KATERINA GUROVA

ELEVATE

A PROPOSAL FOR TIMBER SKYSCRAPERS AS A VERTICAL CITY

Chalmers University of Technology

Department of Architecture and Civil Engineering

Tutor: Jonas Lundberg

Examiner: Kengo Skorick

ELEVATE

A Proposal for Timber Skyscrapers as a Vertical City

Contact: gurovadk@gmail.com

Chalmers University of Technology

Department of Architecture and Civil Engineering

Master's Thesis in Architecture and Urban Design

MPARC ACEx35 'Material Turn'

Tutor: Jonas Lundberg

Examiner: Kengo Skorick

CHALMERS

THANK YOU

Jonas Lundberg
Kengo Skorick
Jonas Runberger
Karl-Gunnar Olsson
Tabita Nilsson
Linda Sköneskog
Linnea Kikuchi
Material Turn gang
Family and friends

ABSTRACT

We as humans have reached a time where amazement over our great technological achievements is obscured by the fear of ruining our planet. The building sector is faced with the challenge of building more than ever to sustain population growth, demographic changes and urbanization. It is time to rethink how we build.

This thesis explores the concept of the Vertical City typology as a solution to increased urban density, and aspires to raise awareness of mass timber as a viable and sustainable structural material for tall buildings. The Vertical City is a concept of massive skyscrapers, providing the functions of a city in the sky. As we progress technologically and our cities become denser, we have the tools and motivation to create such typologies in the near future. The challenge we face is not only to increase our cities in height, but also to elevate them into pleasant, humane and sustainable environments. As our cities rise from the ground, the new habitats should be given the same care as the ones in regular urban planning, and be equipped with functions such as outdoor parks, public activities and culture.
This thesis uses a design oriented method and the process is focused primarily on conducting design studies. External knowledge from literature and reference projects is translated into new ideas through iterative design experiments, conducted in themed loops focusing on massing, structure, program and relation to site.

The knowledge gathered in this thesis results in a design proposal of a skyscraper complex using structural timber, located in Frihamnen in the heart of Gothenburg. Since this area is currently growing in rapid speed, the proposal joins the discussion on how to densify. The culturally significant surroundings are a constant reminder of the carefulness needed when designing something of such massive scale. The proposal aspires to offer a valuable Vertical City typology.

TABLE OF CONTENTS

1: INTRODUCTION

STUDENT BACKGROUND

EDUCATION

BACHELOR OF ARCHITECTURE

2014 - 2017	Bachelor of Architecture	Chalmers University of Technology, Gothenburg

MASTER OF ARCHITECTURE

2017 - 2018	Exchange year	Tongji University, Shanghai
2019 - 2020	Architecture and Urban Design	Chalmers University of Technology , Gothenburg

WORK

2018 - 2019	Internship	Reflex Arkitekter, Stockholm

KEYWORDS

URBANIZATION

Similar to urban densification. The amount of people living in an urbanized area. The term is often used in urban planning when approaching sustainable ways of handling compactness in cities.

SKYSCRAPER

A building that is noticeably taller than its surroundings. According to the Council on Tall Buildings and Urban Habitat (2020), a tall building is over 50 meters, a supertall is over 300 meters and a megatall is over 600 meters.

VERTICAL CITY

In this thesis Vertical City refers to a skyscraper typology of one or several massive skyscrapers that strive to recreate the conditions and functions of the city within the building. The term Vertical City can also refer to a city that is noticeably denser vertically than horizontally, such as Hong Kong.

MASS TIMBER

Or engineered wood. A composite material made from parts of wood. Assembled by gluing or in other ways combining smaller wood components into a material stronger than solid wood. Used primarily in building construction in the form of for example beams, columns, and arches. Examples of mass timber products are Cross-laminated timber and Glulam.

RESEARCH STATEMENT

PROBLEM STATEMENT

It is predicted that by year 2050 we are 10 billion people and 67% live in cities (United Nations, 2018). The building sector is facing a dilemma: on one hand, we need to build more than ever to satisfy population growth and increased urbanization of most larger cities. Simultaneously we must become more mindful of the environmental impact of these actions as we become more aware of the environmental damages and resource scarcity that we face. Currently, the building sector accounts for 40% of the world wide CO^2 pollution (United Nations, 2017). Therefore, solutions are needed on how to continue building in order to sustain the needs of many growing economies, while minimizing the environmental impact. Increased urbanization may also have social, cultural and mental consequences. Today most European cities, relatively to Asian and American Cities, are less dense and carriers of historical architecture. How to introduce tall and large scale typologies to these cities without disturbing their heritage is a sensitive topic.

PURPOSE

Imagine a village. What does it contain? Homes, workplaces, hospitals, schools, elderly homes, daycares, stores, restaurants, transportation, nature and places of worship. Now imagine it vertically. This is the concept of the Vertical City. The purpose of this thesis is to explore a new skyscraper typology in an attempt to offer an architectural solution to problems caused by increased urbanization. The aim is to use the skyscraper as a starting point but challenge the form and program to meet new urban needs. The purpose is also to explore structural timber as a building material, to normalize the choice of sustainable building materials on large buildings.

OBJECTIVES

The main goal of this thesis is to design a conceptual proposal in Gothenburg based on the needs and limitations of a Vertical City using mainly structural timber. The proposal relates to Gothenburg's current state but addresses a potential future situation, motivated by the City of Gothenburg's current plans to rapidly expand and the general trend of urbanization. The written part of this thesis analyzes the Vertical City as an approach to urban density and mass timber as a structural element in tall buildings. The proposal embodies these theoretical findings. Throughout the evolution of its design it mainly explores questions regarding massing, structure, relation to site and program.

CONTRIBUTION

This thesis contributes to current discourse about urban densification through the evolution of the skyscraper into a Vertical City, the discourse about structural timber in tall buildings and the discourse about the densification of Gothenburg, by discussing and analyzing these topics.

NOVELTY

To my knowledge, there is no current research about Vertical Cities specifically in structural timber, nor in the Nordic cities. This thesis offers a unique take on the Vertical City typology by suggesting a structural timber construction, and by situating it in Gothenburg. The shape of the building complex with its connecting bridges, deriving from the specific needs of the site, is unique. But as usual in architecture, the design uses existing ideas and assembles them into an original proposal, so the claim of novelty becomes complex.

RESEARCH QUESTIONS

"HOW CAN A SKYSCRAPER FUNCTION AS A VERTICAL CITY?"

This question seeks to establish the unique traits of a Vertical City. Potential strengths and weaknesses should be identified to analyze how to maximize the utility of the typology.

SUB-QUESTIONS

How should a Vertical City handle the contrasting needs of mixed functions and their interconnection?
How can a Vertical City promote a sense of community and create a homelike environments for its tenants?
How can the Vertical City adapt to future program changes?
How should a Vertical City relate to its site, when it potentially can function as a city in itself?

HYPOTHESIS

The hypothesis is that the Vertical City will be successful in providing qualities in terms of aesthetics, structure and program, but will be challenging in terms of human scale, daylight and relation to existing low-rise buildings. Another hypothesis is that a something as large as a Vertical City should be as ecologically sustainable as possible in order to be considered a viable solution for the future.

"WHAT ARE THE STRUCTURAL AND SOCIETAL IMPACTS OF BUILDING TALL IN TIMBER?"

This question aims to identify the consequences of building tall buildings in timber on two levels: firstly on a structural level, to determine if it is possible, and secondly on a societal level, to determine if it is desirable.

SUB-QUESTIONS

What are the possibilities and limitations of building tall in mass timber?
How does the use of wood affect the Vertical City?

HYPOTHESIS

The hypothesis is that very tall buildings can be built in structural timber either now or in the near future when knowledge increases and technology evolves. Their main effect on the structure will be that thicker material dimensions will be needed to compensate for the lighter properties of the material, compared to a concrete or steel structure. The main environmental impact will be lower CO^2 emissions by offering a renewable alternative to concrete and steel. The main psychological effects will be increased calmness and a feeling of closeness to nature.

METHOD

APPROACH

This thesis primarily uses a design oriented method were research is conducted primarily through design studies. The process combines external knowledge from literature and reference projects with design experiments, translating the existing ideas into new forms. This approach stimulates an open ended and bold approach while filtering current ideas through a new lens, in a strive towards contributing with a novel take on relevant matters. The aim is to better understand external knowledge through design, and hopefully also contribute with new knowledge gained through the design process and/or outcome. The goal is to arrive at a specific design proposal, expectedly embodying answers to the research questions, while the process of repeated design iterations show alternative ways to tackle the same issues.

DESIGN ITERATIONS

Prior to starting the design process, focus areas are defined to set a framework for the thesis. Four themed iterations, hereby called loops, remained relevant throughout the design process: massing, structure, relation to site and program. Each loop was initially carried out exclusively for a week, to later blend into a combined task. The aim of this approach is to explore each topic openly, and through this conscious naivety perhaps arrive at an idealistic result, that will inevitably be deconstructed one week later when new parameters are added. The reasoning behind this approach is not efficiency, but to stimulates many interesting solutions. Each loop contains an element of external knowledge gathering, experimenting through sketching and models, reviewing the outcome in writing and arriving at a favored design to move on with.

LOOP 1: MASSING

Due to the unfamiliarity with the Vertical City scale, the first loop is aimed at achieving an understanding of massing, scale and proportions, and their qualities in terms of aesthetics, inner flows and daylight. See *Design Process* page 63.

LOOP 2: STRUCTURE

The second loop intends to gather knowledge about existing structural principles of skyscrapers and specific qualities of timber structures, how they manage loads and what shapes and heights they can support.

LOOP 3: SITE

The connection between the proposal and its surroundings is crucial for this thesis, but the choice of the exact site is secondary. The site creates a relationship to neighboring architecture and nature, affecting massing options, external connections, meeting with the ground, shading, and views.

LOOP 4: PROGRAM

In the forth loop, the needs of the mixed used program is studied in terms of functions, connections and flows. The goal is to design a base building that creates the conditions for a versatile program that can change over time.

TOOLS

The main design tool is Rhino. The goal is to utilize the complex forms this software can create, causing few restrictions outside the skills and imagination of the user. Designing mostly in 3D is essential to comprehend the entirety of the proposal, supported by extracting 2D representations for better understanding of chosen parts. Additional tools are sketching by hand, building models, InDesign, Illustrator and Photoshop.

THEORY AND DELIMITATIONS

THEORY

The most essential literary references for this thesis are Structure Systems by Heino Engel (1997) and The Skyscraper Bioclimatically Considered by Ken Yeang (1996). Structure Systems has provided an overview of common height-active structural systems and their principles, creating a starting point for the structural design of the proposal and earlier iterations. The Skyscraper Bioclimatically Considered summarizes common aspects and requirements of Skyscraper design, with focus on innovative and sustainable solutions. It has contributed with many ideas for the Vertical City in this thesis.

ORGANIZATION

This thesis is divided into seven chapters in a non-chronological order. *1. Introduction* is a general overview of the purpose and method of this thesis. *2. Context* presents background and analysis of chosen topics. *3. Design Proposal* showcases the final proposal. *4. References* summarizes facts about relevant reference projects. *5. Design Process* documents the iterations and design evolution throughout the project. *6. Discussion* reflects over and critically evaluates the results of the thesis. *7. Bibliography* shows all references.

DELIMITATIONS

ECONOMICAL ASPECTS

This proposal has no cost limit nor profit oriented motive, allowing it to focus on creating a high quality design in response to the demands of a timber Vertical City. It exists in a conceptual reality where it could provide public parks and social housing, and ignores the reality that such a large and innovative project in the city center would be expensive and consequently result in high rents.

STRUCTURAL ENGINEERING

A principle structural solution grounded in literature and project references is proposed based on my knowledge level. Since the proposal is not tested, this thesis can not stand as proof of whether or not it can be built. It is not within the framework or capacity of this thesis to prove if timber construction it suitable for tall buildings.

WIND, FIRE, ENERGY SYSTEMS, FLOODING...

A long journey through an extensive list of fields is required to design a realistic skyscraper. Due to the time frame of this thesis, some of these have been consciously overlooked, in favor of the focus areas stated on the previous page.

2: CONTEXT

Figure 1. Packhuskajen Göteborg. (Artist: Linda Sköneskog, 2018). Reprinted with permission.

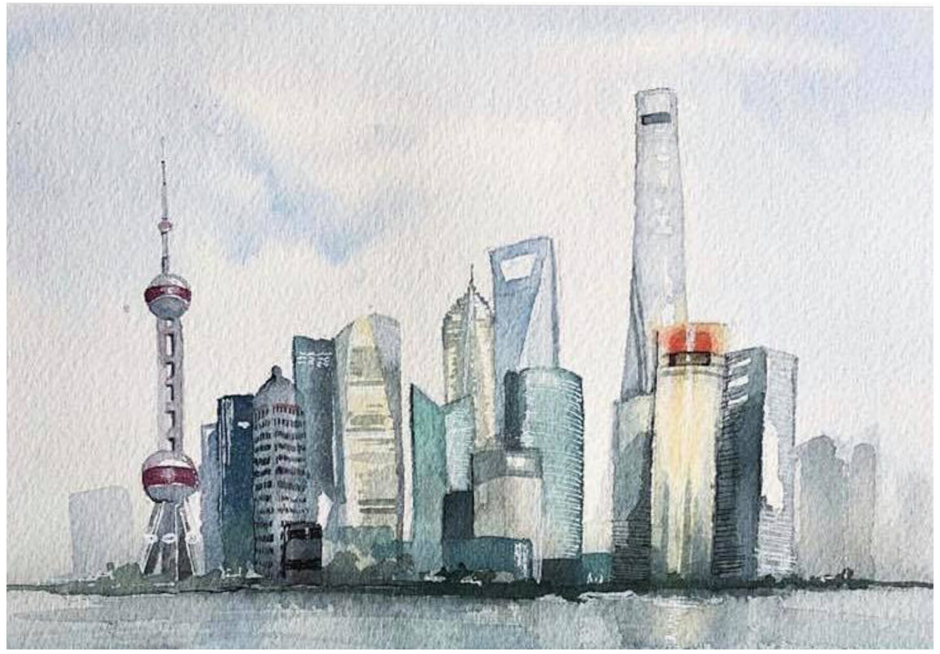


Figure 2. Shanghai. (Artist: Linda Sköneskog, 2018). Reprinted with permission.

THE FUTURE OF CITIES

"The city is the necessary instrument for the evolution of humankind." – Paolo Soleri

In year 2050, two out of three people are expected to live in cities. That's a prediction of 2,5 billion more people moving to cities within the next 30 years, most of them concentrated to a few countries (United Nations, 2018). This rapid increase in urbanization will inevitably have consequences on people's wellbeing and lifestyles, cultural heritage, pollution and ecology. While this thesis focuses on exploring the possibilities of the Vertical City, we should also acknowledge and consider other approaches to manage urban densification sustainably.

COMPACTNESS

In "Urban Density Done Right" (2017) the Swedish National Board of Housing, Building and Planning points out that the experience of density is different from actual density. Their surveys show that the convenience of closeness to activities is a priority for people living in cities. Compact cities have the potential of reducing the need for private cars by offering good pedestrian, bike and public transportation options. They warn that the risks of dense cities are crowdedness, pollution, noise pollution and lack of daylight. They advocate for mindful densification, for example preserving culturally significant buildings, increasing greenery and parks, meeting housing needs, using sound insulation and maximizing daylight in buildings.

HORIZONTAL SPRAWL

A horizontal or urban sprawl is the opposite of compactness. Instead cities grow around the outskirts of the city and get spread out into sparsely built communities. Many people who have the possibility prefer living in such areas for the benefit of a larger dwelling, private gardens, playgrounds, safety for children from car traffic, silence and closeness to nature. Compact cities should aim to offer these same comforts, by introducing more greenery and safe and clean pedestrian areas. OECD (n.d) warns of negative consequences of the urban sprawl due to car dependency, pollution from many single purpose trips, long commutes to work and services, human interference on larger parts of nature disturbing natural ecosystems, unaffordable housing and risk of social and economic segregation.

DOWNSIZING

Downsizing is an approach aimed at minimizing use of resources by saving space and energy. To become socially accepted, the association of a large dwelling and office as a sign of success and prestige should be set aside. It is profoundly connected to lowering consumption in general. A movement practicing downsizing is the Tiny House community.

