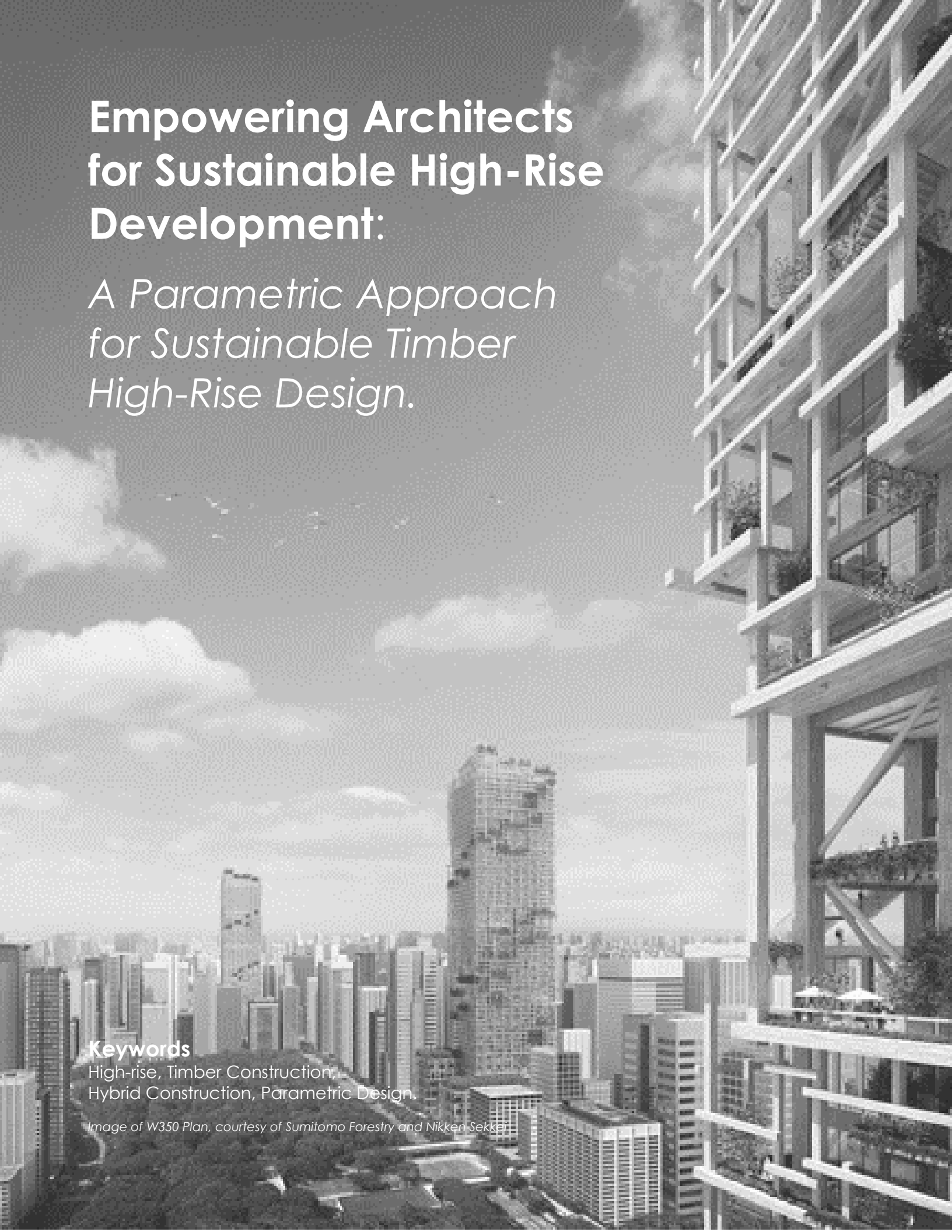
Empowering Architects for Sustainable High-Rise Development:

A Parametric Approach for Sustainable Timber High-Rise Design.



Keywords
High-rise, Timber Construction, Hybrid Construction, Parametric Design.

