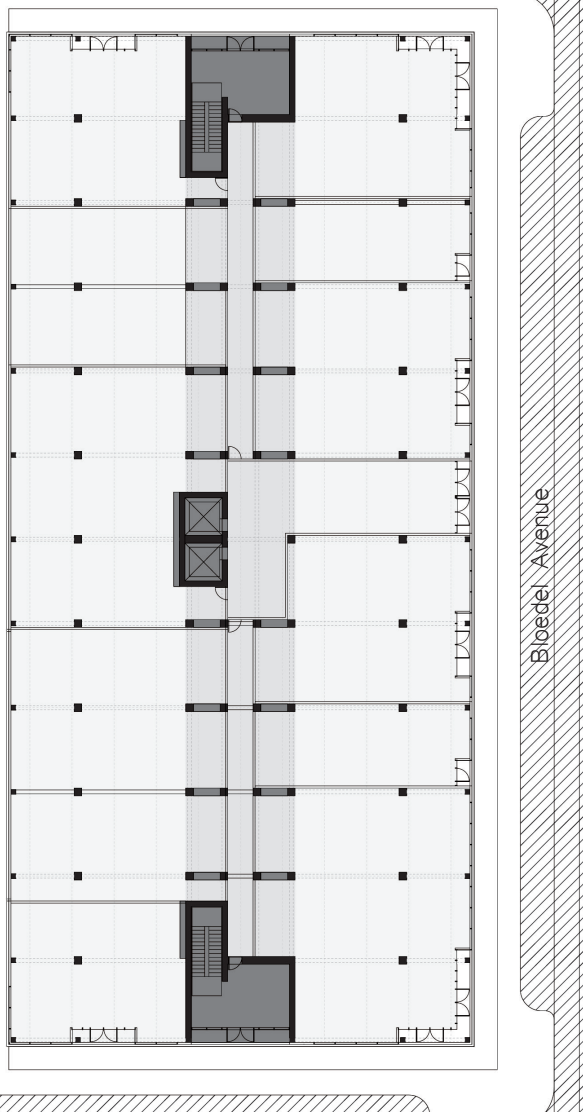


Fig. 7-9 Example of a podium layout using the structural grid as a guide to partition storefront and back-of-house spaces in a variety of sizes and shapes.

system and service distribution plan flexible enough to accommodate the very different programming requirements of residential and office space. The intent is that by creating one structure and core system able to accommodate both extremes, it would be inherently flexible enough to handle other programmatic changes and thus increase the potential overall service life of the building. The proposed system is offered as a framework to be modified and changed for each iteration and individual site but, with the idea that the potential environmental savings could be spread across the whole district and form a new baseline for urban development replacing steel and concrete as the main structural systems.

#### SITE & MASSING

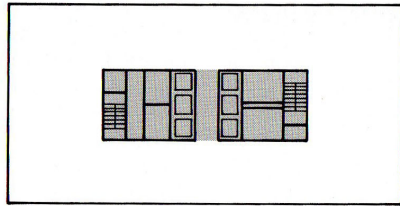
Proposed is a six story, 110,000sqft mixed-use building. A 22ft tall street edge podium located on the primary corner of Commercial Street and Bloedel Avenue responds to the 2013 Waterfront District Master Plan's requirements for pedestrian-oriented development at street level with ground floors able to accommodate "commercial, retail, service or public facility use."<sup>39</sup> At just under 100ft tall the proposal comes in under the zoning height restrictions but also means to push the current IBC restrictions on type IV Construction (Heavy Timber) that limits sprinklered residential buildings to 85ft. The taller height is proposed to maximize daylighting potential along with providing ample room for service distribution.<sup>40</sup>

The site represents the larger end of the parcel sizes in the Downtown Waterfront District where building blocks are not to exceed 240ft in order to provide pedestrians access and scale.<sup>41</sup> The proposed corner site is 110ft by 240ft with a 20ft wide alley to the west. Stepping back

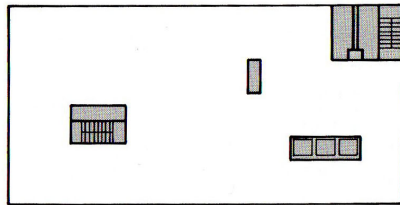
39 Port of Bellingham, Waterfront District

40 International Code Council. "2015 International Building Code."

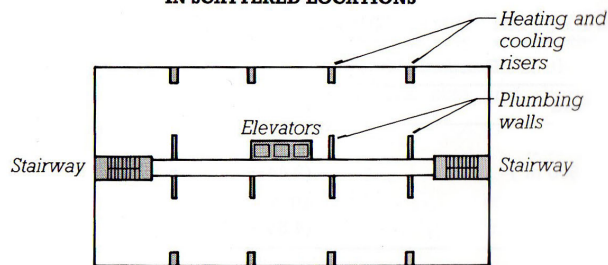
41 Port of Bellingham, Waterfront District



**HIGH-RISE OFFICE BUILDING: VERTICAL SERVICES IN A CONCENTRATED CORE**



**LOW-RISE BUILDING: VERTICAL SERVICES IN SCATTERED LOCATIONS**



**HOTEL OR APARTMENT BUILDING: VERTICAL SERVICES BETWEEN UNITS**

Fig. 8-1 Typical Building Core Configurations  
Source: Edward Allen, Joseph Iano, *The Architects's Studio Companion*

the tower from the podium helps maintain view corridors running the lengths of Bloedel Avenue and Commercial Street while also adhering to the desired pedestrian scale and providing a comfortable buffer between neighboring buildings.

## 8. FINDINGS

### BUILDING CORE & VERTICAL SERVICE DISTRIBUTION

Providing a space plan flexible enough for modifications by its users is key to a building's survival through different program demands as exemplified by the Victorian box's "support core." In order to achieve the desired flexibility on a

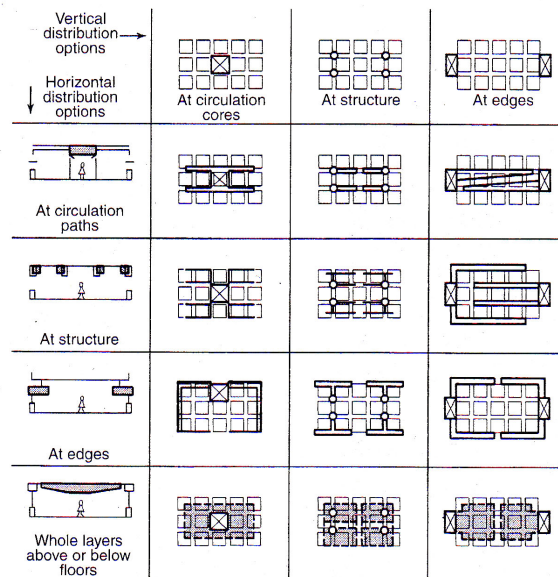


Fig. 8-2 Typical Horizontal Services Configurations  
Source: Grondzik, Kwok, Stein, Reynolds, *Mechanical and Electrical Equipment for Buildings*. Developed by G.Z. Brown, University of Oregon

larger building scale, modifications have to be made to the typical apartment or high-rise office core layouts.

A concentrated central service core, found in many office and high-rise buildings, meets the desired open, flexible, day-lit perimeter space, but provides for an inefficient layout when subdivided into residential units, particularly in terms of circulation.

Vertical services in a scattered pattern, often found in low-rise buildings, can also provide the desired open, day-lit perimeter but can cause major issues when trying to reprogram the space. A scattered pattern of vertical chases leads to an even greater inefficiency of space when subdivided into a residential layout. Having large vertical chases including stairwells, elevator shafts and plumbing walls scattered throughout the structural grid overspecializes the layout and is a more intensive process to alter, leaving little flexibility to change under the scope of a tenet improvement.