CO-LIVING

An alternative approach to downsizing is co-living. Co-living is sharing spaces with neighbors, friends or strangers, whether it be sharing entire dwellings or certain functions such as kitchens, gardens and laundry rooms. Sharing can be socially beneficial by creating meeting places and preventing social isolation. Co-working and sharing venues is also rising in popularity, as well as sharing vehicles in car pools.

THE VERTICAL CITY

THE SYMBOLISM OF TALL STRUCTURES

Not too long ago, no building was allowed to exceed the height of the church bell. When Bulgaria was under Ottoman rule in the late 14th century they where allowed to keep their Christian religion, but no church was allowed to be taller than the raised sword of a Turkish soldier on a horse (Woods, 2011). Tall buildings have been associated with power far before the emergence of skyscrapers. Through their height and grandness, they seem to defy gravity and lead our eyes towards the skies. We have an ambiguous relationship with power. It is something approximating fascination mixed with fear. Some fear that the emergence of skyscrapers will ruin the delicate balance of historical cities, or distort their unique identities into indistinguishable modern clones. Others are drawn to the appeal of their cutting edge technology and futuristic ambiance.

THE SKYSCRAPER

Skyscrapers are the symbol of the 20th century. They represent technological advancement, architectural brilliance and globalization. Their necessity appeared due to lack of land and high land costs. Skyscrapers became possible through the invention of the electric elevator in 1883 and mass produced steel in 1855 (Bellis, 2020). The first modern skyscraper is the ten storey Home Insurance Building, built 1885 in Chicago (Guinness World Records, n.d.). Traditionally skyscrapers are office buildings with steel or iron frames (Bellis, 2020). Only in recent years are we exploring new options for their use and structures. Skyscrapers are most prominent in Asia and America, but the global trend is growing.

EVOLUTION: THE VERTICAL CITY

The idea of the Vertical City is an evolution of the concept that we can build our way into the skies. Combine the technology of building massive Skyscrapers with notions of how to plan a good city, and you have the beginning of a recipe for the Vertical City typology. Unlike the common office high-rise, the concept of a Vertical City is to contain the multitude of functions that a regular City does. Due to the scale of the Vertical City, it can be conceptualized as both architecture and urban planning.

VERTICAL CITIES TODAY

There are few or no Vertical Cities today depending on how the term is defined. This thesis defines the Vertical Cities as a skyscraper typology of one or several massive skyscrapers that strive to recreate the conditions and functions of the city within the building. But the term is broad and is also used to describe cities with many skyscrapers, for example Hong Kong. The word city should imply a mix of functions, however it is already common for modern skyscrapers to contain a certain mix of mainly commercial functions, often on the ground floors. Residential skyscrapers are a newer concept but growing in popularity due to housing shortage. With this in mind, the meaning of the concept in this thesis includes a significant mix of functions. An example of a mixed used skyscraper complex is Raffles City by Safdie Architects in Chongqing, China. Read about Raffles City on page 57.

BIGNESS

Rem Koolhas coined the term 'Bigness' for megastructures. When a building exceeds a certain scale, it gains the quality of "Bigness". It no longer relates to the city scale and is therefore neither conventional architecture nor urban planning, but something of a city in itself. He defines the modern city as a generic city, suggesting that complete planning (of mega structures) is impossible as it must be open for the unpredictability of the market and future (Rabaca & Martins, 2018). When introducing Bigness to for instance European cities with plenty of cultural heritage, consideration should be taken towards balancing the meeting between the historical and the modern, the small and the large scale.

ARCOLOGY

Paolo Soleri invented the concept Arcology, a synthesis between architecture and ecology. Arcology criticizes the slow manner in which sustainability is approached today, and leads the way to more radical approaches. *"It's reported that if the 7.4 billion people on earth were to consume like the average American, we would need over 4 globes to sustain us."* - arcosanti.org (n.d.). Arcology suggests that cities must co-exist with nature and grow in organic manners. They present design strategies such as designing cities for pedestrians instead of the automobile, building dense and tall cities to achieve flourishing urban environments, introducing farming to cities and reducing energy consumption through smart technology (arcosanti.org, n.d.).

MANIFESTO OF NEW URBAN FORM

The vision for a Vertical City is a sustainable, clean, self-sustaining, diverse and inclusive community, that capitalizes on the possibilities of dense, vertical living. In the 8-8-8 Manifesto of New Urban Form, the creators of the Vertical City Organization list their intentions for a good Vertical City (verticalcity.org, n.d.). The main environmental goals are counteracting global warming by using sustainable energy sources, freeing up land for farming by replacing the horizontal sprawl, storing rainwater, purifying air through plants, recycling, and growing food locally. Their formal aims include to maximize density and use elevator sky lobbies for ultimate efficiency, having a collective mass transit system connect the Vertical City to nearby districts, and using underground parking to prioritize pedestrians activities. Their socio-economical goals are to offer education, employment, healthcare, housing, and recreation, cultivate inclusiveness and respect cultural diversity, stimulate healthy lifestyles, and support political decisions that acknowledge the importance of sustainability and humane values.

LIFE IN A VERTICAL CITY

A Vertical City can be experienced as one mega structure, or as several towers interconnected by bridges. It may be located in the heart of a megacity or amidst the wilderness. It is ideally self-sustainable, and generates energy through solar and wind power, and food through vertical farming. It provides all necessary functions for people of different cultures, ages and preferences, so its tenants never have to leave unless they want to. It strives to be as health promotive as possible, with natural daylight, ventilation and materials.

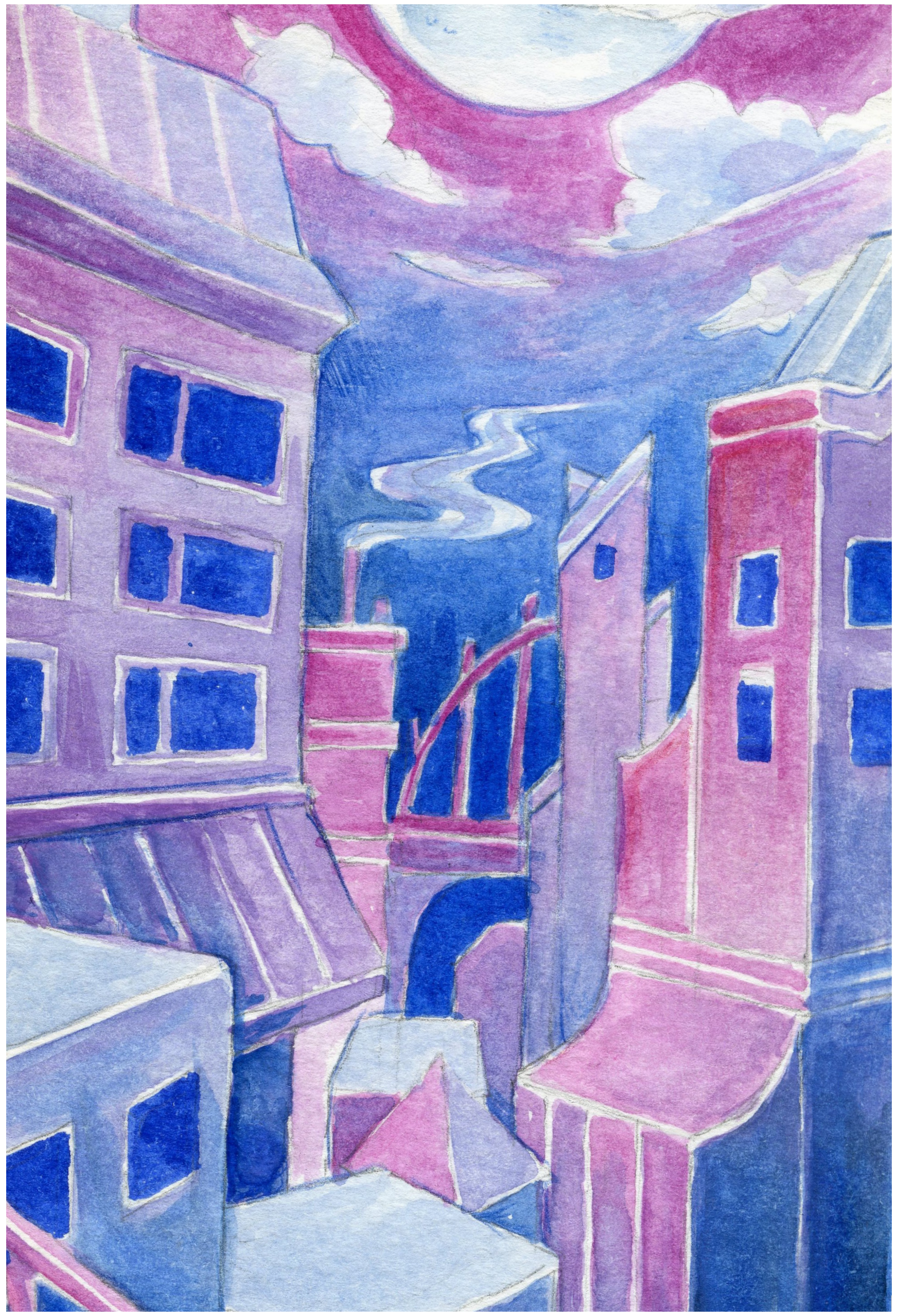


Figure 3. A City in the Sky (Artist: Linnea Kikuchi, 2014). Reprinted with permission.

STRENGTHS

UTILIZE THE SKY

The possibility of building super tall gives us a new resource for managing urban densification: the sky. Densifying vertically lightens the need for super compact city centers or an urban sprawl. By balancing these methods in urban planning, the Vertical Cities can take some pressure off the ground.

PRESERVE NATURE

Freeing up ground space leaves more room for natural ecosystems and biodiversity to develop organically. It also leaves space for parks and recreational areas. In parallel, artificial nature can be introduced into the Vertical City itself, for air purification, rainwater filtration and mental wellbeing.

PROXIMITY

The multi-functional Vertical City offers a multitude of functions, only a staircase walk or elevator ride away. Through smart elevator systems, it can manage vertical transportation efficiently. It could also have an integrated speed train station connecting it to other areas. Proximity to neighbors could be planned to foster community and offer quality shared spaces.

SELF SUSTAINMENT

A Vertical City could aim to be self sustaining through the integration of the latest technology, and thereby take control of its resource consumption, bring people close to production and eliminate long distance transports of products. It could invest in smart energy systems such as solar panels, rainwater cleansing, robot maintenance, climate adaptive facades, and heat recovery windows (Havgrave, 2013).

WEAKNESSES

COST

Due to the novelty, complexity, scale, and height of the Vertical City, construction will be very expensive and time consuming. Maintenance will also be costly. Before investing in such a proposal, every aspect should be carefully investigated to prevent durable and costly mistakes. If divided into several towers, the Vertical City can develop gradually.

DOMINATION OVER SURROUNDINGS

How do we include a Vertical City into an existing area without completely visually and physically dominating it with its colossal presence? Massing, architectural style, connection to the ground, wind management, and shading must be carefully planned with respect to its surroundings.

NON HUMAN SCALE

The megastructure is automatically not human scale. Massive skyscrapers may lack the homeliness and coziness experienced through the enclosure of low-rise buildings and narrow pedestrian streets. Instead, the Vertical City can aim to create a local human scale within the structure, through material details, visual effects and variation of building heights.

ARTIFICIALITY

It is hard to imagine existing in a completely artificial structure. Humans are naturally drawn to nature. The disconnection to the physical earth should therefore be countered with greenery, balconies, natural daylight and ventilation, views of the surroundings and natural materials such as wood. Naturally, the ground level outdoors should also be accessible.

THE REVOLUTION OF ENGINEERED WOOD

TIMBER HISTORICALLY

Timber construction has been around since the stone age, with the oldest discovered timber house built more than 10.000 years ago in what is now Britain. It is rooted in the tradition of many cultures and in the tradition of construction itself. (Living with wood, 2016). One of the oldest wooden structures preserved in the world today is the Hōryū-ji temple in Nara, Japan, dating back to the 7th or 8th century (Unesco, n.d.). Timber is an important part of Sweden's building tradition, and has shaped our architectural landscape to this day. Sweden's oldest wooden building is Granhult church in Lenhovda, built approximately year 1220 (Granhults kyrka, 2018). Wood plays an important role in our history and culture, and it seems like it will also play an important role in our future.

'INTRINSIC QUALITIES'

The role of materials and materiality in architecture has changed over time (Borden & Meredith, 2012). During the modernism movement, Adolf Loos claimed in his writing "Regarding Economy", that the former tradition of a worship of ornaments should be replaced by a worship of materials. By uplifting the material and letting it supersede decoration, he promoted the "inherent qualities" of materials. This birthed the prevailing and nostalgic idea of a material's purity (Borden & Meredith, 2012). But since technological possibilities have expanded greatly, it might be time to reevaluate our attitude towards materials.

A MATERIAL REVOLUTION

According to Borden and Meredith, the Industrial Revolution brought an increased urban workforce, new transportation infrastructures and advancement of technology such as steel and concrete. This changed the attitude towards material's intrinsic qualities as well as the link between the construction of materials and the construction of buildings in scale and proportion. Materials were now detached from their supposedly intrinsic physical qualities, such as bendability, tensile limits and compressive strengths. The advancement of technology now allowed us to view materials from a different lens and stray away from that material's traditional function.

To both save money and decrease our impact on the environment, we have chosen to use materials in more ways than how they are supposed to act based on the inherent qualities. The advancements in technology have allowed us to reconstruct wood, glass, steel, plastic, and concrete into almost any design or shape imaginable. The rise of digital fabrication processes has further developed our ability to produce and reconstruct materials. We can cut, bend, roll, and cast a multitude of materials with nearly endless possibility. This makes the tools used just as important as the materials and helps change the qualities of said materials to fit our needs or imagination (Borden and Meredith, 2012).

MASS TIMBER

Mass timber is a composite material made from parts of wood. Timber is taken apart into small pieces and reassembled through for instance gluing, into a new, stronger material in the form of beams, columns, arches, solid walls, or other structural members (Mass Timber in North America, n.d.). One of the most common mass timber products, Cross-laminated timber (or CLT), was invented 1958 in France. It has been widely used internationally for building construction since year 2000 (Coats, 2017). The invention of mass timber has allowed us to take wood construction to new heights and levels. It has a bit of the best of two worlds: it keeps the natural qualities of wood in terms of being a renewable material growing from the ground and storing great amounts of CO^2, while retaining new properties in terms of strength - making it a worthy opponent to the current status quo building materials concrete and steel (Green, 2019).

FIRE RESISTANCE

The biggest public fear regarding timber construction is fire resistance. As we associate timber with an easily flammable material, it is natural to get uncomfortable by the thought of a wooden skyscraper. But mass timber has altered the natural qualities of wood and behaves differently under fire. Thick, solid panels form a top charred layer when exposed to fire, which protects the inner mass from heat, causing it to burn in a slower and more predictable manner. It is considered to behave well during fire tests and meets the qualifications of many international regulations. (Green, 2019).

TIMBER VERTICAL CITY

Building a Vertical City in timber would mean to adopt a value of sustainability into the very bones of the project: its structure. Additionally, visible wooden elements would give this massive man-made structure a natural appeal with beneficial mental consequences.

With great power comes great responsibility. A structure the size of a small city will have a large environmental impact. As the impact becomes amplified, it has more potential to create positive change but also more potential to cause damage. In order for a Vertical City to call itself sustainable, it must regard its entire lifespan. From material production, processing, transportation, and construction - to daily energy use, maintenance costs, and waste. It must be prepared for future changes in terms of how it will be used differently with gradual societal change, but also for more drastic change such as climate catastrophes. It must be prepared for economical changes in society, or sudden temporary changes such as a power outage, or the breaking of certain parts of the structure.

Before building a Vertical City in structural timber, we should observe how timber acts on the skyscrapers built and planned. Only when we are sure of their performance and have gained more knowledge and skill, can we commit to a structure of such magnitude. For the sake of our planet, we can hope that a revolution in technology, knowledge and mindset towards sustainable and renewable building materials comes soon.

Figure 4. Stavershult. (Artist: Linda Sköneskog, 2019). Reprinted with permission.