Image of W350 Plan, courtesy of Sumitomo Forestry and Nikken Sekkei

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Argumentations of choice of the studio

In the last couple of years, I've developed a significant fascination for high-rise architecture. This started when I embarked on a new chapter and moved to Rotterdam right after completing my bachelor's degree. When moving to Rotterdam, which is of course well known for it's relatively large amount of high-rise buildings, I encountered high-rises on a daily basis, both through city life but never the less at the office where I was working at the time.

During my time working there, I never had the opportunity to work on these high-rise projects, at least not for a significant amount of time. Nevertheless, the complexity and grandeur of these projects consistently captured my attention when seeing them every now and then passing by when being in the office. What made the idea of working on high-rise projects more compelling over time.

Now during my masters, and more specifically my graduation year, I find myself in a unique position. I have the opportunity to pursue a self-defined case that is centered around the task of designing a high-rise building myself. Upon careful consideration of my options, it became evident that this was best suitable within the Architectural Engineering Graduation Studio. Therefore, I applied for this studio.

Source: https://singularityhub.com/2022/04/27/could-future-skycrapers-be-made-of-wood-two-new-timber-towers-are-going-up/

General Problem Statement:
Rethinking High-Rise Construction for Sustainability

In the Netherlands, the significant majority of its population resides in urban areas, constituting about 74% of the total population. Of these urban residents, 44% are located in cities (Nabielek en David Hamers, n.d.). *This strong preference for urban living is driving the demand for high-rise construction, and the need for high-rises in the Netherlands is becoming increasingly evident, especially in cities like Rotterdam* (***Emiel Arends: "Als We de Binnenstad Willen Verdichten, Ontkomen We Er Niet Aan Om de Hoogte in Te Gaan" – Gebiedsontwikkeling.Nu***, n.d.).

High-rise development presents a valuable opportunity for urban densification, perfectly aligned with the 'Compact City' concept. It makes efficient use of limited land resources while reducing urban sprawl. The vertical organization of high-rises also promotes mixed-use, enabling the creation of vibrant communities with easy access to amenities and job opportunities.

The compact city concept, as highlighted in 'The Compact City Concept in Today's Urban Contexts' (2012)*, consists of the following fundamental aspects:*

1. ***Dense and proximate development patterns****: This aspect underlines the need for urban areas to be thoughtfully and efficiently designed, ensuring that every square meter of space is purposefully used.*
2. ***Urban areas connected by public transport systems****: An effective network of public transportation not only enhances mobility but also diminishes reliance on personal vehicles, a cornerstone of sustainable urban development.*
3. ***Accessibility to local services and jobs****: Proximity to essential services, educational institutions, healthcare facilities, and employment opportunities is central to the compact city's vision.*

Concentrating people and activities within high-rises in line with the principles of the compact city, reduces car dependency and encourages sustainable transportation (Bibri et al., 2020). *As a result, carbon emissions will be significantly reduced through shorter commute distances* (Bibri et al., 2020)*, among many other positive effects as can be seen in 'Figure 1'.*