A common apartment or hotel core configuration, based on a double loaded corridor, provides the

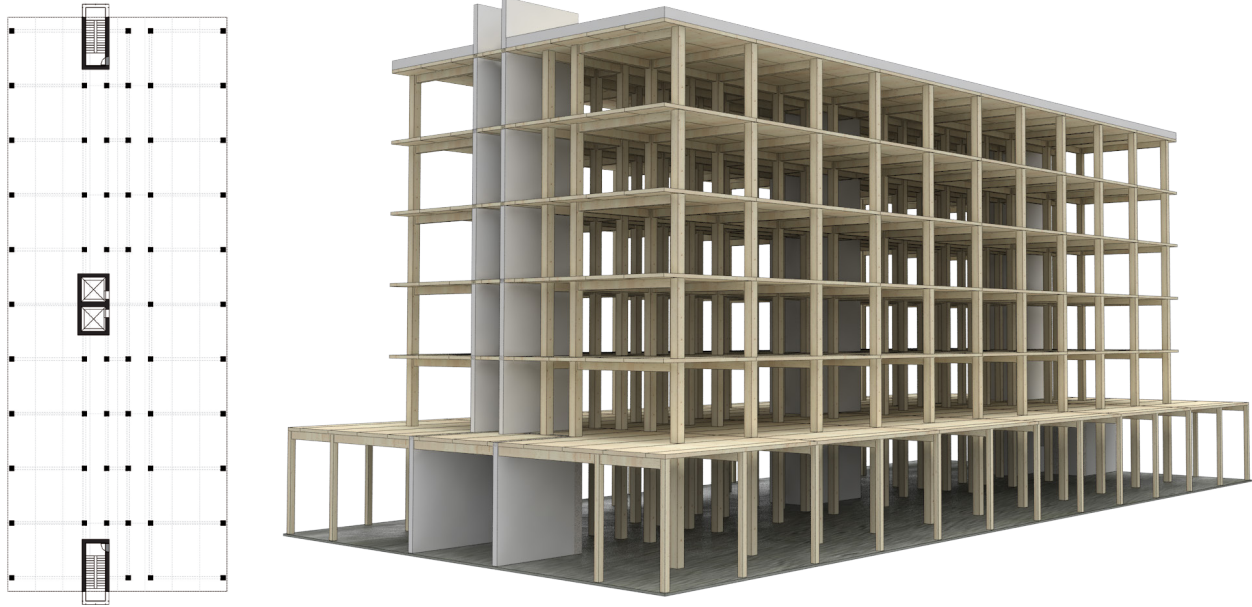


Fig. 8-3 Structural Layout – Mass Timber Column Grid System provides the maximum in space planning flexibility. The example shows Glulam columns and beams with a concrete foundation and CLT floor plates.

most efficient starting point for a structural and service layout, capable of providing efficient space plans for both residential and office settings. The limiting factor is the smaller subdivided units in a residential space plan. By starting with the most efficient layout for a residential space plan, it is easy to remove or reconfigure the non-load bearing partition walls into a space capable of being used for office or some other program/use that requires larger, open spaces including education, storage, artist lofts, manufacturing, etc.

To accommodate the flexibility that non-bearing, partition walls provide, a column and beam system is adopted as preferred structural method for arranging the building. The column and beam system also provides guides for the interior wall partitions, and a logical location for vertical service distribution chases such as stacked plumbing walls, air ventilation ducts, and electrical wiring.

Inexpensive, quickly built, army barracks constructed for World War II, demonstrate the effectiveness of this concept. Their simple, open structural grid plan, has proven an adaptable structural system utilized by the National Park Service and other government

institutions providing different permutations of office configurations after fulfilling their original duty of housing soldiers.<sup>42</sup> Adapting these simple lessons is crucial to increasing the flexibility of a building and maximizing its service life.

#### HORIZONTAL SERVICE DISTRIBUTION

Using the structural members as a guide for the subdivision of space and the placement of vertical services around the grid also works in the horizontal distribution of services. However, increasing the flexibility beyond that of the vertical distribution is vital to making the space as adaptable and autonomous to the user as possible. Making the overall floor layout autonomous means the user is able to adapt the space with minimal effort. This can be achieved by providing ample space for the horizontal distribution of services to be added, rerouted or otherwise changed. For example, a structural grid that allows for a vertical stacked plumbing wall every 20 feet makes for a logical place to separate apartment units but

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42 Brand, *How Buildings Learn*

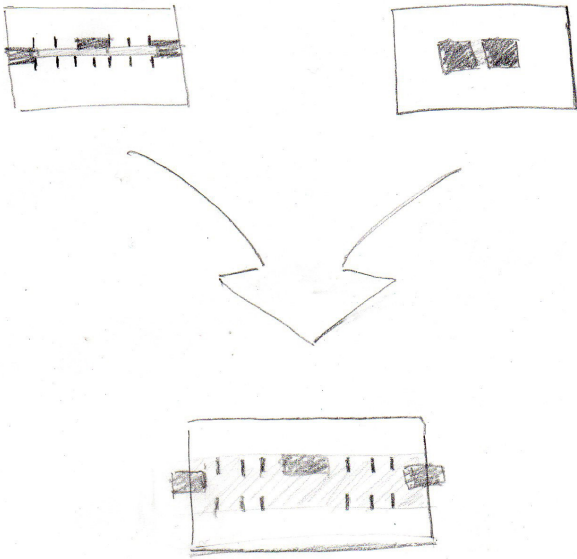


Fig. 8-4 Flex Core Diagram

electrical outlets must be available at a finer scale. To accommodate this, space must be provided to run the electrical wiring horizontally whether in the ceiling or floor. In order to provide concealment of the electrical conduit without the burying the wiring into a layer that changes at a different rate, it is preferable to provide room for drop ceilings and/or raised floors depending on the user requirements.

These void service spaces also provide opportunities to run air ventilation duct work and other services as required by code and changing user demands without conflict. The problem with devoting so much space to flexible horizontal distribution is the decreased height of the occupied space. To get around this problem and to increase available natural daylighting deeper into the space, taller than average floor-to-floor heights are required and exemplified by the TriBeCa and SoHo neighborhood building examples.

#### FLEX CORE

In the proposed layout, a “flex core” is introduced as a means of concentrating the largest elements of the vertical and horizontal distribution of services

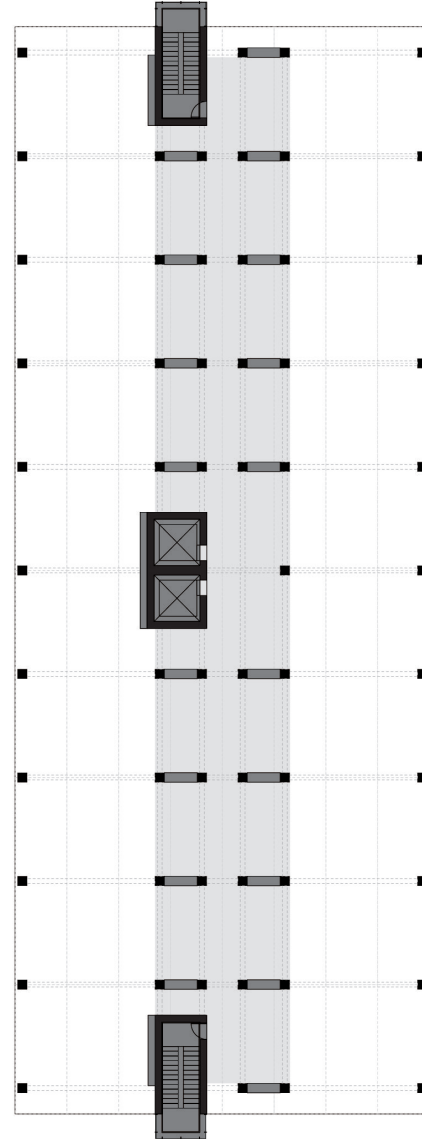


Fig. 8-5 The Flex Core, (highlighted in gray) is the densest part of the structural grid, intended to accommodate the majority of the vertical distribution of services, including circulation and more opaque programing such as bathrooms or storage.