STRENGTHS

LOWER CO^2 FOOTPRINT

Sustainability is the primary driving force behind the attractiveness of mass timber. According to Green (2019), timber is the most sustainable material in terms of CO^2 emissions, and with the least total amount of water and energy waste. One cubic meter of wood stores 1-1,6 tons of CO^2, which will be captured in the wooden product during its whole life span.

RENEWABLE AND LOCAL

Trees grow naturally making wood a renewable resource, unlike any other construction material. Sweden's forests have doubled during the last hundred years, due to proper cultivation and regulations for sustainable forestry (The forest and sustainable forestry, n.d.). Local growth and production reduces transportation related emissions and costs.

MENTAL WELLBEING

Wood is a natural material that has a calming and stress reducing effect on tenants through its visual presence (Fell, n.d.).

CONSTRUCTION

Mass timber is strong in comparison to its weight. The lower weight, compared to concrete and steel, makes transportation and construction easier and cheaper (Green, 2019).

FABRICATION

Timber construction is suitable for prefabrication, which is efficient, reduces cost and construction time. CLT and Glulam can be shaped into many forms, making it suitable for curved and unusually shaped structures (Swedish wood, 2019).

WEAKNESSES

DEFORESTATION

We need to cut down forests in order to obtain timber. If done in unsustainable rates or ways, it will harm forests and lead to areas of deforestation. This can be managed through sustainable forestry. (Cossalter & Pye-Smith, 2003) But can we grow new trees fast enough to replace concrete and steel on a significant scale?

WIND RESISTANCE

Tall mass timber structures are more sensitive towards lateral loads, since timber is lighter than concrete and steel (Green, 2019). Winds get incrementally stronger higher up. Tall buildings must manage lateral loads through sufficient self weight and structural stability. Lighter tall buildings can sway from wind forces, causing discomfort among tenants (Yeang, 1996).

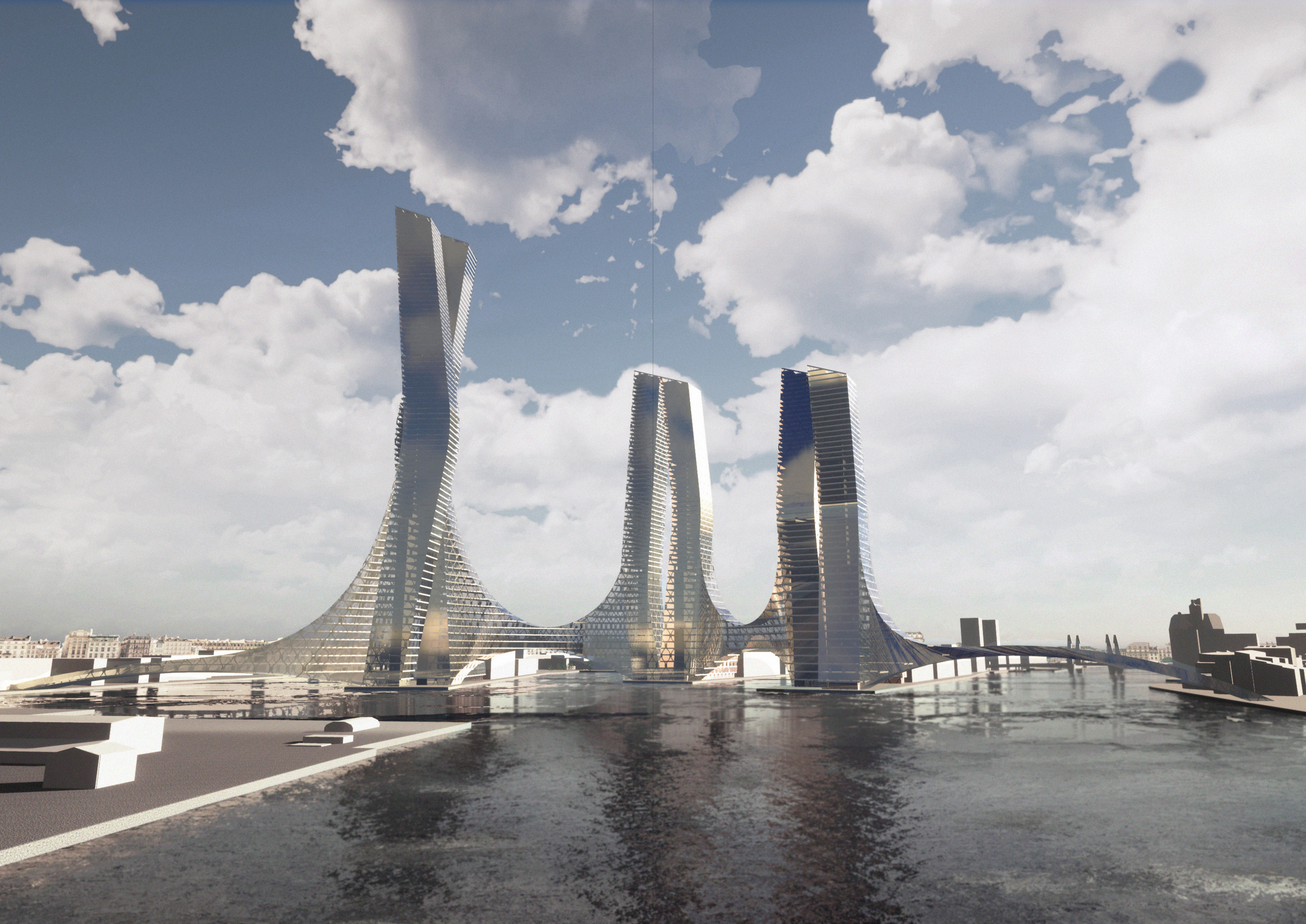
FEAR OF THE UNKNOWN

There are currently few examples of large or tall mass timber structures. Unlike concrete structures, that we have seen preserved for thousands of years, the idea of structural timber leaves people feeling skeptical. Many worry about wood as a construction material, especially regarding fire safety, structural strength and aging.

COST

Mass timber products are relatively new on the market, and still manufactured by few producers in rare locations. The hybrid timber tower W350, planned for 2041 in Tokyo, is predicted to cost twice as much as if it was built in traditional materials. (dezeen, 2018). See page 59 for more on W350.

3: DESIGN PROPOSAL



DESIGN STRATEGIES

MASSING

WOOD MATERIALS

DIGITAL DESIGN

NATURE AS INSPIRATION

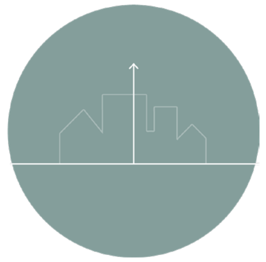
STRUCTURE

TIMBER CONSTRUCTION

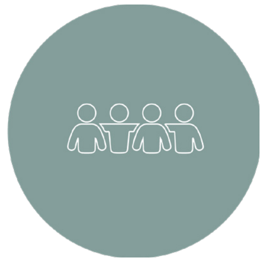
LOW CO^2

STRONG STRUCTURAL PRINCIPLE

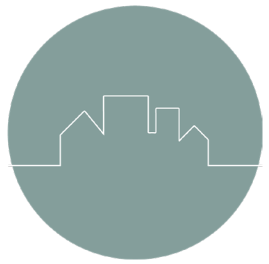
SITE



EXTENSION OF THE CITY

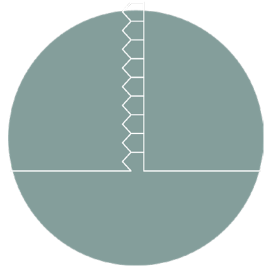


CREATE COMMUNITY

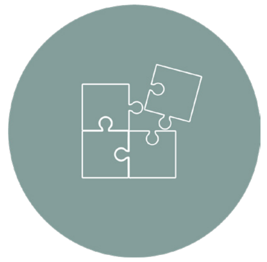


RELATE TO SURROUNDINGS

PROGRAM



VERTICAL URBANISM



ADAPTABILITY

MIXED USE

VERTICAL CITY IN A CITY

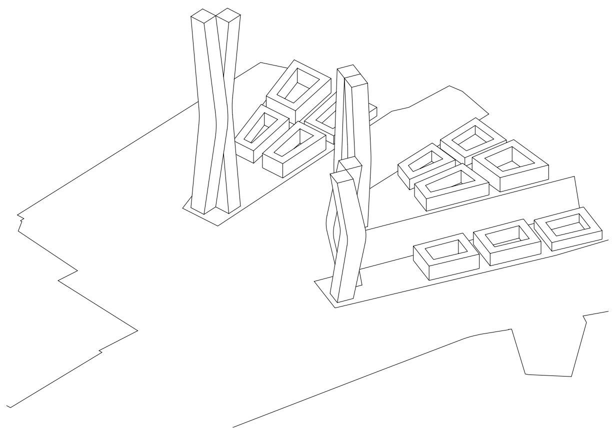
The proposal is a Vertical City complex consisting of three connected towers with a total GFA of 590 000 square meters. It is located in the heart of Gothenburg on three piers in Frihamnen. It has long been a challenge to connect the two sides of the city that are separated by the river and make them feel less segregated, physically and emotionally. Today the piers are mostly empty, and have an abandoned, industrial vibe. The rightmost pier, called the Banana pier, is only 300 meters from the Opera, yet it takes 20 minutes to commute from the nearest station. The lack of pedestrian bridges disconnects the two sides. Bridges significantly raised from the ground or lift bridges are required to allow for boat traffic.

This site was chosen because it is a part of City of Gothenburg's developmental plans for year 2050 (Rivercity Gothenburg Vision, 2012). The city plans to urbanize in a rapid speed. This proposal takes urbanization to its edge. It explores an extreme scale for this site. It responds to City of Gothenburg's strategies to connect the city, embrace the water and reinforce the center. The choice of site poses several challenges: How can large towers relate to a less dense environment? How can they connect both sides of the water? How can they extend the city and offer more housing, job opportunities and quality public spaces? What is the relationship between the Vertical City and Gothenburg?

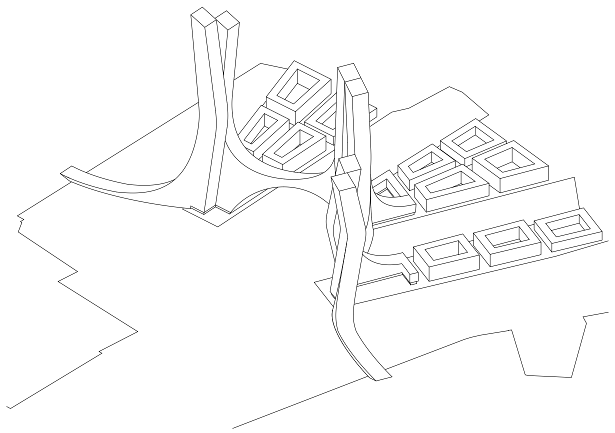
Retrieved from Chalmers Geodata Portal.

MASSING AND RELATION TO SITE

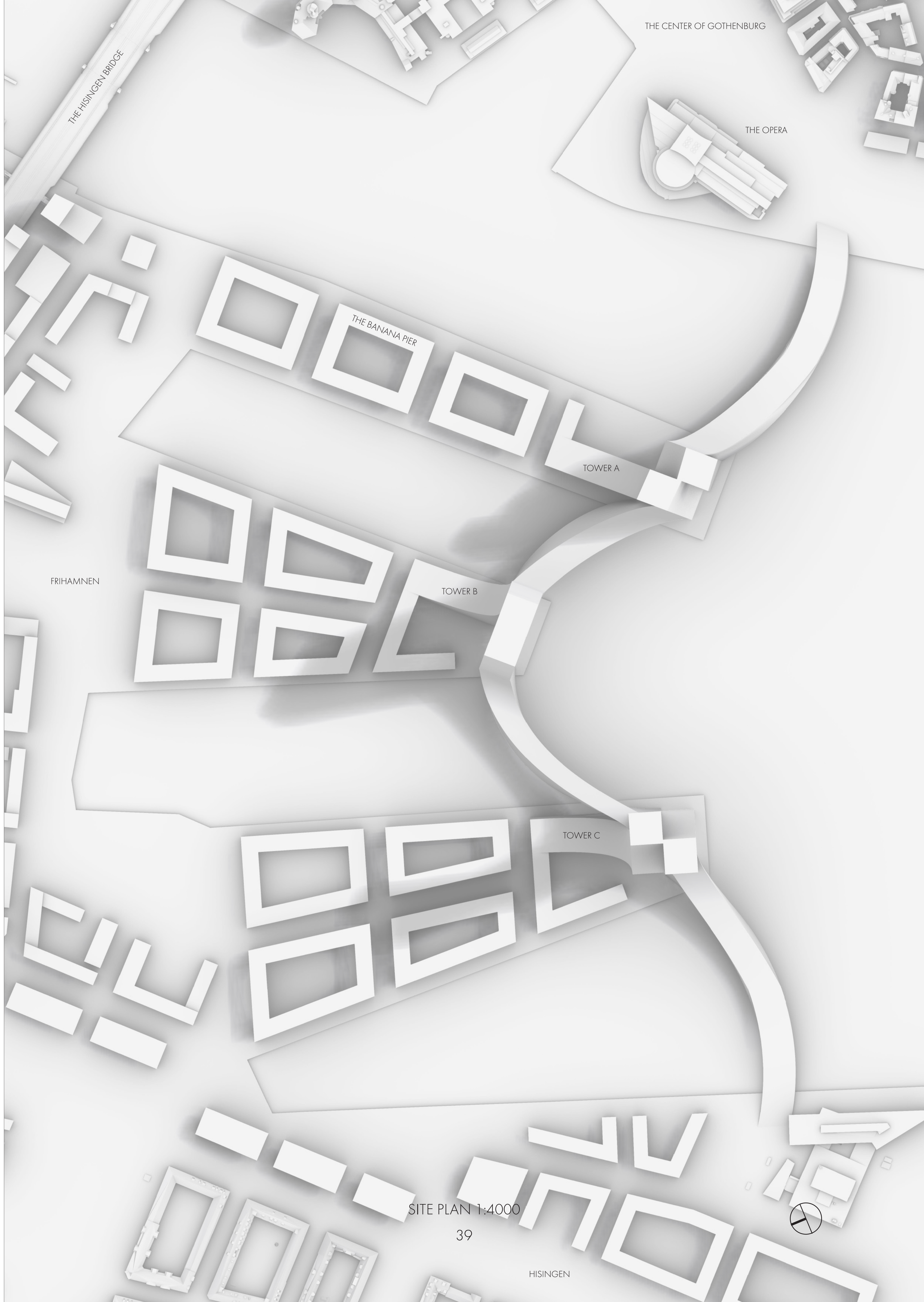
One building is placed on each pier. The building body is separated into two bodies of 30x30 meters. These dimensions create excellent interior daylight conditions. Having two bodies rather than one provides enough space, while more than two feels too massive on this site.



The duo interacts to create interesting sculptural volumes. The buildings on the sides share the same DNA-inspired shape, but are rotated 90° to one another, to be experienced as different. The middle buildings is unique to bring versatility to the composition. The towers decrease in height towards the more historically sensitive city center. This division of buildings makes it possible to construct the complex in parts, presumably starting with the lowest tower.



The towers are connected through bridges, creating a 700 meter walkway from the Opera to Frihamnen. The bridges connect the two sides of the city currently separated by the water. The towers extend "arms" towards their building neighbors and meet the ground in a conventional block manner. This helps create a human scale on the bottom floors. The first floor is also pushed in to break down the scale.