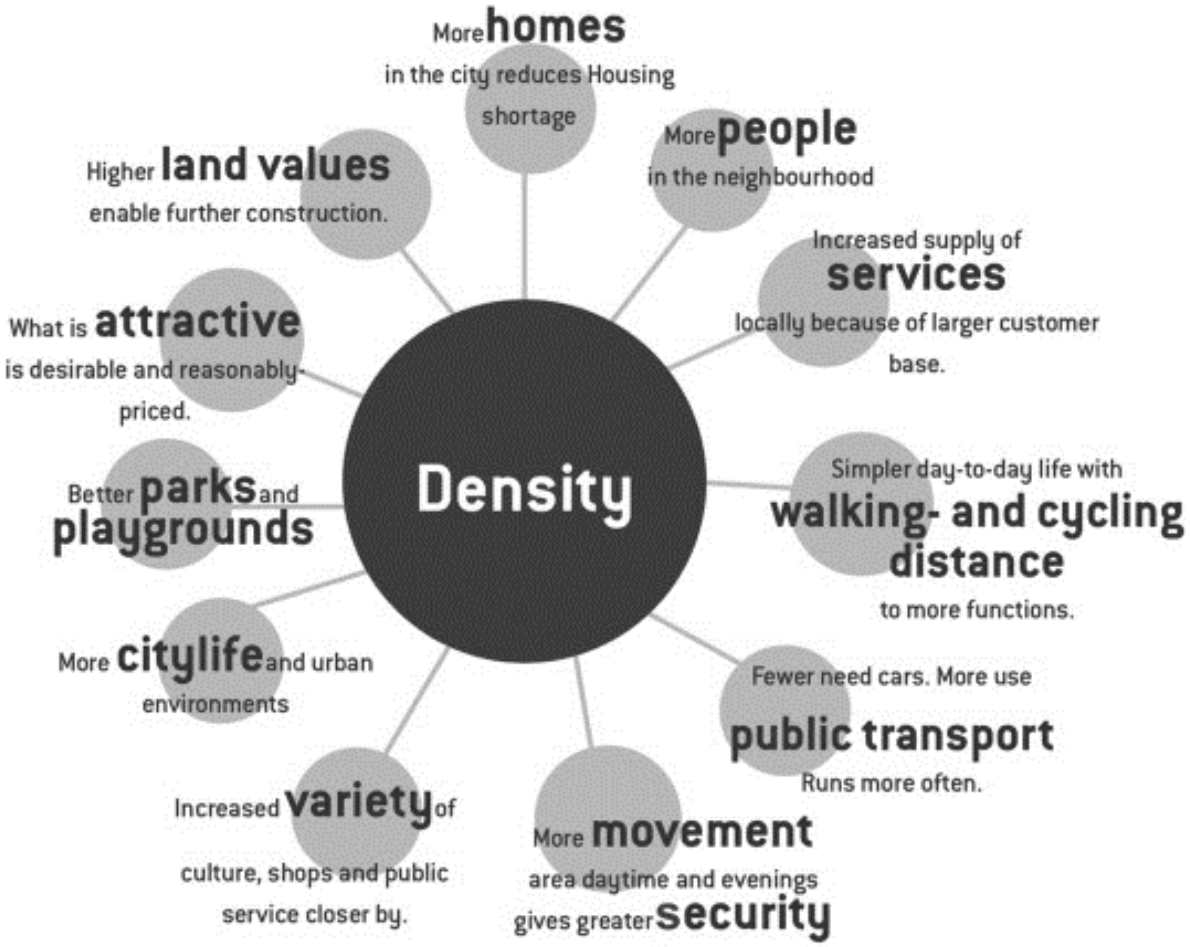

Figure 1: Multiple positive effects of population density
Source: (Bibri et al., 2020)