and circulation in the center of the building as to not disrupt, natural daylighting, and views on the perimeter. Vertical chases run to the right and left of a central six foot wide corridor left for horizontal distribution and a hallway in a residential space plan, sandwiched between the column grid. The larger vertical chases for the elevator and stairs are placed to one side of the main 6 foot wide corridor to keep end views visible when used as a double

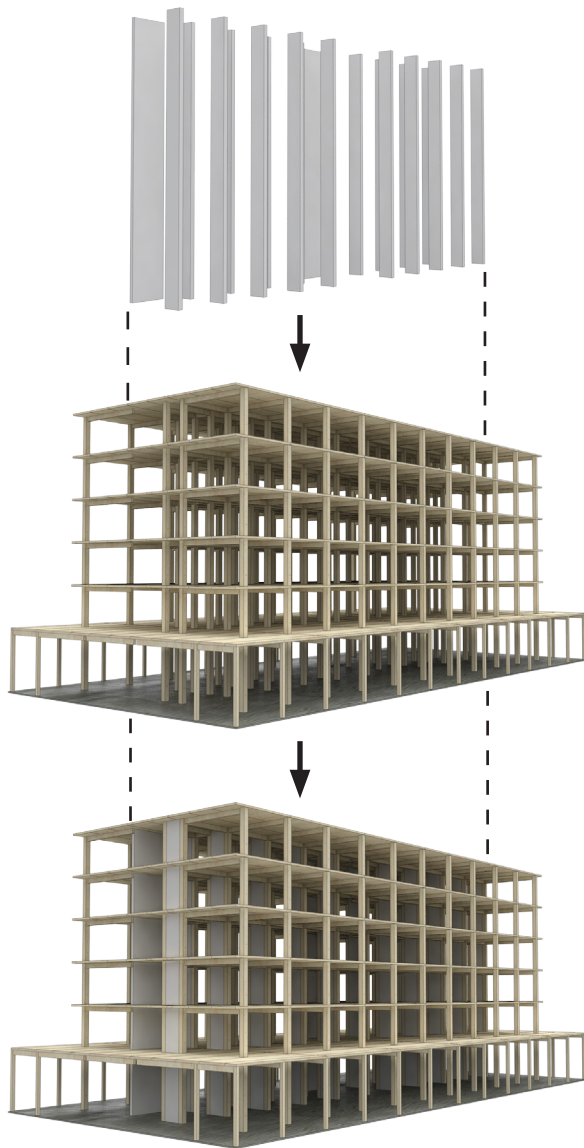


Fig. 8-6 Vertical Chase and Structural Integration

loaded corridor. Splitting the stairs and elevators aims to keep in compliance with safety egress needs as well as even distribution for users access and structural stability. The “flex core also provides an effective guide to fill-in with more opaque uses in an office layout such as storage, bathrooms, private conference rooms etc.

#### FLEXIBILITY IN A MASS TIMBER STRUCTURE

Glulam beams and columns provide the basic load bearing structural support along with cross

laminated timber (CLT) floor plates. The use of such materials have many sustainability benefits as mentioned but they also have very important implications in the adaptability and flexibility of the building itself. CLT is made by gluing dimensional 2x wood material together in alternating layers to form structural panels as large as 10ft by 40ft. The advantage to gluing the individual pieces together allows for smaller diameter trees to be productively harvested while the final 2-way structural panel is able to be precut and shaped in the factory, increasing accuracy and on-site assembly time by as much as 25% over other construction types for similar buildings.<sup>43</sup>

Being made of glued together wood elements also makes it possible to cut, attach, and otherwise modify the floor plates after construction in ways pre-cast concrete floors cannot be, especially, tensioned systems. It would be far more possible to remove or alter CLT floor slabs for a stairwell between adjoining floors or creating a double height space to accommodate user needs then it would be in a concrete building.

As a factory produced kit-of-parts assembled on-site, mass timber has the potential to be as easily disassembled as assembled. The ease at which the mass timber is disassembled is dependent on the connections and subsequent layering of other building components. If they do not inhibit their removal, the removal and replacing of individual pieces is less of a hindrance to repairing and/or changing the structure, making it far more resilient to all four of biggest reasons cited for demolition: area redevelopment, physical condition, not suitable for anticipated use, and fire damage. Making a structure and other building components as easily accessible, maintainable, and replaceable as possible increases the overall service life potential of the building.

43 reThink Wood. “Mass Timber in North America: Expanding the Possibilities of Wood Building Design.”



Fig. 8-7 Horizontal Distribution & Dedicated Systems. The example shows a radiant in-floor system providing thermal heating and cooling while operable windows and a under structure, low profile, duct system maintain a healthy air exchange. Electrical distribution follows the main vertical chases and additional partition walls or be distributed horizontally under the drop ceilings or conduit systems depending on aesthetic and/or programing choices of the user.

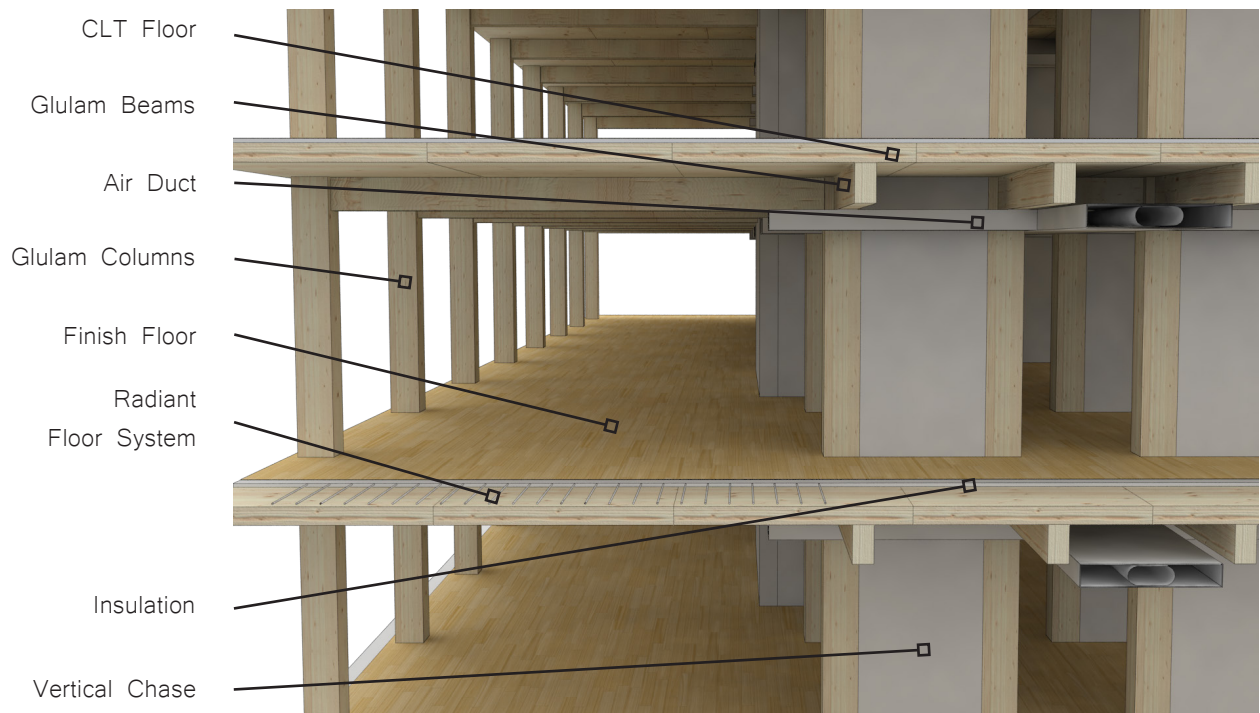


Fig. 8-8 Example of a horizontal system distribution section.