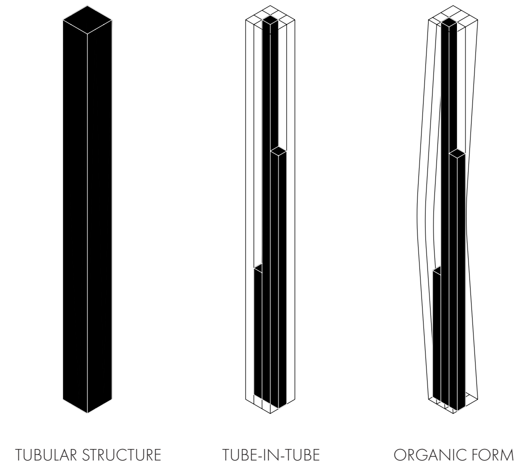
SITE PLAN 1:4000

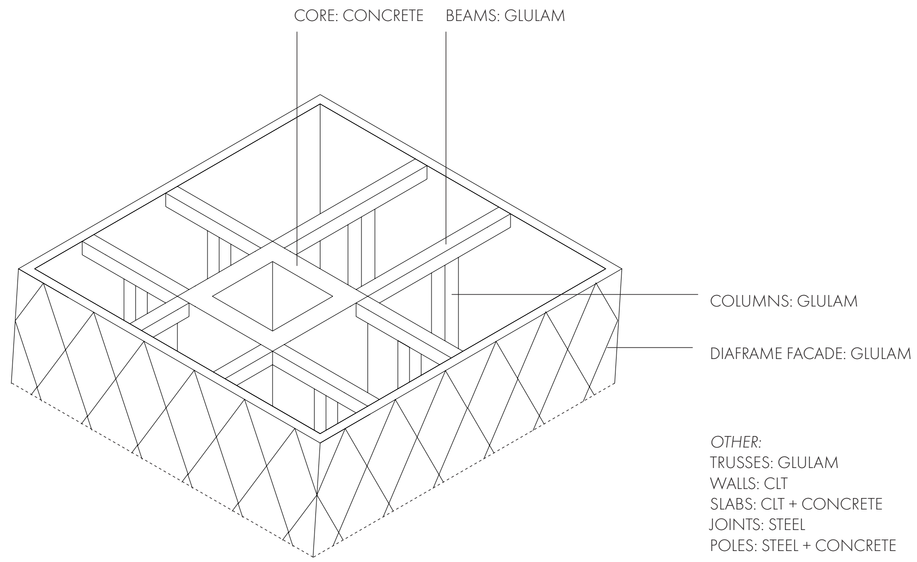
HYBRID TIMBER STRUCTURE

Mass timber is very strong compared to its weight. However it is a light material compared to concrete and steel. When structures become very tall they are exposed to very strong wind loads. To resist swaying and bending, more weight and stability is needed. Based on the Vertical City's need to be tall, this proposal uses a hybrid timber structure. Most of the construction is in mass timber, but concrete cores, concrete coated slabs and steel reinforcement are used to provide extra weight and stability.

TUBE-IN-TUBE STRUCTURE

A tube-in-tube structure is a member of the tubular structure family. In a tubular structure, the structural members (beams, columns etc) work together as a structural tube, creating strong resistance toward lateral and gravity loads. The main load bearing members in the tube-in-tube structure are the facade and the core. They are connected with horizontal beams and occasional outrigger trusses to transfer loads between them (Engel, 1997). The core, serving as a service core with elevators and fire escapes, increases in size in the bottom part of the tower, to provide more stability and space for vertical communication. The strength of the tube-in-tube structure allows for large column-free spans, which provides a spacious interior suitable for the versatility and adaptability of the Vertical City. It also allows for the bent shape of the towers. Each body bends around its central core.



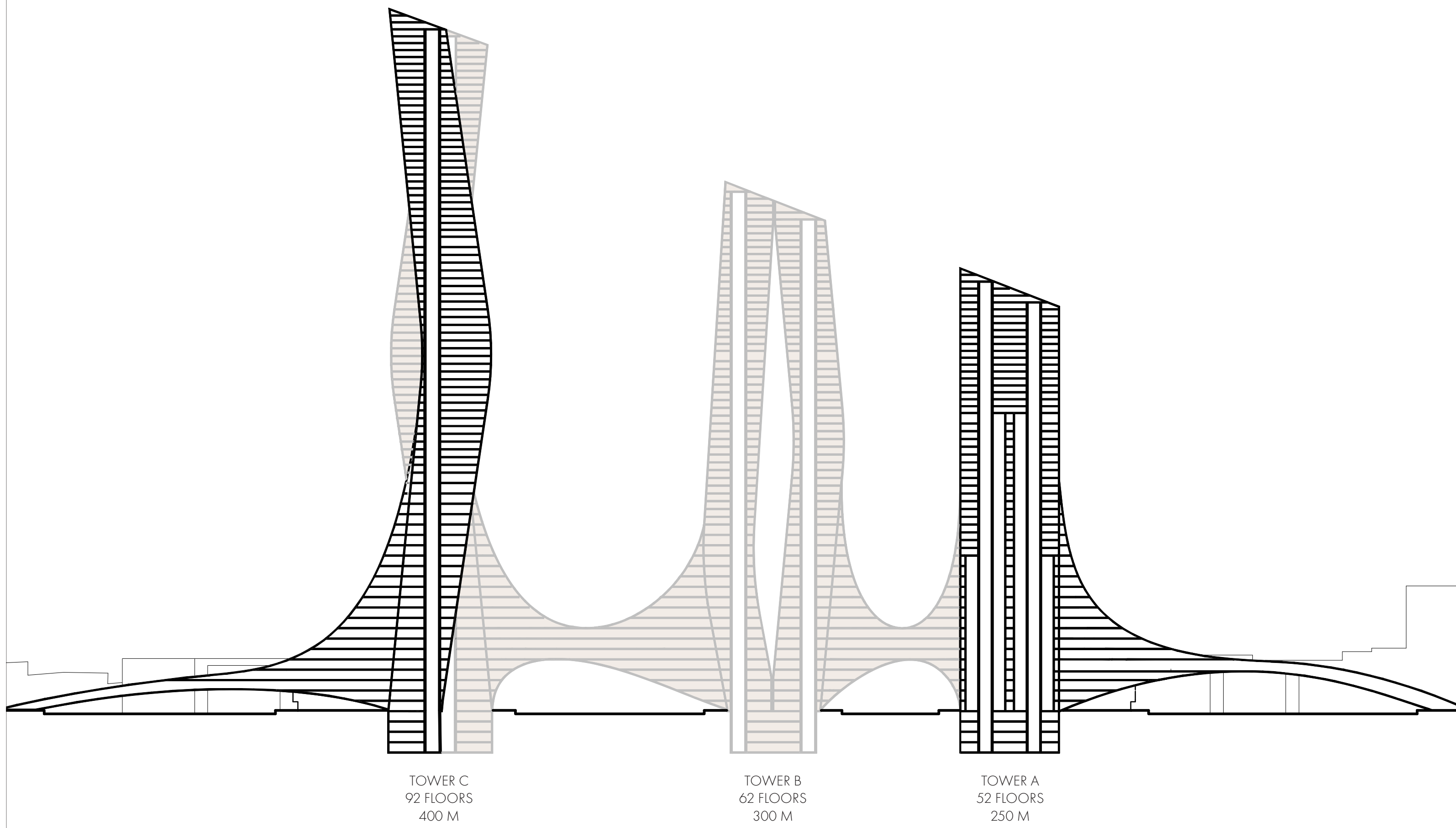


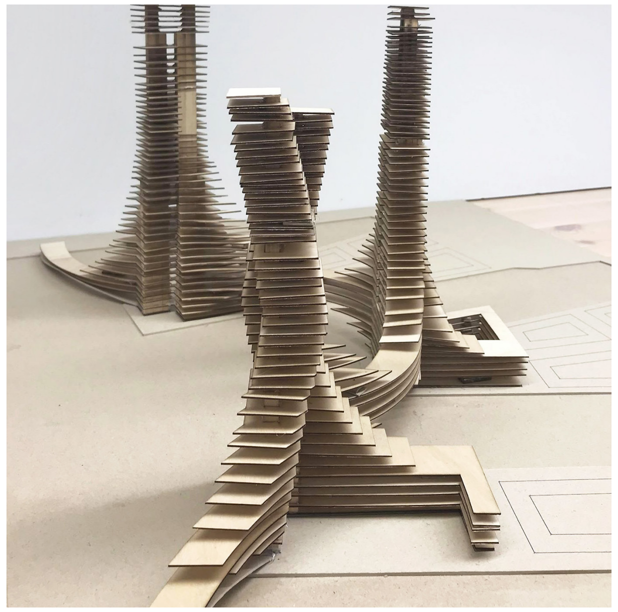
DIAGRID FACADE

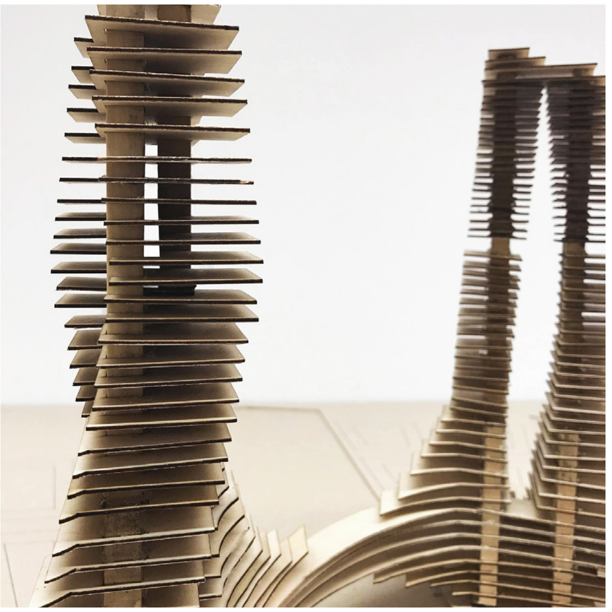
A glulam diagrid facade is used to allow for an organic design. A diagrid facade is a load bearing facade with only diagonal exterior members. The diagonal members carry both lateral and gravity loads, which reduces material use, and therefore cost, compared to a more traditional braced tube structure, where the diagonal members carry only lateral loads (Rahman, n.d.).

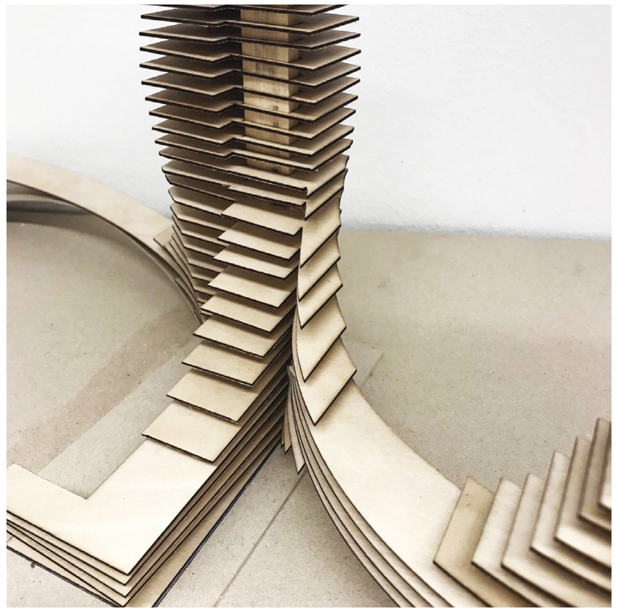
BRIDGE STRUCTURE

The towers are connected through bridges. The bridges have an arch-bridge structure, where large trussed arches in glulam carry the loads to each end of the arch. Due to the curved shape of the bridge plans, a plan is reinforced and connected to the cores, in order to resist tipping.









MODEL 1:1000

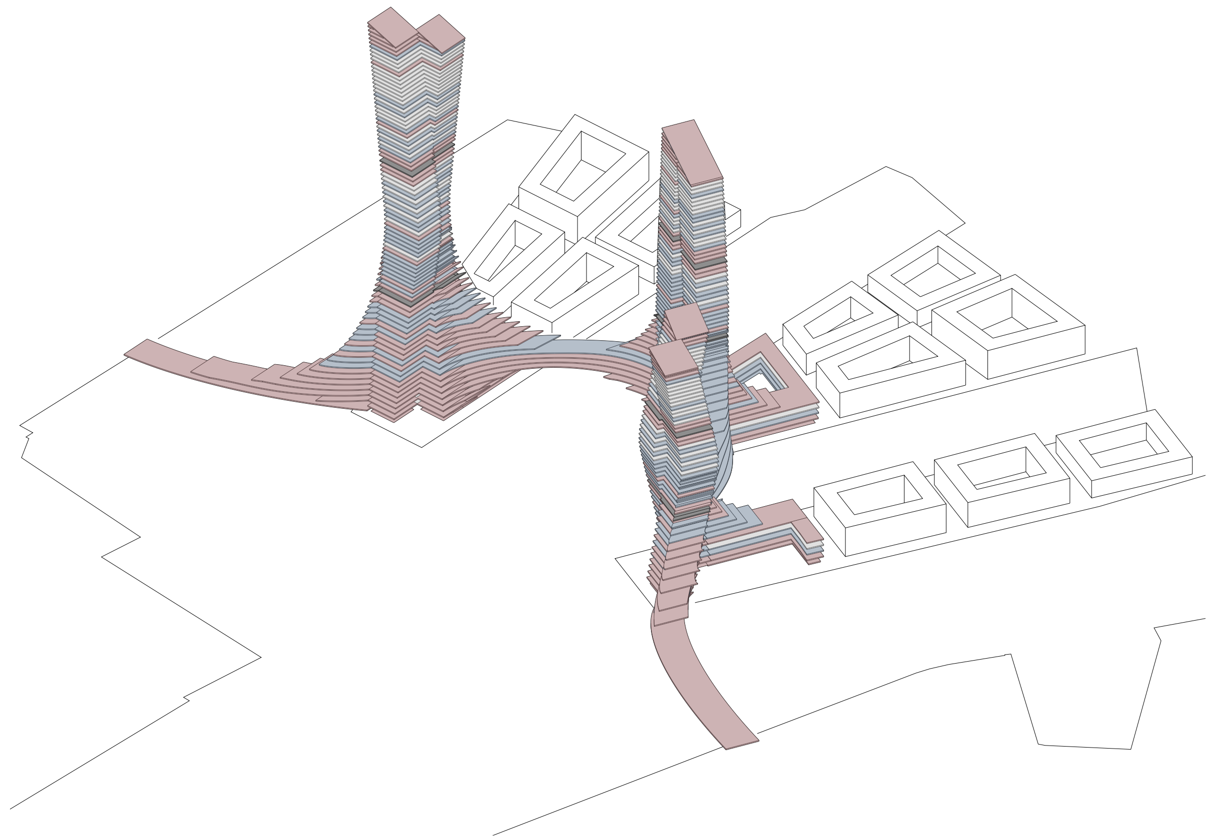
MODEL 1:1000

ADAPTABILITY

The exact program of this proposal is unspecified due to its extensive versatility. The proposal adopts a base building principal, which is to design a functioning building shell and core that can fit the needs of a versatile and adaptive program. Adaptability is important for future proofing the Vertical City, as the structure will outlive most tenants. The 30x30 meter bodies provide a regular square plan, that can host eight smaller tenants or one large, allowing for a wide range of tenants. The interior walls are not load bearing, so they can be moved for the arrival of a new tenant. If one tenant rents several floors, local staircases can be installed.

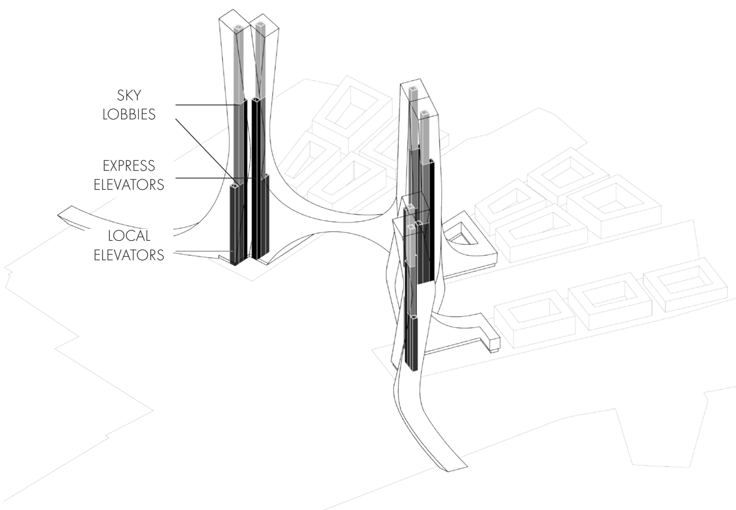
PROGRAM

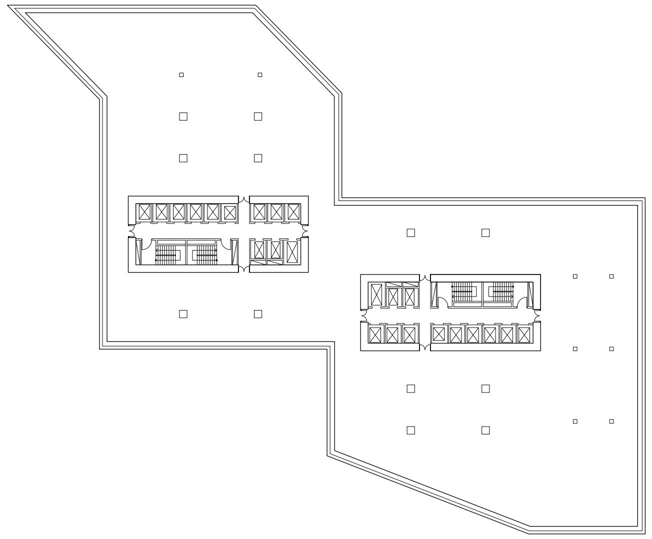
The program is divided into three broader categories: a residential neighborhood, a business district and a city center. The residential neighborhood will have housing of different sizes and types (including student and senior housing), shared community spaces, kinder gardens, small businesses and stores. The business district will consist of different offices (large corporations, private businesses, rentable office space, co-offices, restaurants, hotels and leisure. The city center will contain libraries, schools, parks, commercial functions, restaurants, leisure, churches, banks etc. The towers increase in size near the bottom to provide more space for the larger and more active functions.