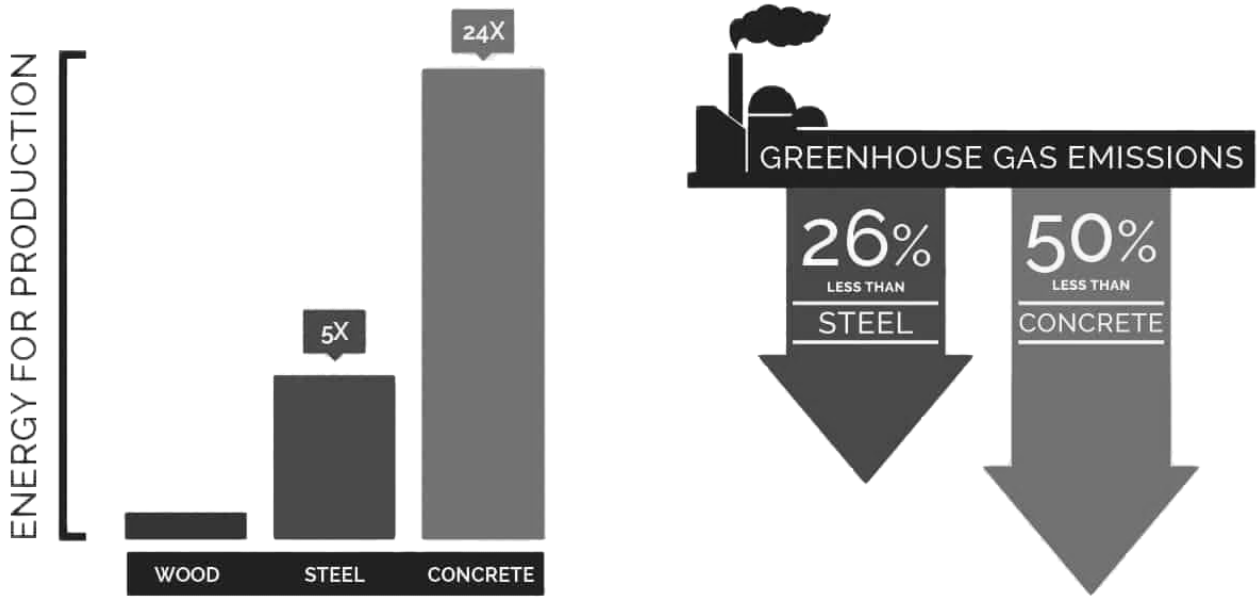

Figure 2: Comparison of the energy-demand and greenhouse gas emissions for production of different building materials.
Source: https://www.pioneerloghomesofbc.com/sustainability/

Concrete Usage in Highrise and its Carbon Footprint

However, in the context of sustainability, there is a pressing issue with the conventional approach to high-rise construction, which relies mainly on concrete as the primary structural material (Bester & Bester, n.d.). *While concrete has undeniable structural qualities, it also brings a substantial carbon footprint along that poses a significant burden to the* environment (Ali et al., 2015).

Concrete production is a highly energy-intensive process and contributes significantly to greenhouse gas emissions, notably through carbon dioxide emissions during cement production, one of the key components of concrete(Ali et al., 2015). *In the Netherlands, the construction industry processes approximately 14 million cubic meters of concrete annually, resulting in a CO2 emission of approximately 3.5 million tons per year. Notably, 80% of this emission is related to cement production. This 3.5 million tons accounts for 1.7% of the total annual CO2 emissions in the Netherlands. The amount of CO2 emissions per cubic meter of concrete is on average 508 kg* (***Betonmortel En CO_2-Emissie | Betonhuis***, n.d.). *When comparing it to alternative structural materials, the environmental impact of concrete becomes even more evident, as illustrated in 'Figure 2'.*

In recent years, the environmental impact of the excessive use of concrete in high-rise construction has raised concerns (Nico Schouten, 2021). *Therefore, developments in high-rise construction have shown interest in utilizing timber as a sustainable alternative to concrete and steel in high-rise projects. While still structurally a challenging alternative, timber construction offers the potential to significantly reduce the carbon footprint associated with these building materials. Therefore, transitioning from concrete towards timber construction aligns with modern environmental objectives, symbolizing a promising shift toward eco-conscious urban environments.*

Timber's Emergence in High-Rise Construction

The modern construction industry is witnessing a growing interest in timber as a construction material, driven by sustainability and environmental considerations (***Sustainable Mass Timber Products Are Key to Green Building | World Economic Forum***, n.d.). *While this interest has predominantly manifested in low- and mid-rise buildings, there is a notable shift toward incorporating timber in high-rise construction projects now as well* (***Why Timber Is the Environmentally Friendly Building Material of Tomorrow | World Economic Forum***, n.d.).