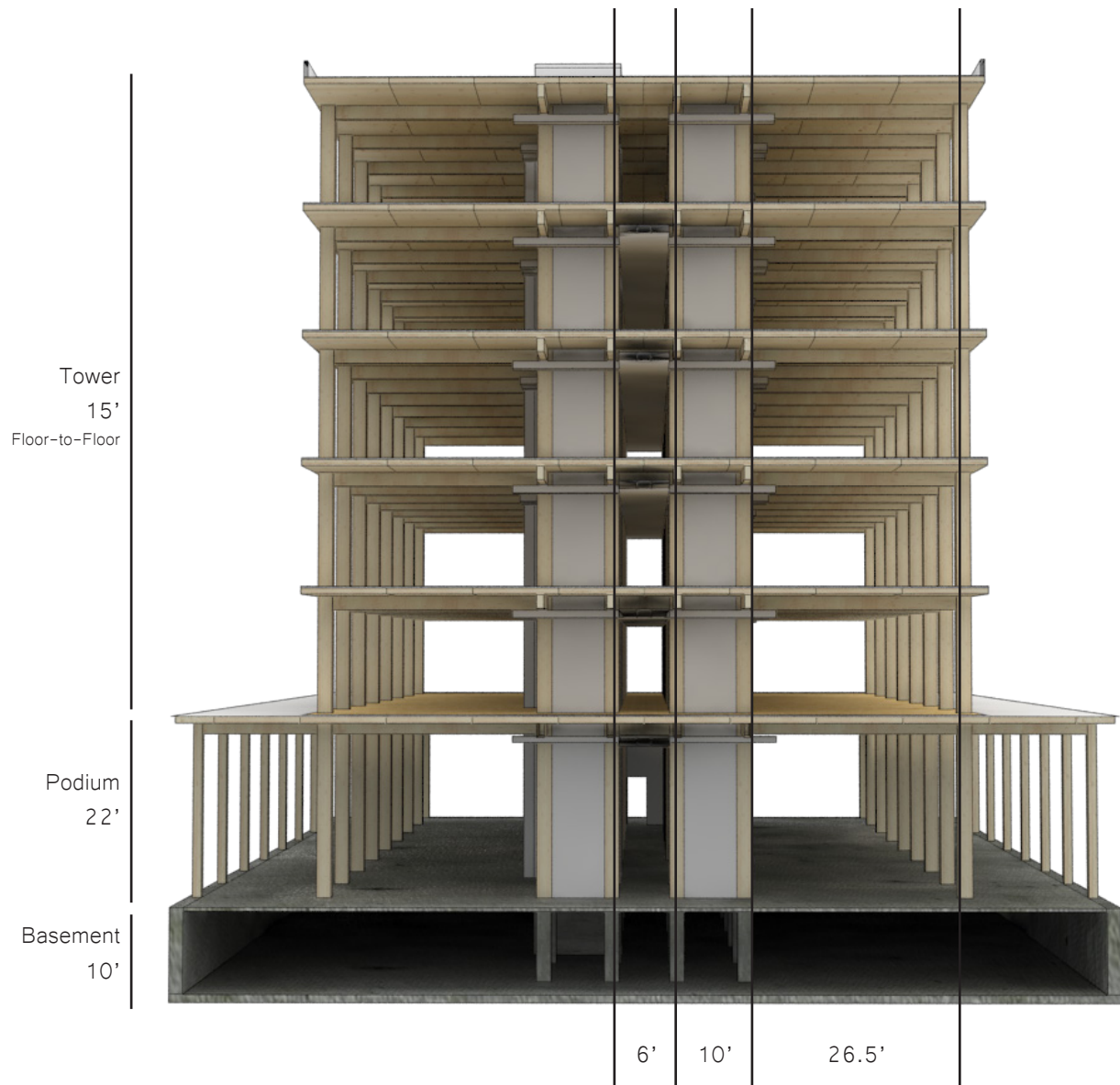


Fig. 8-9 Section

Taller than average Floor-to-Floor heights maximize natural daylighting and increase the flexibility for horizontal systems distribution.