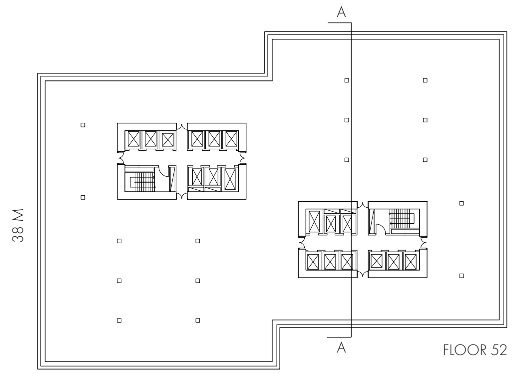


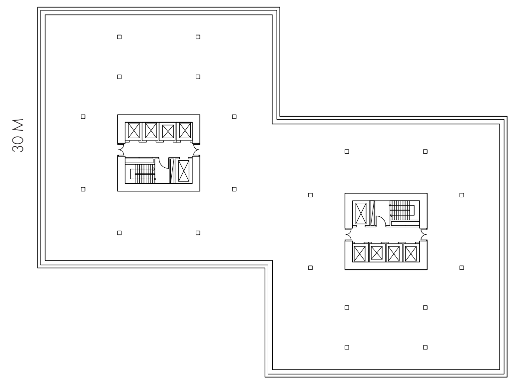
VERTICAL COMMUNICATION

The main motivation for the division of the program is efficiency in vertical communication. Much fewer elevators are needed for residential buildings than for office buildings. Therefore smaller and more private functions are placed higher up in the towers, so that fewer elevators and fire escapes need to reach all the way up. Consequentially, less space is consumed by the service cores. The towers have an express elevator system, where local and express elevators cooperate for higher efficiency, as is common in skyscrapers. Each tower has two sky lobbies. Sky lobbies are the bus stops of the Vertical City. Express elevators go directly to the sky lobbies, and from there the visitor is redirected to a local elevator. The sky lobbies separate the three broader categories of the program. The towers slab-to-slab heights vary based on the needs of the program: the city center has 6 meters, the business district has 4,5 meters and the residential neighborhood has 4 meters.



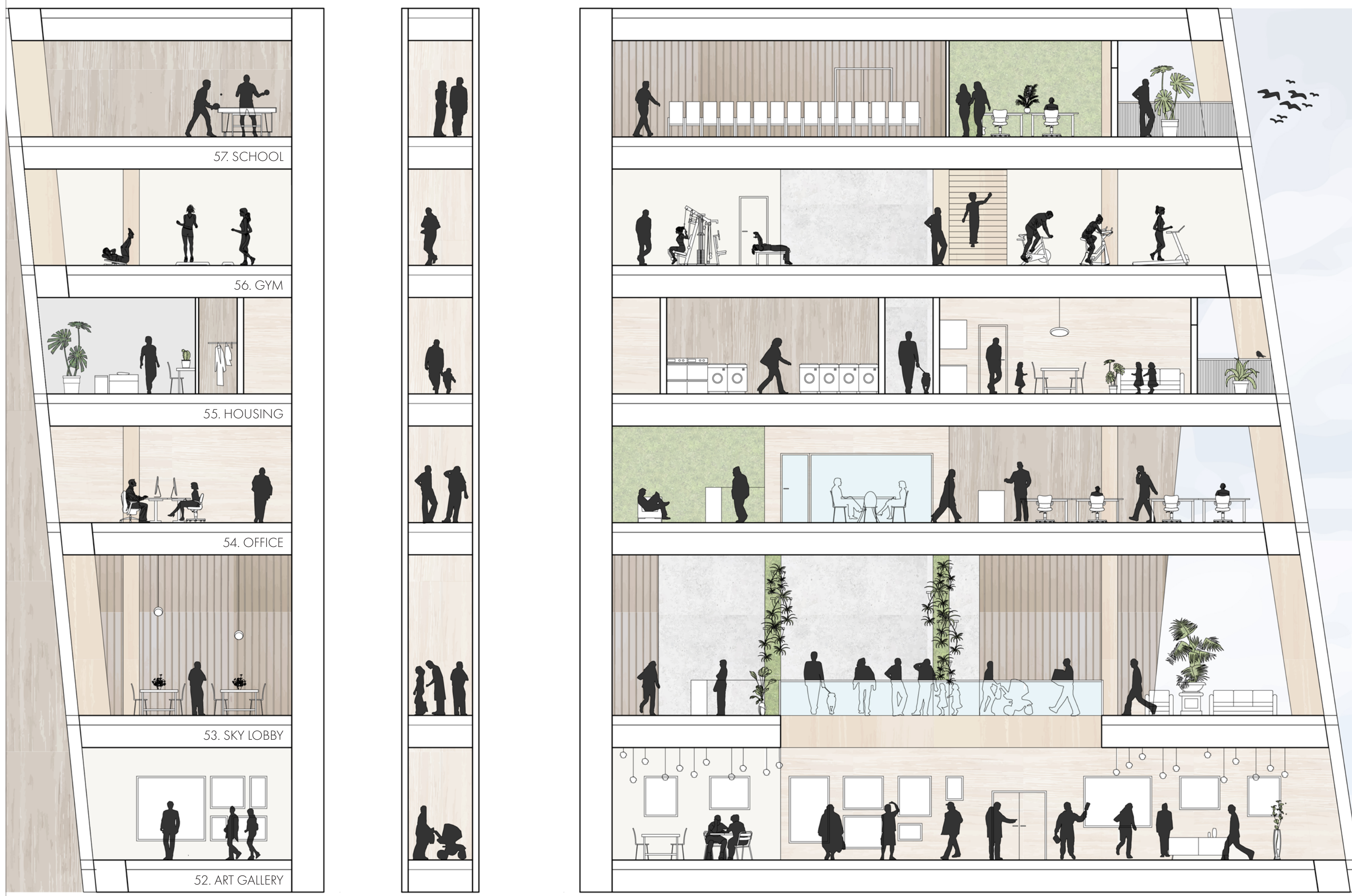






LAYERS OF ACTIVITY AND SCALE

The program gradually decreases in activity and scale towards the top. Different tenants may have widely different needs, for example, residential areas have a higher demand for daylight, calmness and privacy. The more slender tower tops provide excellent daylight conditions. Offices and public functions have a greater need of space. This is provided by the bridges and extending parts of the towers that compose larger floor plans towards the bottom. For all tenants, a sense of safety, community and privacy is possible by limited access to certain floors. For example, only residents of a residential unit may enter those floors. The residents may share laundry rooms, community spaces and gardens. The same principle applies to offices. Public floors are however open to everyone and welcome all of Gothenburg into the Vertical City.



SECTION A-A TOWER C 1:200

MASS TIMBER STRUCTURE

The exterior of the building tells a story about its structure. The mass timber structure is visible in the facade, reminding bypassers that the towers are made out of structural timber. The timber adds a soft and natural element to the otherwise mostly brick covered surroundings. It also stands as a symbol for its environmental benefits.

WOODEN INTERIOR

The towers likewise have a wooden interior. The presence of the wood brings the tenants closer to nature. It has a warm and calming effect that is beneficial for the health of all tenants, from those living there to stressed workers.

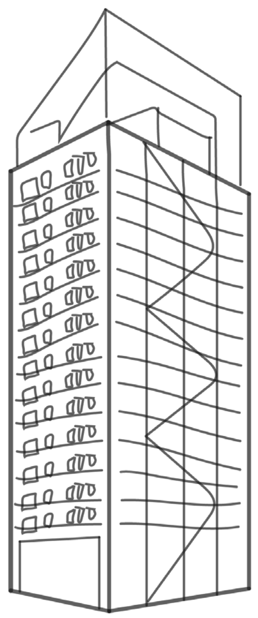
ACCESS TO NATURE

Pushed in balconies are spread out throughout the towers, as they give value to many tenants. Some will be private balconies, others will be public meeting spots. It is important that the tenants have close access to fresh air without having to go all the way out. Greenery is encouraged on balconies and interiorly. The already existing Jubileum Park is expanded to connect the three piers. Building tall allows for more space and less density on the ground. Walks are created along the buildings on the bays. Public functions on the bottom floors invite visitors to enjoy the proximity to the water. The activity will bring more people to the area.

4: REFERENCES

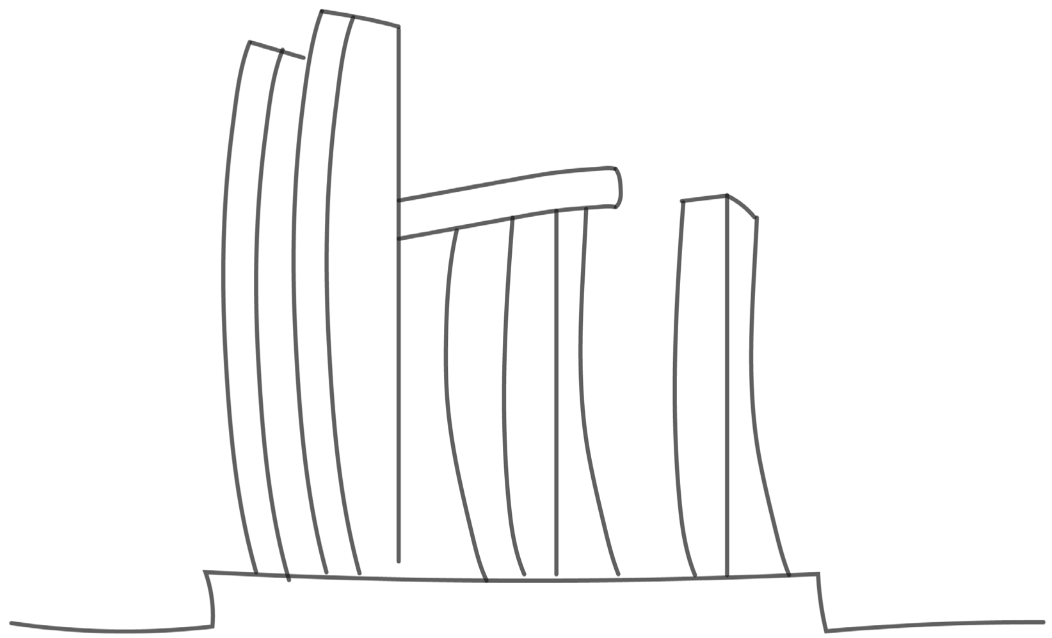
MJOS TOWER

ARCHITECT: Voll Arkitekter. *STATUS:* Completed in 2019. *LOCATION:* Brumunddal near Oslo. *PROGRAM:* Office and hotel. DIMENSIONS: 18 storyes, 85,4 m. *RELEVANCE:* Mjos Tower is the current tallest mass timber building in the world. It is therefore an important reference for what is currently possible, and a landmark for timber construction. It has paved the way for many upcoming timber high-rises. The Mjos Tower is constructed with Glulam beams and columns, and CLT core walls. Its upper floors are strengthened with a layer of concrete for extra weight and stability. Monitors are currently collecting data on how the structures is reacting to wind loads, to use for future research. (Abrahamsen, 2018)



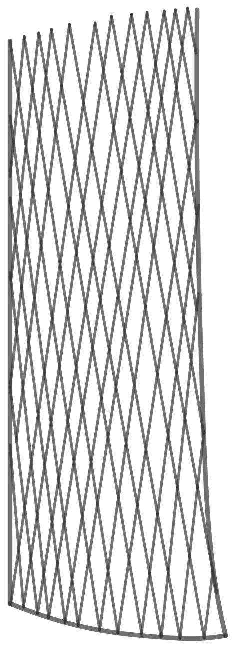
RAFFLES CITY

ARCHITECT: Safdie Architects. *STATUS:* Completed in 2019. *LOCATION:* Chongqing. *PROGRAM:* Office, residential, hotel, commercial. *DIMENSIONS:* 250 and 350 m towers. *RELEVANCE:* Raffles City is a reference in being a modern sort of Vertical City in scale and program. Raffle City is a complex consisting of 8 towers, connected in the bottom to a shopping mall podium, and on the top through the worlds longest "sky bridge" or "horizontal skyscraper", a 300 m long structure resting on top of the other skyscrapers. Residential, and office + hotel, are placed in separate skyscrapers. The structure consists of concrete cores and slabs and a composite outer moment frame. (Safdie Architects, n.d.)



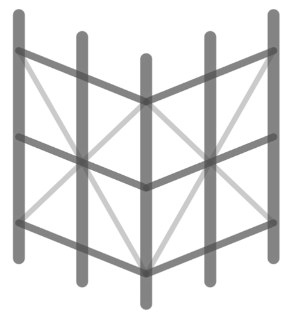
THE LODGE

ARCHITECT: PLP Architecture. *STATUS:* Proposed. *LOCATION:* Netherlands. *PROGRAM:* Residential and commercial. DIMENSIONS: 130 m. *RELEVANCE:* The Lodge, also called Oakwood timber tower 2, is a reference for a tall mass timber proposal. The main structural element is a glulam diagrid facade in two layers, following the oval form of the building. The proposal's interior visualizations show how the wood and diagrid facade benefit the interior aesthetics of the residential environment. Commercial functions are placed in the bottom and a sky lobby on top. (Plp Architecture, n.d.)



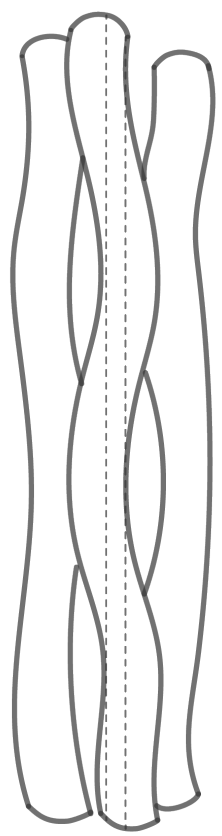
W350

ARCHITECT: Sumitomo Forestry + Nikken Sekkei. *STATUS:* Planned for 2041. *LOCATION:* Tokyo. *PROGRAM:* Offices, residential, hotel, commercial. *DIMENSIONS:* 70 storeys, 350 m. *RELEVANCE:* W350 is a mostly structural timber proposal in similar height to this proposal. It is a hybrid timber skyscraper made out of 90% timber and 10% steel. It has a brace tube structure with exterior timber and steel columns and beams strengthened by steel braces, to resist lateral loads. The interior is entirely in wood. Balconies and greenery are placed along the facade. The project aims to transform the city into a forest. (Sumitomo Forestry Co., 2018).



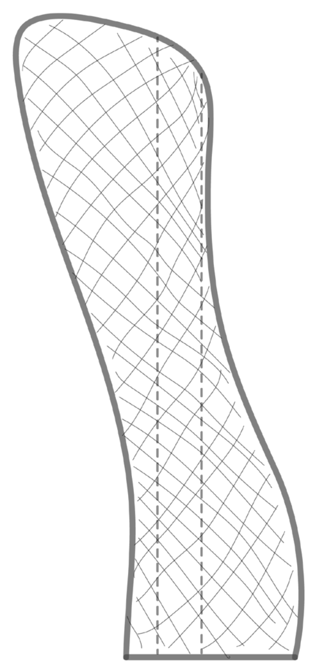
BUNDLE TOWERS

ARCHITECT: FMA. *STATUS:* Competition entry for replacement of World Trade Center 1 from 2002. *LOCATION:* New York. *PROGRAM:* Office. *RELEVANCE:* The Bundle Towers are an aesthetic and structural reference for the bundling of organic tubes concept of the proposal. The proposal is dynamic, brave and unique in its shape. The thin body of each tower provides good amounts of daylight. Each tower is carried by a central service core. The towers meet at several locations, forming sky lobbies to offer transfers between the buildings (FMA, n.d.).