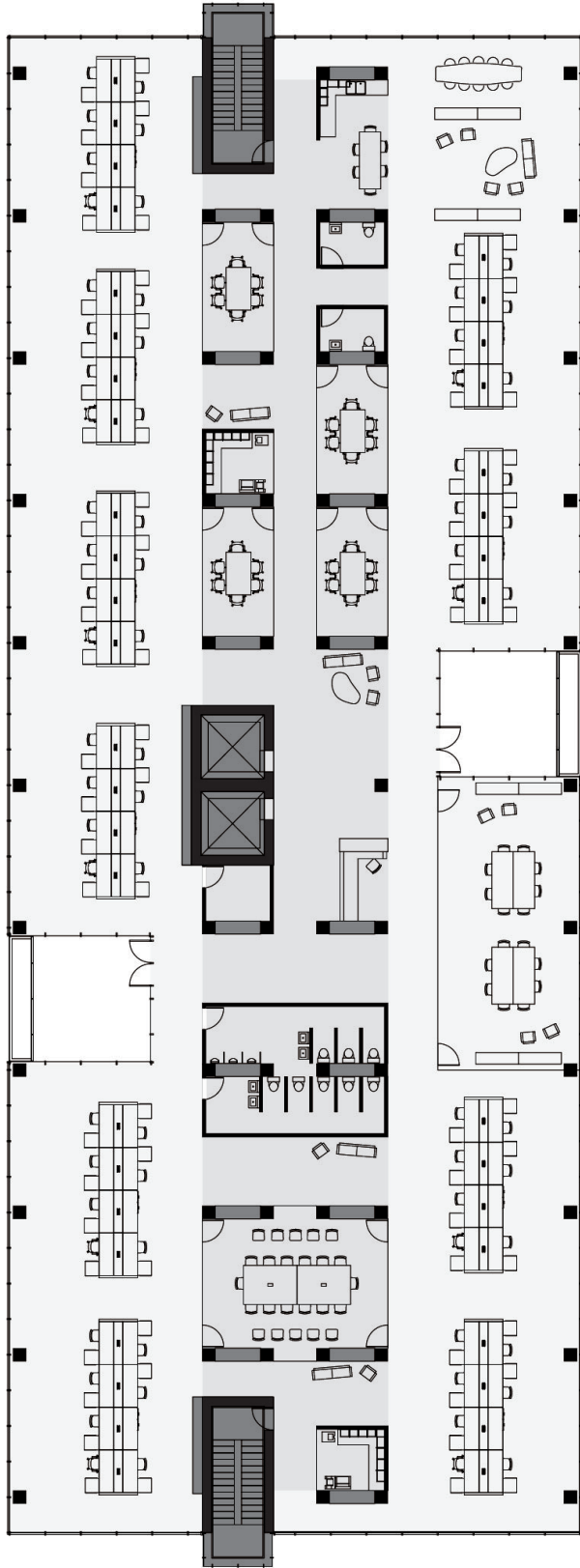
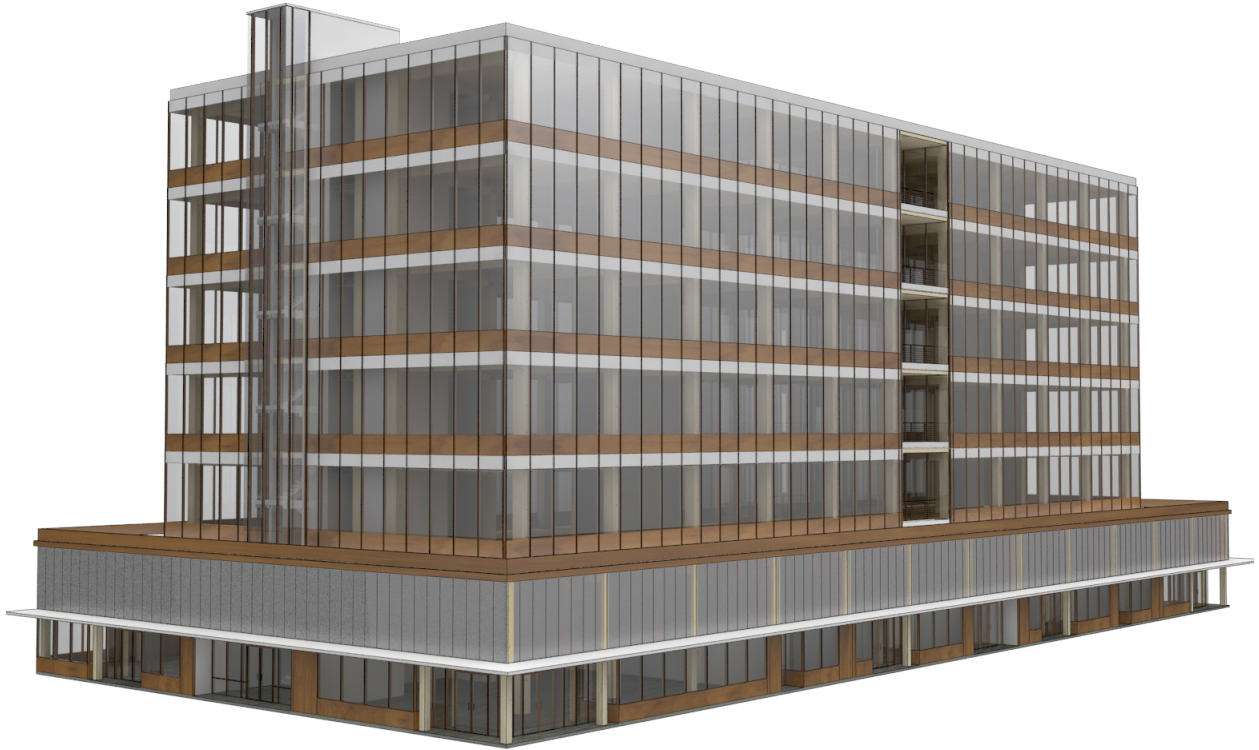


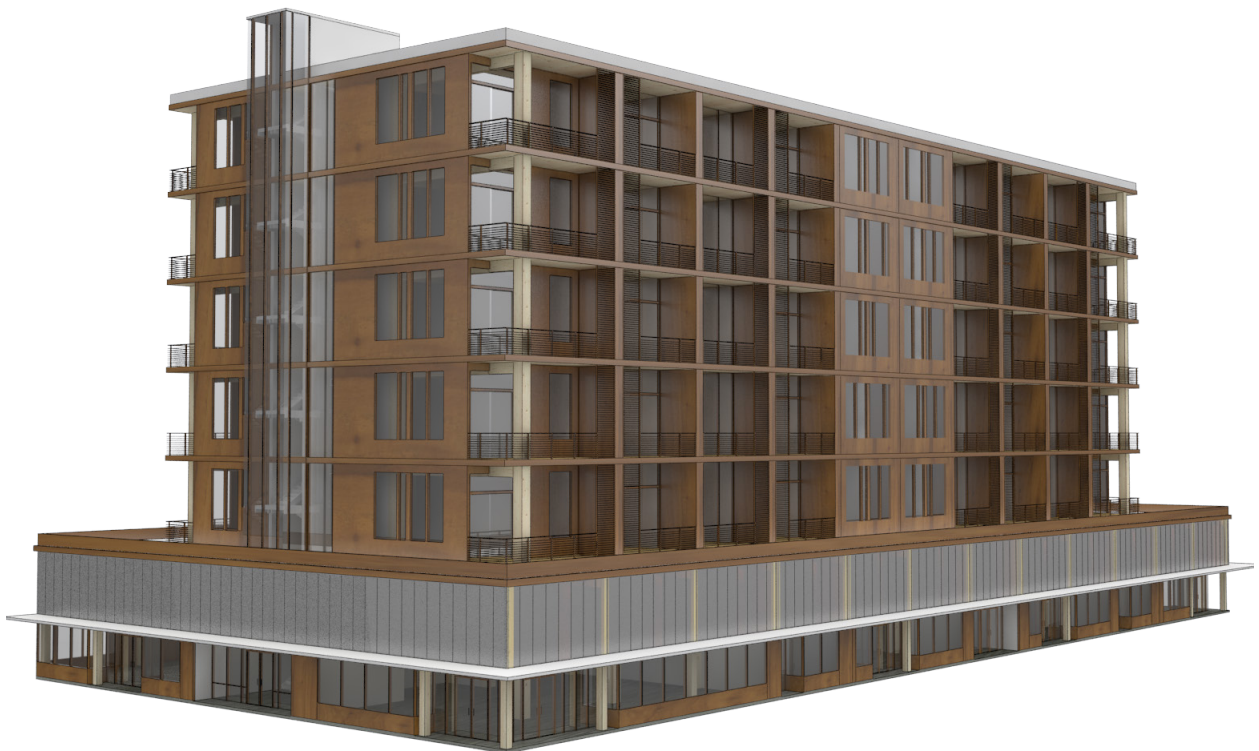
Fig. 8-10 Office Floor Plan, demonstrating a single tenet, open floor plan.



Fig. 8-11 Residential Floor Plan, demonstrating studio, 1, and 2 bedroom units.



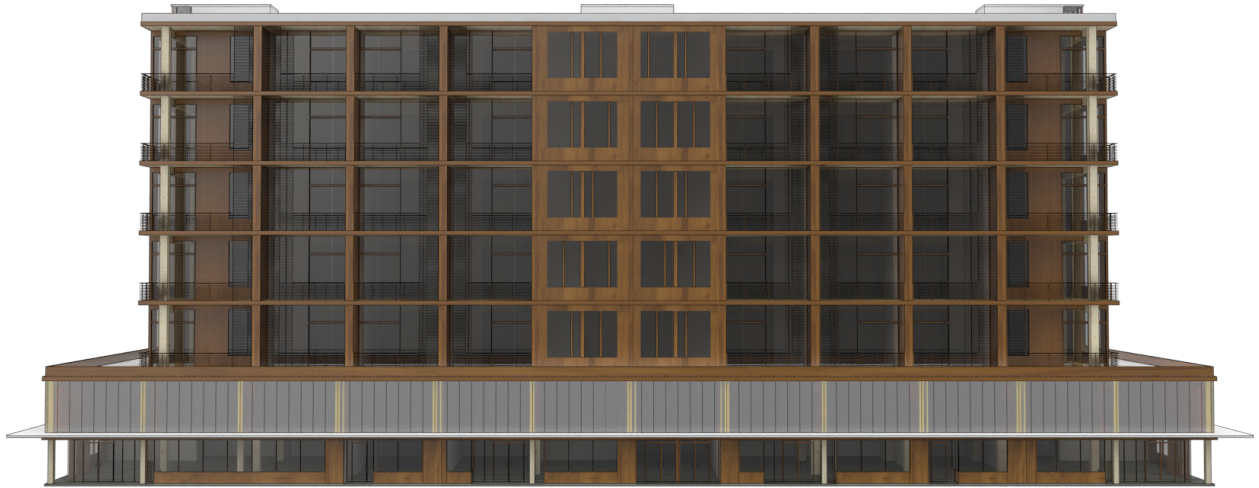
*Fig. 8-12 Office Facade Example*



*Fig. 8-13 Residential Facade Example*



*Fig. 8-14 Office Facade Example - Front Elevation*



*Fig. 8-15 Residential Facade Example - Front Elevation*



*Fig. 8-16 Office Facade Example - Side Elevation*



*Fig. 8-17 Residential Facade Example - Side Elevation*

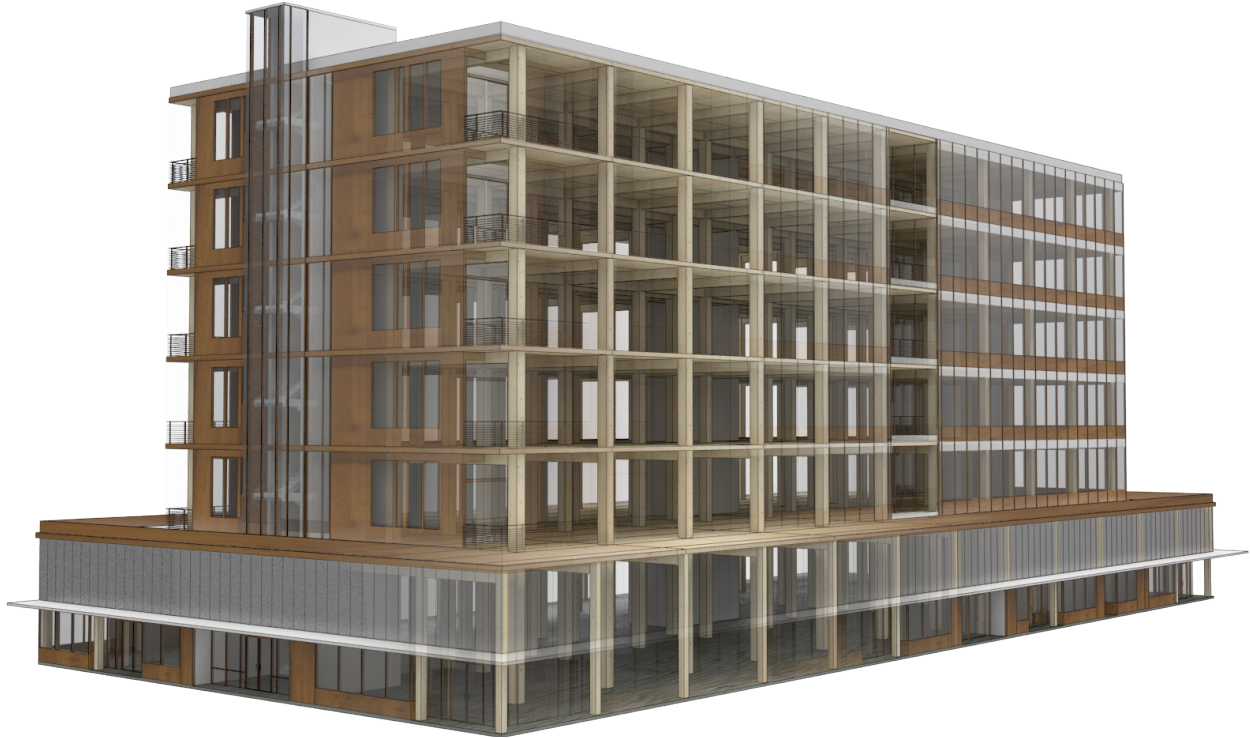


Fig. 8-18 Flexible Frame

Mass timber construction is the first step in achieving this goal. Providing a solid structure and service layout made from modifiable materials presents the widest range of options for user changes, buffering the building to the unpredictable future.

#### MASS TIMBER AS A REGIONAL RESOURCE

Washington state is the second largest lumber producer in the United States with the forest industry the third largest manufacturing employer in the state.<sup>44</sup> The boom and bust timber industry is ingrained in Bellingham and Whatcom County culture as evident by the annual, local, Deming Logging Show which showcases “contestants who chop, cut, climb, splice and saw logs with a blend of modern tools and time-honored techniques.”<sup>45</sup>

44 Washington Forest Protection Association. “Forest Products Industry Economic Impact.”

45 Bonnell, Isaac. “A Look at Whatcom County’s Logging Past, Present.” The Bellingham Business Journal, June 9, 2011.

In 2017, the Port of Bellingham started a 5 year lease with GrandCamp International, LLC for the export of whole log timber to buyers in Asia, continuing the logging industry’s long tradition on the waterfront.<sup>46</sup> The Pacific Northwest is also home to a large number of engineered wood manufactures including 4 out of the 5 CLT manufactures listed on the APA’s (The Engineered Wood Association) manufacture directory.

Local production provides local jobs and economic benefits to the area while the close proximity of manufacturing, resource extraction and site reduces the CO2 transportation emissions even more than might be expected in other areas of the globe. The local essence of the material helps to further strengthen the case for mass timber as a replacement for concrete and steel as the main structural component in the Pacific Northwest and

46 Gallagher, Dave. “Port signs deal with company that will ship timber to Asia.” The Bellingham Herald, January 5, 2017.

at the core of Bellingham’s new mixed-use, urban infill, Waterfront District.

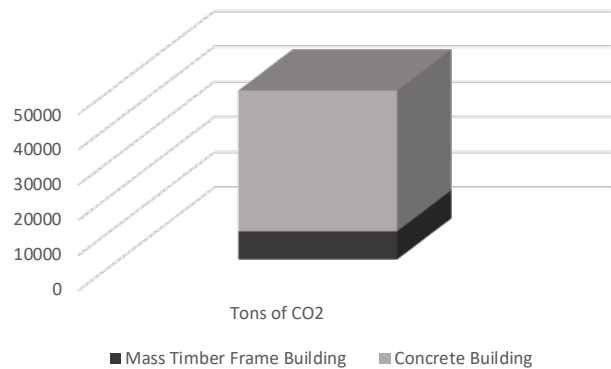
### CARBON EMISSIONS COMPARISONS

Using the proposed mid-rise structural system as a base, the expected carbon emissions were calculated for the same structure in both concrete and mass timber. The calculations are based off of CO2 production emissions data from *Timber City* and calculated in a spreadsheet based on volume, created in the University of Washington’s 2016 Wood Research Design Studio.