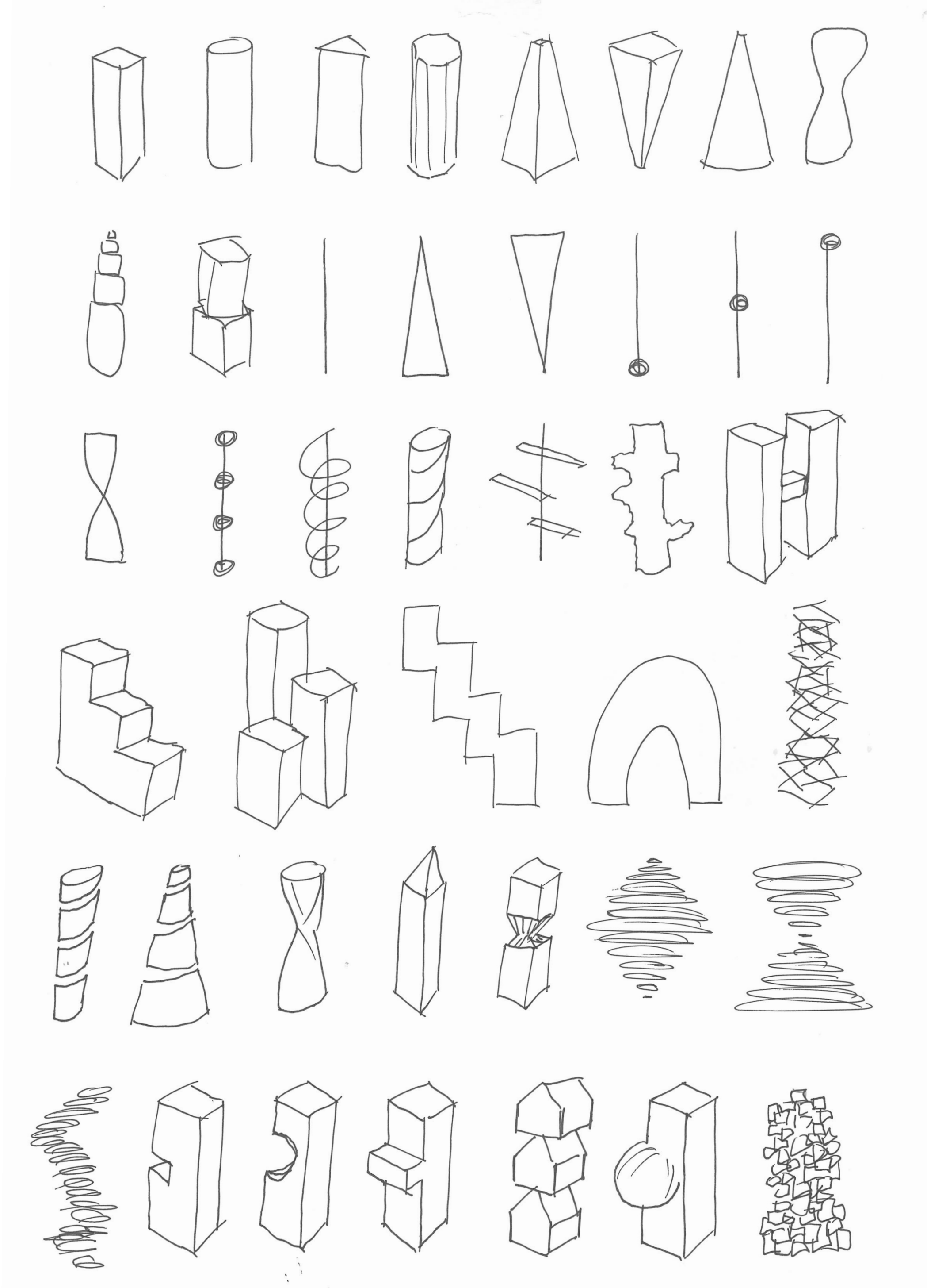


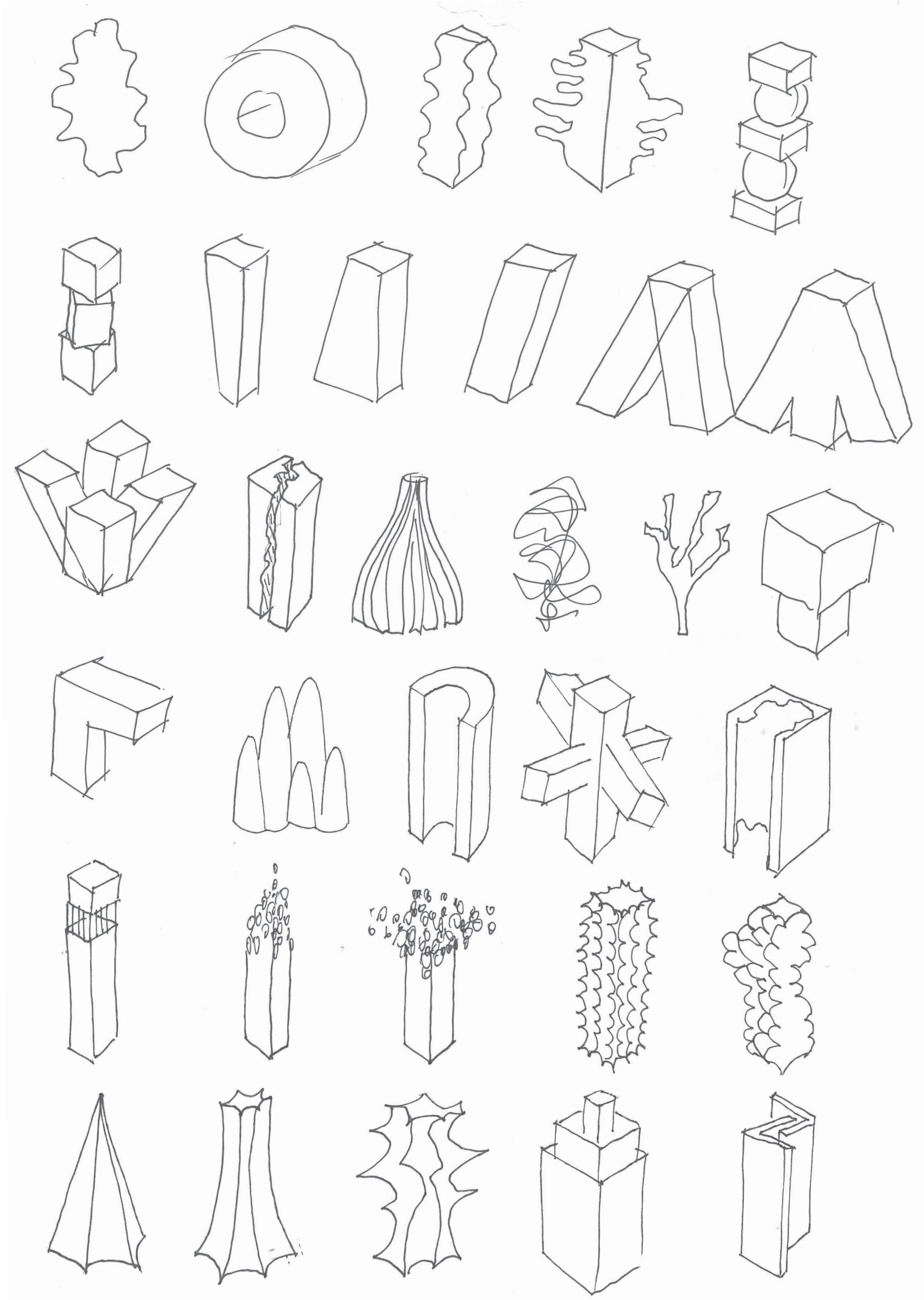
CAPITAL GATE

ARCHITECT: RMJM. *STATUS:* Completed in 2011. *LOCATION:* Abu Dahbi. *DIMENSIONS:* 35 storeys, 165 m. *PROGRAM:* Office, hotel, commercial. *RELEVANCE:* Capital Gate is the worlds most leaning tower, with its 18° lean. It is a central structural reference for the proposal due to its well documented structure, with a central core bearing and diagrid facade in structural steel. The building was constructed with a slightly leaning core, to balance the incline in the contrary direction. The efficient and innovative diagrid structure needs less steel than for instance a braced tube structure. (Capital Gate Abu Dhabi, 2018)



5: DESIGN PROCESS





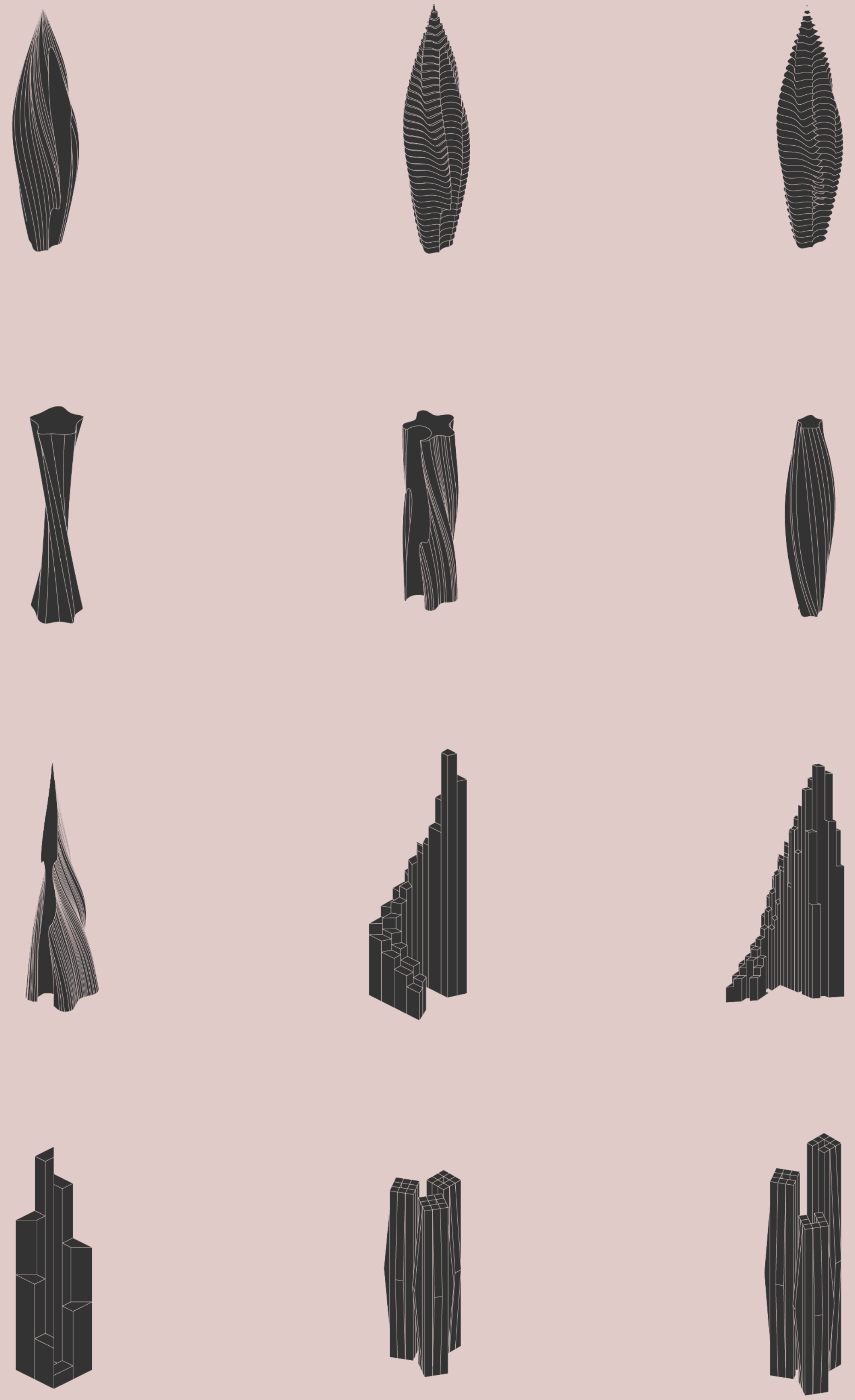
ONE HOUR SHAPE WORKSHOP

MASSING: EARLY ITERATIONS

This chapter documents iterations from loop 1-4. For explanation of method see page 16. For motivation of final proposal, see page 30. Massing iterations are conducted from the first week and throughout the entire project, and are the most well documented due to their visual nature. While categorized as *massing*, many of the iterations directly respond to structural, site-related and programmatic needs. But not the ones on this page. They are conducted in the first weeks, and aim to explore a wide range of possibilities.

From top right:

1. The following designs are inspired by the amorphous and wavy shapes of nature. In this design the service core is placed in the facade of the building, to give good daylight conditions and outlooks of nature to the vertical "streets" of the tower.
2. Voxelated version of 1.
3. Floor plans from 1. Deriving floor plans from the mass and not vise versa gives more control over the overall appearance, but less control over the shape of each floor plan.
4. Twisted shape.
5. Twisted shape with exterior elevator.
6. Twisted shape.
7. Twisted shape with exterior elevator.
8. Design inspired by ice.
9. Design inspired by ice.
10. Design inspired by ice, decreasing in gradual steps.
11. Configuration of three towers with open atriums facing each other.
12. Variation of 11. with versatile heights.



MASSING: MODEL

In the early part of the project this shape was a favorite due to its aesthetic qualities. However, when structure became an increased focus point, this idea was put aside in favor of others. A reflection is that many of these massing studies could have been projects. One shape can be constructed with several structures and one structure can be formed into a multitude of shapes. The more complex a shape is, the more constraints are placed on the structure. Supertall buildings are reliant on strong structural stability due to the massive lateral loads they are exposed to. This speaks in favor of a simple design that follows the structure. Still skyscrapers often adopt extravagant designs. Due to their impact on the skyline and symbolic significance they refuse to be plain.

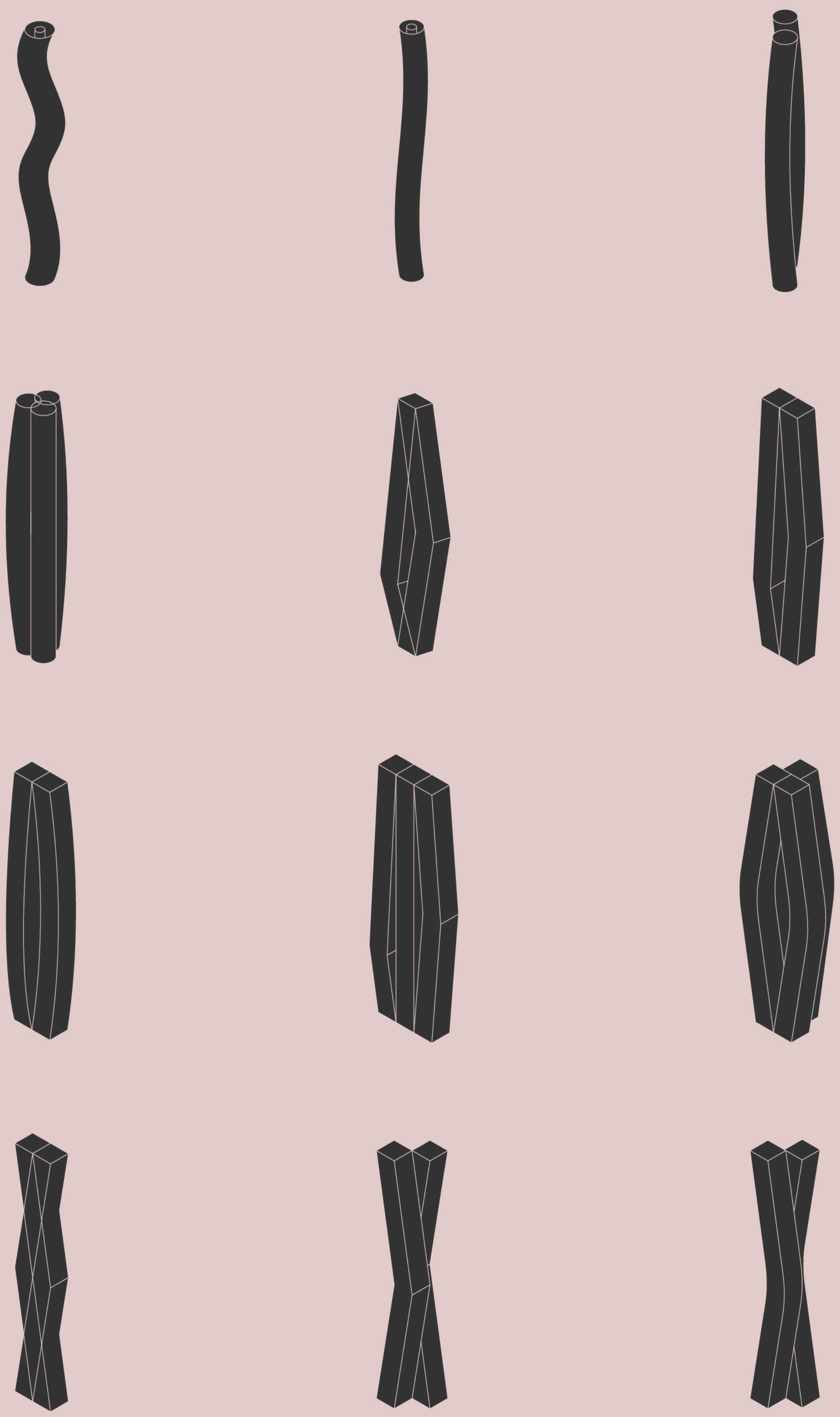
MODEL 1:500

MASSING: STRUCTURAL TUBES

These are massing iterations of bent structural tubes. The premise for the design is that the tubes only bends as much as a straight interior line allows, or more specifically the service core. The core becomes the main load bearing element, and allows the rest of the body to "move" around it. Once I decided to work with a tubular structure, the iterations became oriented towards finding interesting solutions within its capacities. Each tube can be conceptualized as an individual tower, or as parts of an tower, as in the final proposal.

From top right:

1. Wavy tube.
2. Less wavy tube.
3. Two curved tubes.
4. Three curved tubes.
5. Two straight bent tubes, melting together in top and bottom.
6. Variation of 5 with a more subtle curve.
7. Curved variation of 6. and close to final proposal.
8. Variation of 7. with a straight interior tube.
9. More bent variation of 7. with three towers.
10. Two mirrored straight bent tubes melting together.
11. Variation of 10. with the tubes separated, creating a DNA inspired volume.
12. Curved version of 11. and close to final proposal.

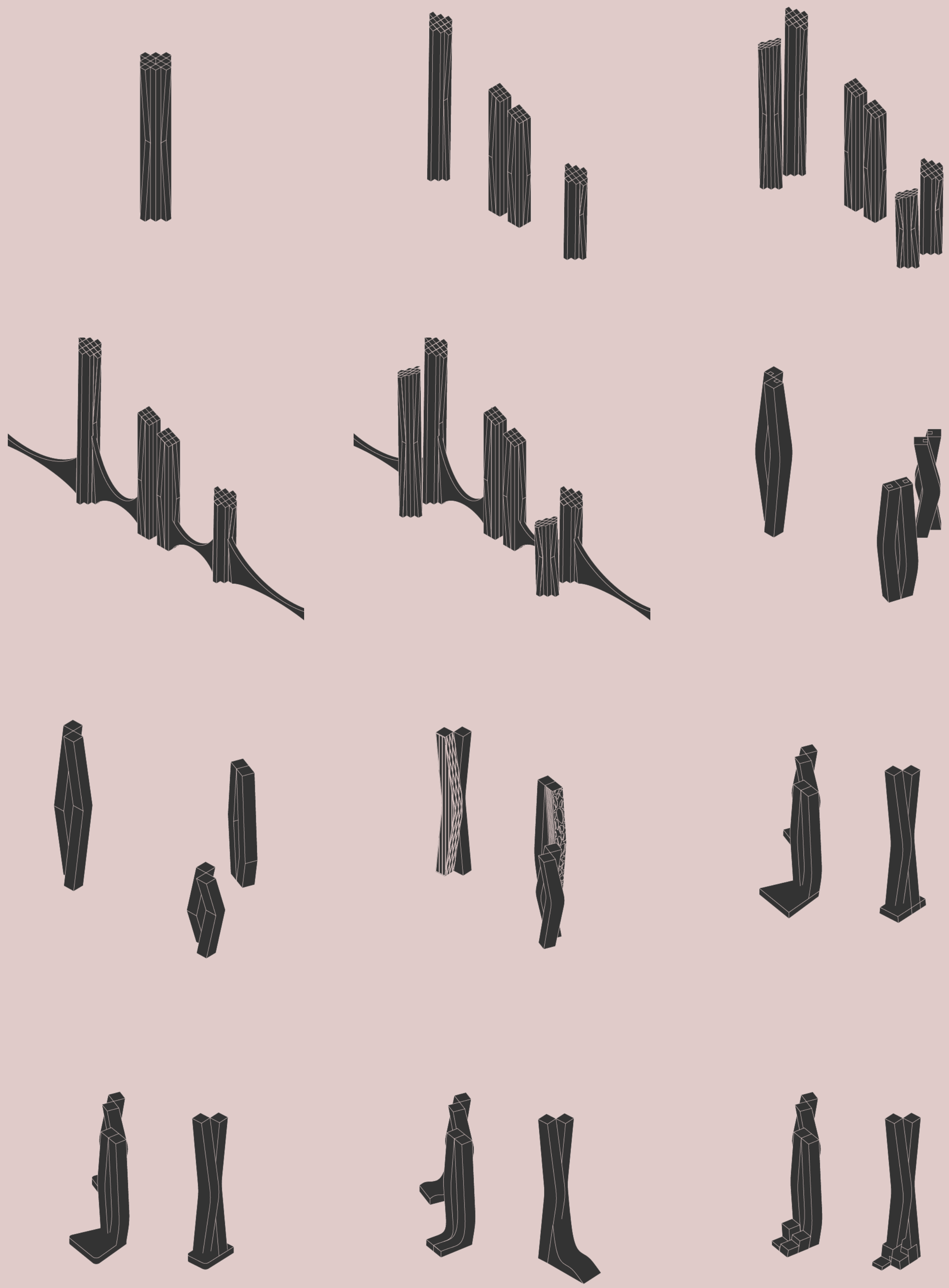


MASSING: CONNECTED TOWERS

A great challenge has been to create a tower composition on the three piers, to connect them to the ground and to connect them with bridges. The aesthetic challenge of the bridges is to connect the towers in a natural way. The bridges should neither be too delicate, thus leaving the towers looking like separate entities, nor too dominant, making the composition look too heavy and massive.

From top right:

1. A design deriving from a bundled tube structure consisting of nine 10x10 m tubes with triangular elements on the sides.
2. A configuration of four 1:s, placed on the piers with two towers on the middle piers. The towers are placed in a straight row. The towers and tower tops decline towards the city center, as in the final proposal.
3. A configuration of six 1:s, two on each pier. The two towers work together as one closely connected unit through local bridges.
4. 2. with bridges connecting the towers and two sides of the city.
5. 3. with bridges.
6. A configuration of tubes, see previous page. One tower consisting of two structural tubes is placed on each pier. The tubes help stabilize one another but could also stand as individual structures. In the O-shaped tower the program is also more separated, while the DNA shaped tubes are completely connected. The towers are not placed in a row to to create a more dynamic composition.
7. Variation of 6.
8. Variation of 6 and final proposal, with facade tests.
9. Final proposal of towers with podium test. The purpose of the podium is to connect the towers to the ground in a natural way that relates to the surroundings.
10. Variation of podium with curved edged.
11. Variation of podium with curved roofs.
12. Terraced podium.



From top right:

1. Final tower proposal with bridge test.

2. Bridge variation.

3. Podium variation and bridge test.

4. Podium variation and bridge test.

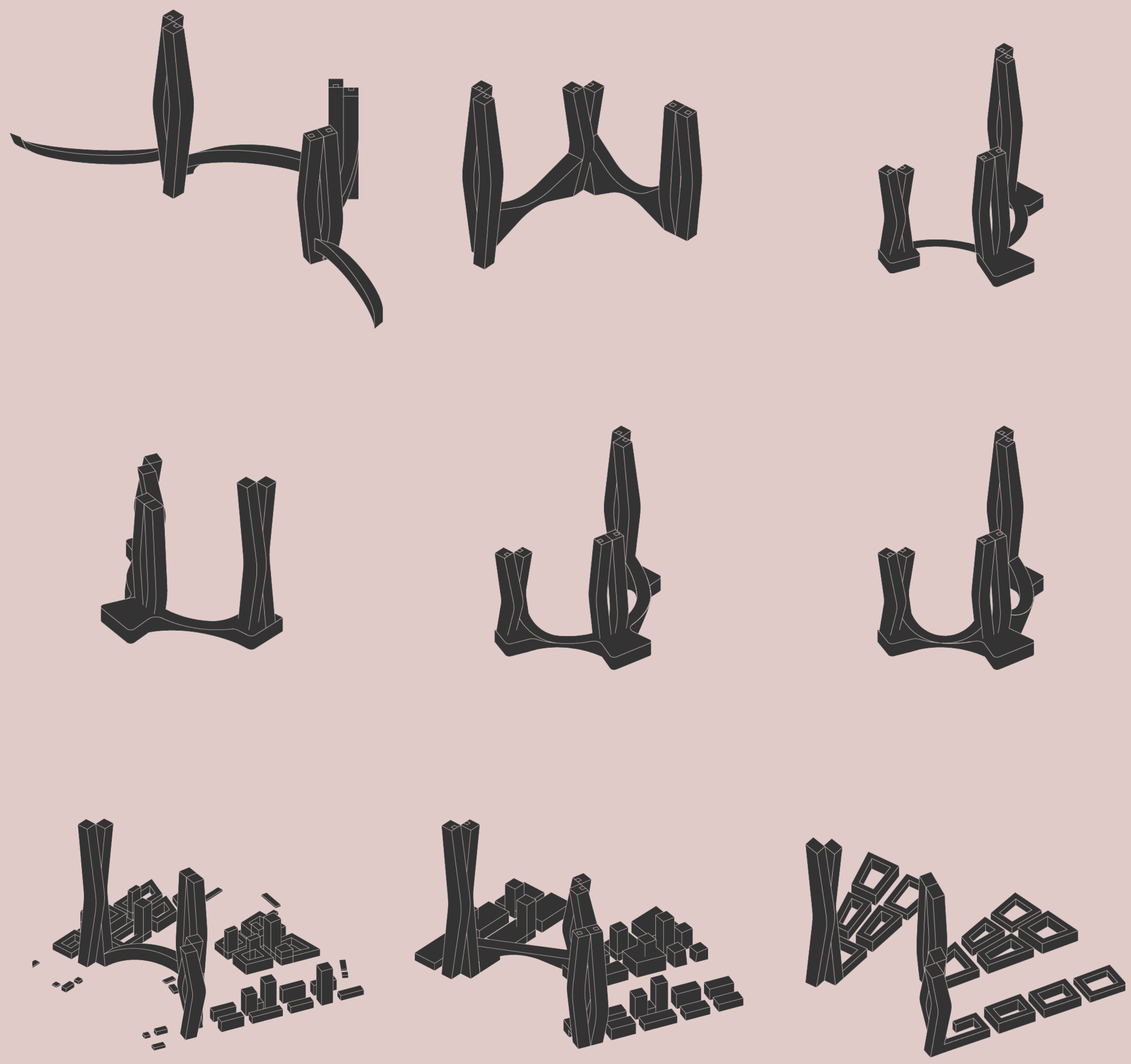
5. Podium variation and bridge test.

6. Podium variation and bridge test.

7. The surrounding buildings are modeled based on approximate plans for the site. Here, the towers are placed further back on the pier, leaving space in front of them.

8. Variation of 7. with towers meeting the water.

9. Final proposal. The surrounding buildings are modeled simply to communicate their typology and height. The towers are placed in the end of the pier and meet the water directly.

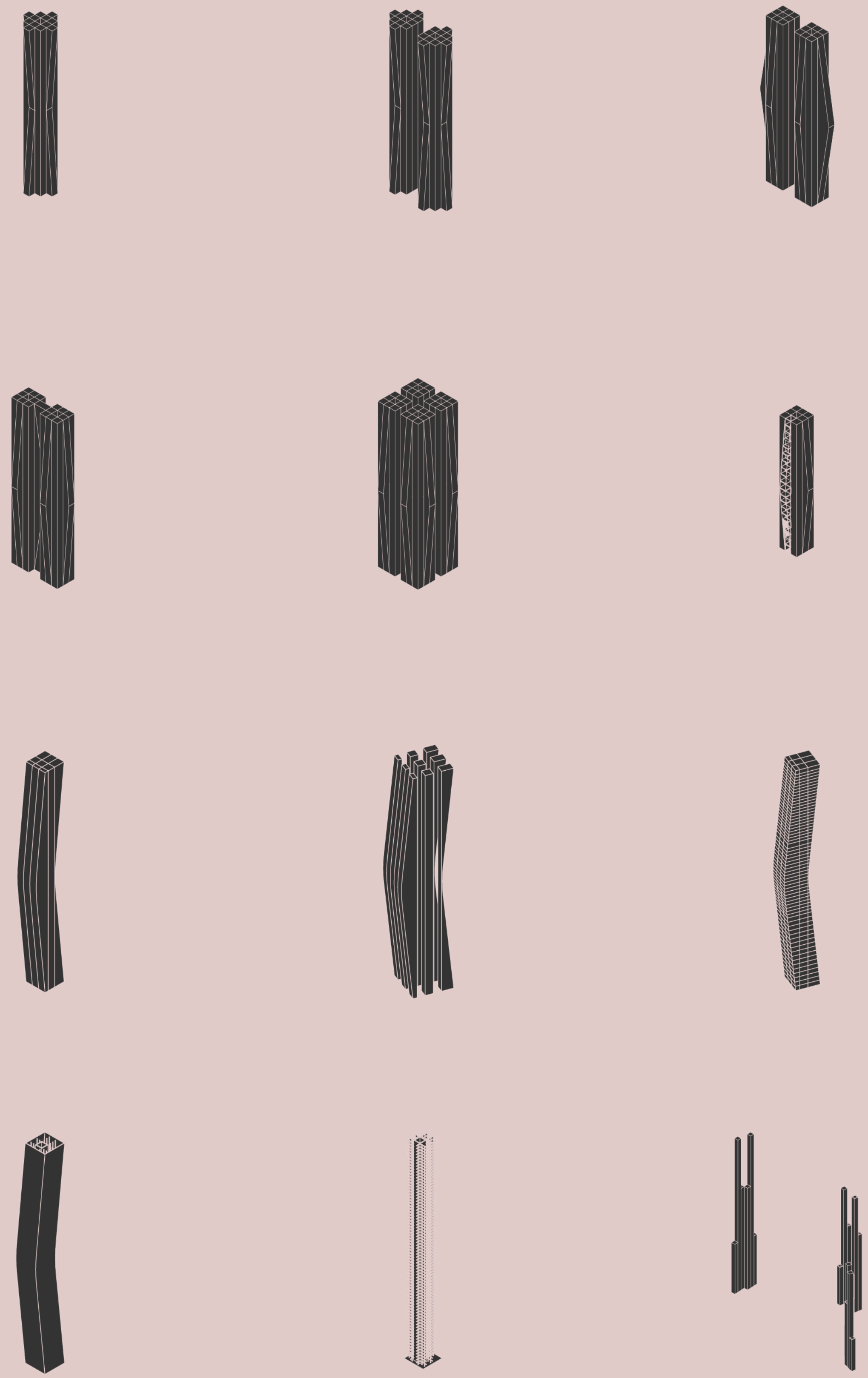


STRUCTURE

The main structural research is aimed at understanding different structures for skyscrapers and identifying their traits. The structures considered for the proposal are a bundled tube structure and a tube-in-tube structure. These are very strong and common skyscraper structures. The tube-in-tube structure was favored in the later part of the project since it allows for greater freedom in creating irregular shapes.