The first calculation compares the total starting carbon footprint (Total CO2 emissions - CO2 sequestration = Carbon Footprint in Tons of CO2) for the same structural volume in both concrete and mass timber for the proposed 110,000sqft building. The calculation takes into account the same concrete foundation for both building assemblies and estimates the steel reinforcement in a concrete assembly at 1% for slabs and walls, 2% for beams and 2.5% in columns. The results, show a carbon footprint ~5 times greater for the same material volume in concrete than in mass timber. This cradle-to-gate starting point is magnified when the building life cycle is taken into consideration.

In the second comparison, concrete and mass timber are compared over time. Three scenarios are used, one for a building with a building life span for each 100 years, 200 years and 300 years. In each scenario the concrete and mass timber buildings are rebuilt after each lifespan cycle. Not included in the total lifespan emissions are modifications or demolition/disassembly but simply the same cradle-to-gate emissions for each material if built from scratch at each different time interval and compared in total. The results demonstrate how increasing a building’s service life can save on total emission irregardless of material but it also illustrates how even in the shortest lifespan scenario, the mass timber building can be rebuilt four or five times before it reaches

Total Carbon Footprint



Structural System:	Concrete	Mass Timber
<b>CO2 Emissions from Production (Tons)</b>		
<b>Timber:</b>	0	1,075
<b>Concrete:</b>	19,919	5,753
<b>Steel:</b>	3,626	1,762
<b>#of Trees:</b>	0	2,827
<b>CO2 Sequestered (Tons)</b>	0	5,271
<b>Total Carbon Footprint (Tons)</b>	<b>39,934</b>	<b>7,988</b>

Fig. 8-19 Total Carbon Footprint Comparison, Mass Timber Vs Concrete Structural Systems

Source: Original Material Carbon Emissions from *Timber City*. Calculations made using a material volume spreadsheet developed in the University of Washington’s 2016 Wood Innovation Research Studio.

the total CO2 emissions of one similar concrete building. Five buildings for the CO2 emissions of one will go a long way in housing the growing population demands both locally and globally. Even in the likely event that this ratio is lowered, as is hypothesized with a more accurate emission modeling accommodating for tenet improvements, maintenance and the demolition/disassembly stages of a building life cycle, it is still nearly impossible to discredit the large net CO2 emissions reduction

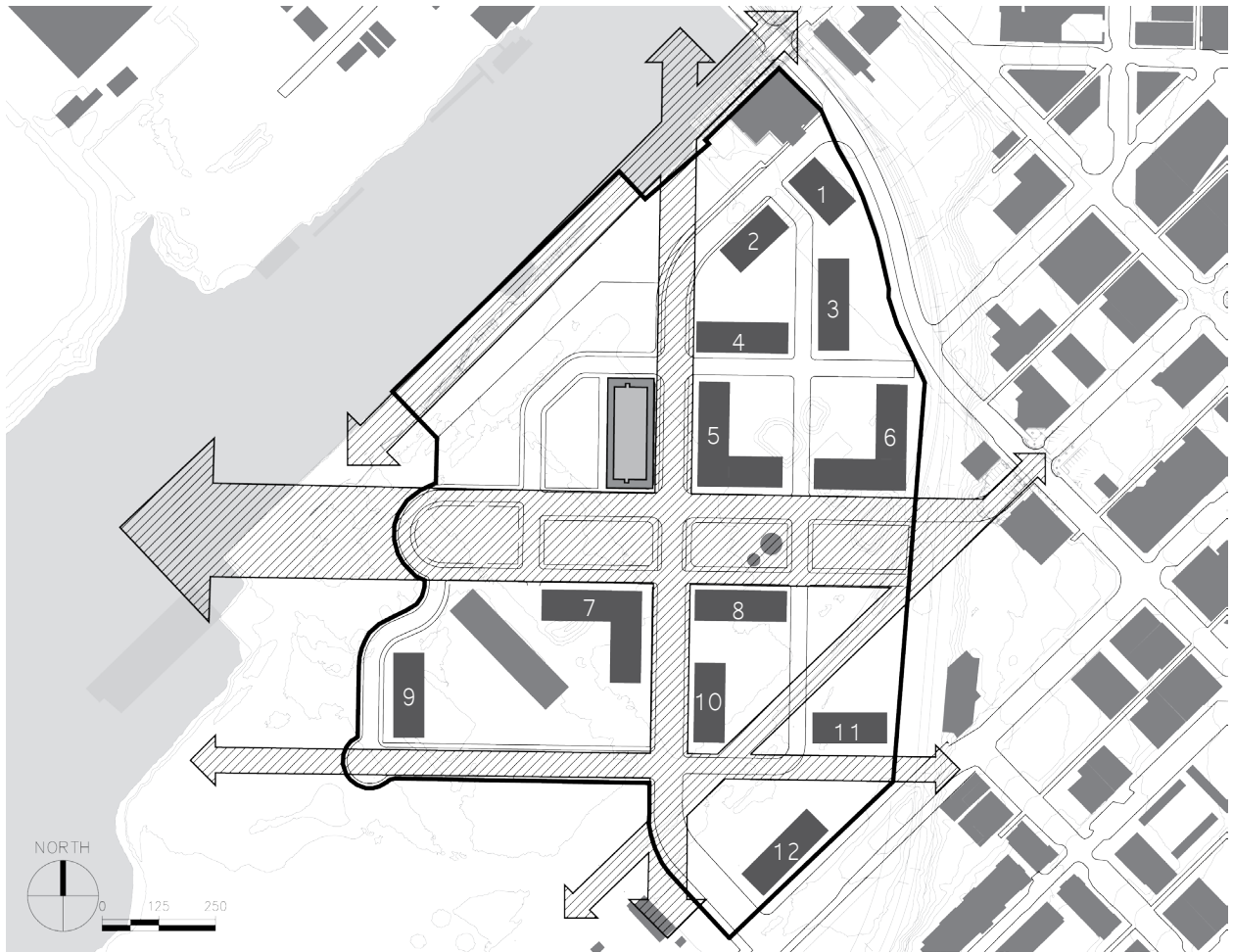


Fig. 8-20 The potential sites of similarly scaled buildings in the Downtown Waterfront District demonstrate the multiplying effect mass timber buildings have over their concrete counterparts in regards to CO<sub>2</sub> emissions and sequestration when extrapolated to the district level. Here, twelve other sites are identified for the calculation comparison but other potential building sites remain. The other remaining sites further increase the potential CO<sub>2</sub> emissions disparity between a district constructed of wood and a district constructed of concrete.

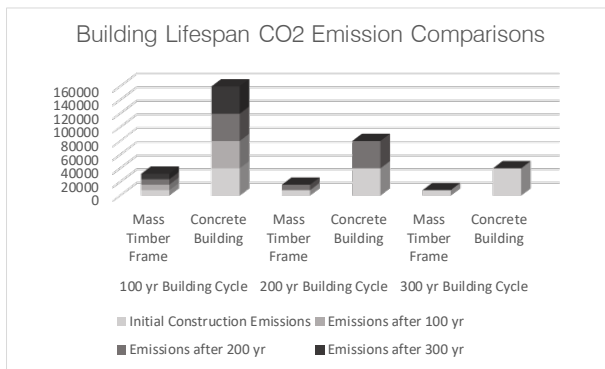


Fig. 8-21 Carbon Footprint Comparisons Related to Lifespan

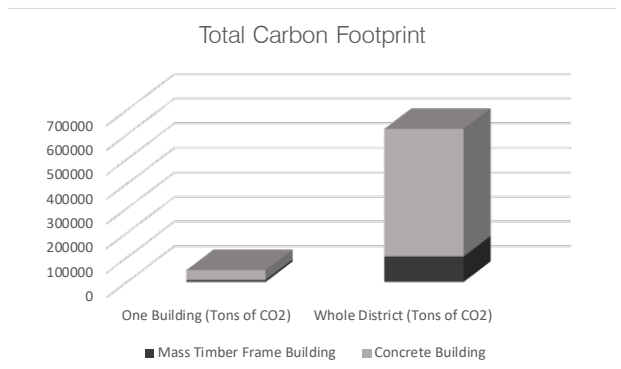


Fig. 8-22 District Carbon Footprint Comparison



*Fig. 8-23 Framework, U.S. Tall Wood Building Winner  
Source: Lever Architecture*

with a switch to mass timber as the main structural building material for urban, heavy-load buildings.