From top right:

1. A bundled tube structure consisting of nine 10x10 m tubes with triangular elements on the sides. The design aims to use a bundled tube structure yet move the design beyond a rectangular form.
2. A configuration of two 1:s.
3. An inverted version of the triangular elements in 2.
4. 3. connected with bridges. The connection explores how two closely placed buildings can function as one.
5. A configuration of four 1:s.
6. An open triangular element is used for shared terraces, reached through the central service core.
7. A bent tube body, leading to the final proposal. The shape derived from starting with 30x30 m bodies and bending them symmetrically around a straight central line, later gradually increasing the middle part to 38 m for increased visual effect.
8. Analyzing if the bend tube can be constructed as nine bundled tubes.
9. Floor plans of 8. Each plan is more of less identical but the service core placement varies due to the offset of the body.
10. Interior columns follow the nine tube grid, leaving approximately 100 m^2 column free spaces in between.
11. Interior beams also follow the nine tube grid, and transfer vertical loads between the diagrid facade and the core.
12. Service cores of final proposal. The cores become larger further down to handle increased gravity loads and supply the increased need for vertical communication.



SITE

The exact site was chosen two weeks into the project. The site related research has been aimed at understanding the site specific conditions and adapting the design thereafter. These iterations are documented under *massing*. The three piers inspired the idea of the three towers. Early in the process, an initial site visit was made. The photographs on the right are from that visit during a February afternoon. They capture the conditions of the current site and the surroundings. The surroundings are characterized by the presence of the water, the industrial vibe, the Opera and red and white high-rise building called *The Lipstick*. The site is wonderful in its placement and complete surrounding by water. However, I experienced the atmosphere of the piers during dusk as unpleasant due to an abandoned feeling, despite the beauty of the surroundings.







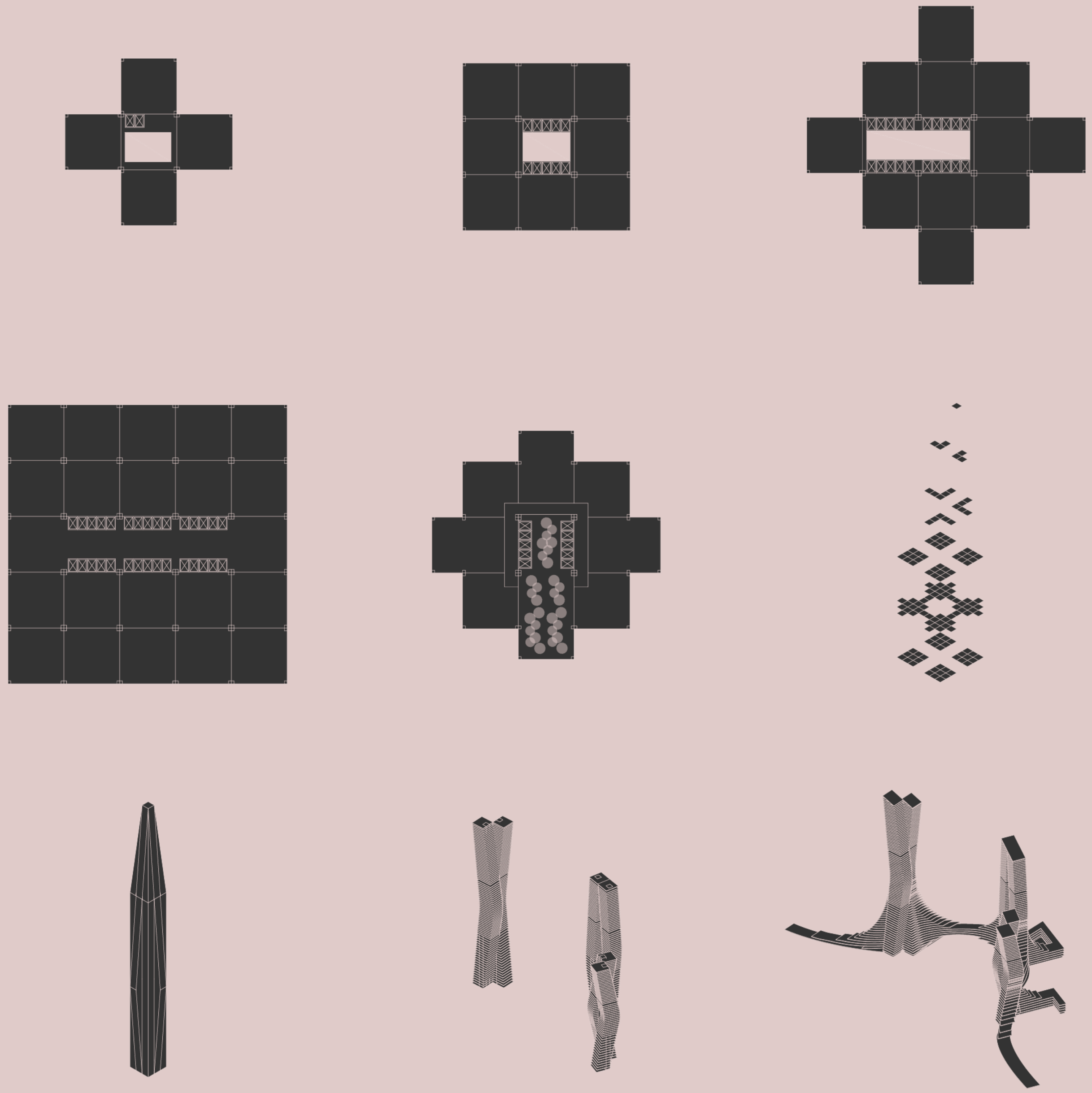


PROGRAM

The program related research has aimed at understanding programmatic needs and capturing them in the massing, structure and floor plans of the proposal. Programmatic needs considered are functions and their placement, how to provide an adaptable solution that simultaneously can meet the needs of the functions, vertical and horizontal communication, daylight conditions, how to create high quality public spaces and how to include nature in the design. As floor plans are not studied in detail in the final proposal due to time limitation, the programmatic impact is seen mainly in its effects on massing and structure.

From top right:

1. A plan derived from the bundled tube structure, consisting of five 10x10 m tubes, with a central service core.
2. Version of 1. with nine tubes.
3. Version of 1. with 13 tubes and a larger service core.
4. Version of 1. with 25 tubes and a larger service core. This creates a dark center more suitable for commercial functions.
5. Plan derived from 6. in Structure, see page 76. It consists of nine tubes, with four tubes varying in size to create a triangular geometry. A large atrium transforms the service core into a public park, seeking to offer high quality public spaces and a connection to nature and the outdoors.
6. Creating a design from the plan configurations in 2-3, gradually decreasing in size tube by tube.
7. Shape derived from lofted floor plans 2-3.
8. Floor plans of towers in final proposal, derived from mass.
9. Floor plans including bridges and extending blocks.



6. DISCUSSION

REFLECTION

When designing for the future, the process becomes speculative. It is easy to be swept away by dreams of endless possibility, or contrarily wonder if any of it will be possible. Through the design and literary findings of this thesis, I conclude that the Vertical City is a smart response to severe urbanization, as megastructures will relieve the city ground space and nature. I estimate that we will have the technological knowledge, environmental motives and economical possibilities to invest in such megastructures.

For architects, a shift towards more urban settings and larger buildings means reevaluating how our current skills can be applied to the changing context. In this thesis, the unfamiliarly large scale has been an essential challenge. It poses a need to relate to more scales, from its impact on the city skyline to its tenants needs for a humane environment. The proposal has focused on the larger scale, much like an urban plan of a city where each building is not detailed but the functions are well disposed and arranged.

CONCLUSION

This thesis aimed to respond to how a skyscraper can function as a Vertical City and how the use of timber can affect the Vertical City structurally and socially. Based on design iterations, a design proposal, research of reference projects and literature studies, this thesis found that the key elements of a skyscraper functioning as a Vertical City is the broadly mixed program and dedication to sustainability, in which the timber plays a crucial role.

The proposal investigates how a Vertical City can act within a city, more specifically in the context of Gothenburg. The challenges of this site have been to connect the towers so they can coexist as one community, connect the two sides of the city through raised bridges and relate to the lower surrounding blocks. By responding to these challenges, the proposal has arrived at its particular design with bridges and extended parts. Connecting the parts into an appealing and sensible composition, and using the connections as extensions of the floor plans for large functions, have been crucial aspects of the design.

The proposal found that a bottom heavy structure that decreases in size further up is ideal for structure, vertical communication and program. The service cores, also being the main load bearing elements, provide more stability and serve the activity on the larger bottom floors. This motivates the division of the program, creating layers of privacy and placing daylight demanding functions further up in the more slender parts of the towers. The rational shape of the plans and the large column free spans provided by the strong tube-in-tube structure allow for future adaptability.

The main motive for using mass timber construction is the lower CO^2 footprint. The main social motives are the physiological benefits of the natural material. A Vertical City in timber brings a calm and soft element to the city, and relates to Sweden's long timber tradition. The biggest constraint on a very tall structure in timber is the challenge of the lower weight of the material. In this proposal, this is balanced by using a concrete core to stabilize the construction. In hybrid structures, the strengths of both materials can coexist. A structure predominantly in timber still provides most of the benefits of the material. I believe it is a good way to introduce more timber into conventional construction. Mass timber is strong enough to largely replace concrete and steel which will have great environmental benefits.

FUTURE RESEARCH

The present work can be continued in several directions. First, the interior environments can be studied in detail. This will give greater insight into programmatic aspects. Secondly, the construction can be studied more in detail as well. Thirdly, the facade can be studied from an environmental and energy standpoint. I also encourage more Vertical City explorations, as this typology might play a significant role in our cities soon. This thesis offers a summary of many potential focus areas of a Vertical City that could be further explored. My suggestions are: a Vertical City on a budget (incorporating the pressing economical issue, yet aiming to keep the quality), a study of a self-sustaining Vertical City, a megatall Vertical City in a super dense megacity, and a Vertical City in an extreme climate.

Another suggestion for future research is more investigation and careful monitoring of tall timber buildings, current and upcoming. I challenge other students and practitioners to be critical of the material choices for their projects, and not chose concrete or steel out of pure comfort. To make it easier for architects to select mass timber, I am missing a design guide for tall timber buildings targeted at architects, providing an easy but comprehensive introduction to mass timber. I am also suggesting critical studies of the environmental impacts of mass timber construction from impartial sources.

7. BIBLIOGRAPHY

LITERATURE

Borden, G.P. Meredith, M. (2012). *Matter: Material Processes in Architectural Production.* Abingdon: Taylor & Francis Group.

Engel, H. (1997). *Structure Systems.* (3rd ed.) Ostfildern: Hajte.

Green, M. (2019). *The case for Tall Wood Buildings: How Mass Timber Offers a Safe, Economical, and Environmental Friendly Alternative for Tall Building Structures.* (2nd ed.) Retrieved from: http://thecasefortallwood.com/

Woods, E.M. *(2011)* Between Latitudes. iUniverse: Bloomington.

Yeang, K. (1996) *The Skyscraper Bioclimatically Considered.* Chichester: Academy Editions.

REPORTS

Abrahamsen, R. (2018). *Mjøstårnet - 18 storey timber building completed.* 24. Internationales Holzbau-Forum IHF. Retrieved from https://www.moelven.com/globalassets/moelven-limtre/mjostarnet/mjostarnet---18-storey-timber-building-completed.pdf

Boverket. (2017). *Urban Density Done Right: Ideas on densification of cities and other communities.* Retrieved from: https://www.boverket.se/globalassets/publikationer/dokument/2017/urban-density-done-right.pdf

SOM. (2014). *Timber Tower Research Project System Report.* SOM. Retrieved from https://www.som.com/ideas/research/timber_tower_research_project

ARTICLES AND WEB PAGES

Arcosanti.org. (n.d.). *The Arcology Concept: Architecture + Ecology.* Retrieved from https://arcosanti.org/project/arcology/

Bellis, M. (2020). *The First Skyscrapers: Learn the history of skyscrapers.* Retrieved from https://www.thoughtco.com/how-skyscrapers-became-possible-1991649

Capital Gate Abu Dhabi. (2018). Retrieved from https://www.e-architect.co.uk/dubai/capital-gate-abu-dhabi

City of Gothenburg. (2012). *Rivercity Gothenburg Vision.* Retrieved from https://stadsutveckling.goteborg.se/siteassets/alla-bilder/rivercity_vision_eng_web-2.pdf

Coats, P. (2017). *Introduction to Mass Timber Construction.* Retrieved from https://www.usg.edu/assets/facilities/documents/foc/2_Introduction_to_Mass_Timber_Construction.pdf

Council on Tall Buildings and Urban Habitat. *(2020) Tall, Supertall, and Megatall buildings.* Retrieved from https://www.ctbuh.org/resource/height

Fell, D. (n.d.). *Wood and Human Health.* Retrieved from http://www.wood100.ca/articles/wood-and-human-health.pdf

FMA. (n.d.). *World Trade Center 2: Ground Zero Memorial Towers.* Retrieved from https://www.farshidmoussavi.com/node/110#world_trade_centre_2_ground_zero_memorial_towers_new_york_110_42

Guidebook Sweden. (2016). *Granhults Kyrka: Sweden's oldest wooden church.* Retrieved from https://www.guidebook-sweden.com/en/guidebook/destination/granhults-kyrka-swedens-oldest-wooden-church-lenhovda

Guinness World Records. (n.d.). *Raffles City Chongqing.* Retrieved from https://www.guinnessworldrecords.com/world-records/first-skyscraper/

Havgrave, J. (2013). *It's Alive.* Retrieved from https://foresight.arup.com/publications/its-alive/

OECD. (n.d.) *Rethinking Urban Sprawl - Moving towards Sustainable Cities.* Retrieved from https://www.oecd.org/environment/tools-evaluation/Policy-Highlights-Rethinking-Urban-Sprawl.pdf

PLP Architecture. (n.d.). *Oakwood Timber Tower 2: The Lodge: The Neatherlands.* Retrieved from http://www.plparchitecture.com/oakwood-timber-tower-2.html

Rabaca, A. Martins, C.M. (2018). *On Bigness and the Problem of Urban Form.* Retrieved from https://www.researchgate.net/publication/324969880_Bigness_and_the_Problem_of_Urban_Form

Rahman, F. U. (n.d.). *Diagrid Structural System: Types, Materials and Advantages.* Retrieved from: https://theconstructor.org/structural-engg/diagrid-structural-system/13731/

Safdie Architects. (n.d.). *Raffles City Chongqing.* Retrieved from https://www.safdiearchitects.com/projects/raffles-city-chongqing

Sumitomo Forestry Co. (2018). *Changing Cities into Forests: W350 Plan for Wooden High-Rise Building.* Retrieved from http://sfc.jp/english/news/pdf/20180214_e_01.pdf

Swedish Wood. (n.d.). *The forest and sustainable forestry.* Retrieved from https://www.swedishwood.com/wood-facts/about-wood/wood-and-the-environment/the-forest-and-sustainable-forestry/

UNESCO. (n.d.). *Buddhist Monuments in the Horyu-ji Area.* Retrieved from https://whc.unesco.org/en/list/660/

United Nations. (2018). *Around 2.5 billion more people will be living in cities by 2050.* Retrieved from https://www.un.org/development/desa/en/news/population/2018-world-urbanization-prospects.html

United Nations. (2017). *Global Status Report 2017.* Retrieved from https://www.worldgbc.org/sites/default/files/UNEP%20188_GABC_en%20%28web%29.pdf

Verticalcity.org. (n.d.). *8-8-8 Manifesto Of New Urban Form.* Retrieved from https://verticalcity.org/8-8-8-manifesto-of-new-urban-form.html

FIGURES

1. Linda Sköneskog (2018). *Packhuskajen Göteborg.* [Watercolor]. Göteborg.
2. Linda Sköneskog (2018). *Shanghai.* [Watercolor]. Shanghai.
3. Linnea Kikuchi (2014). *A City in the Sky.* [Acrylic paint on canvas]. Stockholm.
4. Linda Sköneskog (2019). Stavershult. [Watercolor]. Göteborg.

CHALMERS