A third comparison demonstrates the multiplying effect of the emissions savings over the district scale. Twelve other sites were identified as having potentially similar sized buildings in the 37 acre Downtown Waterfront District adherent to the 2013 master plan zoning and current IBC building codes. More locations or larger buildings could be argued for if density is increased or mass timber building height restrictions are increased as they are expected to with projects like Path Architecture's 85' tall Carbon 12 project or Lever Architecture's U.S.D.A.'s Tall Wood Building Competition winner Framework, leading the way regionally.<sup>47</sup>

## 9. REFLECTION

The future is bright for mass timber construction in the Pacific Northwest. As a key contributor to helping reduce harmful CO<sub>2</sub> emissions that threaten to destabilize the global climate while also benefiting the local economy in addition to housing current and future population demands, mass timber's time has come. It is the hope of this thesis that the benefits of choosing to build with local materials

with low embodied energy have been made clear. It is also the hope that material choice will once again become regionally specific and adaptable by their user as demonstrated by vernacular architecture.

The understanding and implementation of building construction practices that help buildings adapt to changing user demands and allows for easy maintenance and repairs also helps to make a better building, not only in regards to reducing the total harmful emissions through increasing service life, but by providing for a better, more intimate user experience. The bond created by the user's ability to adapt his or her space within the confines of the building's framework creates the requisite bond for people to easily love a building as Stewart Brand has suggested. That same bond is also key to a person's investment in place, turning a person's love of a building from low road to high road makes the world a deeper, richer, more loved place for all.

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47 reThink Wood, Mass Timber

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Source: NOAA*

*Fig. 2-2 Direct CO<sub>2</sub> Measurements. [Graph] Retrieved from <https://climate.nasa.gov/vital-signs/carbon-dioxide/>  
Source: NOAA*

*Fig. 2-3 Estimated Population Growth [Graph]  
Source: United Nations, Department of Economic and Social Affairs, Population Division (2017).*

*Fig. 4-2 Cradle-to-Cradle Biological and Technical Nutrient Cycles [Diagram] Retrieved from <http://www.c2cproducts.com/detail.aspx?linkid=1&sublink=6>  
Source: McDonough Braungart Design Chemistry (MBDC)*

*Fig. 5-1 Number of Demolished Buildings by Reason for Demolition [Graph]  
Source: Athena Institute, Minnesota Demolition Survey.*

*Fig. 5-2 Comparison of Percentage of Demolished Commercial Buildings by Structural Material Related to Reason for Demolition [Graph]  
Source: Athena Institute, Minnesota Demolition Survey.*

*Fig. 5-3 Comparison of Percentage of Demolished Commercial Buildings in Each Age Group by Structural Material [Graph]  
Source: Athena Institute, Minnesota Demolition Survey.*

*Fig. 6-1 Six S's Shearing Layers of Change [Diagram]  
Source: Stewart Brand, How Buildings Learn*

*Fig. 6-2 The Low Road [Photo Layout]  
Source: Stewart Brand, How Buildings Learn*

*Fig. 6-3 The High Road [Photo Layout]  
Source: Stewart Brand, How Buildings Learn*

*Fig. 6-4 TriBeCa Neighborhood Loft [Photo] Retrieved from <https://www.pinterest.com/pin/118360296433693395/>  
Source: ODA Architects*

*Fig. 6-5 Typical TriBeCa Neighborhood Block [Photo] Retrieved from <https://www.squarefoot.com/ny/new-york/tribeca/office-space>  
Source: The Square Foot*

*Fig. 6-6 Timber-Frame Construction [Poster] Create by June Strong-Fairbanks  
Source: Stewart Brand, How Buildings Learn*

*Fig. 6-7 Victorian Box [Diagram] from Anne Vernez Moudon, Built to Last  
Source: Stewart Brand, How Buildings Learn*

*Fig. 7-1 Bellingham Bay to Mount Baker [Photo] Retrieved from <https://www.cob.org/>  
Source: City of Bellingham*

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*Fig. 7-2 Waterfront Demolition [Photo] Retrieved from <http://bbjtoday.com/blog/tumbling-down-old-georgia-pacific-buildings-razed-to-make-way-for-waterfront-development/13682/>*

*Source: Bellingham Business Journal*

*Fig. 7-3 237 Acre Waterfront Redevelopment Site. [Base Photo]*

*Source: Base Image, Google Earth*

*Fig. 7-4 Downtown Waterfront District [Base Photo] Retrieved from <https://westerntoday.wvu.edu/news/presentation-may-21-to-discuss-present-future-of-bellingham-waterfront-development>*

*Source: Base Photo, Port of Bellingham*

*Fig. 8-1 Typical Building Core Configurations [Diagram]*

*Source: Edward Allen, Joseph Iano, The Architects's Studio Companion*

*Fig. 8-2 Typical Horizontal Services Configurations [Diagram] Developed by G.Z. Brown, University of Oregon*

*Source: Grondzik, Kwok, Stein, Reynolds, Mechanical and Electrical Equipment for Buildings.*

*Fig. 8-19 Total Carbon Footprint Comparison, Mass Timber Vs Concrete Structural Systems*

*Source: Original Material Carbon Emissions from Timber City. Calculations made using a material volume spreadsheet developed in the University of Washington's 2016 Wood Innovation Research Studio.*

*Fig. 8-21 Carbon Footprint Comparisons Related to Lifespan*

*Source: Original Material Carbon Emissions from Timber City. Calculations made using a material volume spreadsheet developed in the University of Washington's 2016 Wood Innovation Research Studio.*

*Fig. 8-22 District Carbon Footprint Comparison*

*Source: Original Material Carbon Emissions from Timber City. Calculations made using a material volume spreadsheet developed in the University of Washington's 2016 Wood Innovation Research Studio.*

*Fig. 8-23 Framework, U.S. Tall Wood Building Winner [Rendering] Retrieved from <https://leverarchitecture.com/>*

*Source: Lever Architecture*

# ACKNOWLEDGMENTS

This Thesis has benefited greatly and could not have been completed without the support and dedication of its committee advisors, Robert B. Peña (Chair) and Susan H. Jones. Other contributions to the work include the Elizabeth Golden and Richard E. Mohler led 2015 ACSA *Timber in the City* Competition Studio which sparked the idea for a mass timber thesis. Adding kindling to the spark, the 2016 Wood Innovation Research Studio led by Susan Jones and her team at Atelier Jones were critical to the development and understanding of mass timber required for this thesis. The studio's research built off of the University of Washington's 2013 CLT research studio by focusing on CLT's sourcing, production, environmental benefits, and connection details while pushing to expand its future possibilities. Critical to this process was the work and investment of my fellow studio peers who's pursuit of a combined understanding contributed to a more robust appreciation of mass timber and specifically contributed to creation of the carbon footprint spreadsheet used to compare mass timber and concrete volume emissions. These contributions and those not specifically mention here have made this thesis and rewarding and positive experience. Thank you all for your contributions. And to my wife, Jenna, I could not have done this without you. Thank you.