Contemporary architecture has already demonstrated the potential of timber in high-rise buildings, with successful structures reaching up to approximately 86 meters in height (***Tallest Mass Timber Buildings – CTBUH***, n.d.). *Presently, there are relatively few projects on the horizon aiming to exceed this height limit. One of the notable exceptions include 'The Dutch Mountains', proposed to reach to heights of 100m and 130m* (***The Dutch Mountains***, n.d.). *Globally, other ambitious projects are slowly emerging in other countries as well, underlining timber's potential in high-rise construction, such as plans for structures as tall as 191 meters in Perth* (***World's Tallest Wooden Building to Be Built in Perth after Developers Win Approval | Perth | The Guardian***, n.d.)*, 300 meters in London* (***Oakwood Timber Tower: London's Plyscraper - Ubm Magazin.***, n.d.)*, and a towering 350 meters in Tokyo* (***W350 Plan | Tall Buildings | Projects | NIKKEN SEKKEI LTD***, n.d.).

These upcoming developments underscore the increasing feasibility of timber as the primary construction material in high-rise construction. Although we see increasing potential for timber in high-rise construction, current high-rise design still heavily relies on traditional materials like concrete and steel.

As timber-based high-rise construction gains momentum, it reveals a compelling opportunity for architectural practice. My initiative aims to harness this transformative potential, providing architects with a digital design tool to navigate the complexities of timber-based high-rise construction. This tool empowers designers to simplify the design process, unleashing their creativity while ensuring structural feasibility. By doing so, it marks a profound shift in how architects approach high-rise design, placing design freedom and sustainability at the forefront of architectural advancement.

The current scarcity of literature and reference projects focused on timber-based high-rise construction underscores the importance of my research. It indicates an existing knowledge gap within the field of architecture, further emphasizing the need for the digital design tool I aim to develop within my research. This system will empower architects to design freely within specified parameters, playing a crucial role in the transformative shift towards timber-based high-rise construction, making it a preferred choice in the built environment.

The Opportunity
The exploration of sustainable alternatives in high-rise construction, particularly through the innovative integration of timber, presents as previously mentioned a transformative opportunity for architectural practice. My initiative will provide architects with a digital design tool that offers deeper insights into the constraints and possibilities of timber-based high-rise projects and the boundaries of timber-concrete hybrid construction. By doing so, it empowers designers to unleash their creativity while ensuring that they stay within what is structurally achievable.

To create this digital design tool, I aim to immerse myself in the realms of parametric design. Therefore, it's essential to understand the distinctions between parametric design and two other closely related design concepts, which are computational and generative design.

Computational design involves crafting intricate algorithms and scripts, allowing us to explore the interrelated parameters systematically. On the other hand, generative design takes this complexity a step further, generating a multitude of parametric iterations based on sophisticated algorithms, providing us with a vast array of design possibilities.
In the context of developing a digital design tool for timber-based high-rise design, I think that a parametric design, enhanced by computational design techniques, will be best suited to achieve my goal.

Problem Statement RCD-Plot

The project location chosen for my design study, which will also serve as a case study for my thematical research, is situated in the heart of the Rotterdam Central District (RCD), a part of Rotterdam's 'High-rise zone' (***Hoogbouwvisie | Rotterdam.Nl***, n.d.).
Conveniently positioned in close proximity to Rotterdam Central Station, this location serves all types of public transport within the city, encouraging reduced car dependency alligning with the earlier mentioned principles of the compact city.

Presently, the project location consists of 2 parts: The so-called 'Unilverplot', that contains The Unilever Building and TIO Rotterdam building, and Weenacenter, which is a residential tower, as can be seen on 'Figure 3'. According to the Rotterdam High-rise vision, the Unileverplot is suitable for high-rise construction up to 150m (as illustrated in 'Figure 3' by a dashed-line boundary) (***Hoogbouwvisie 2019***, n.d.). *What makes it an excellent candidate for my study.*

Addressing Housing Shortages
Within the context of the Rotterdam Central District, the current state of this plot presents substantial unused potential for urban densification. Embracing the principles of a compact city is essential to efficiently intensify urban land use and promote sustainable city development. The urgent issue it addresses is the housing shortage in the Netherlands, particularly in Rotterdam's city center (***Woningnood in Rotterdam Gigantisch, Maar Nieuwbouw Dreigt Niet van de Grond Te Komen En Dit Is Waarom - Rijnmond***, n.d.). *The addition of a residential tower in this part of the city with extra housing units and diverse programming on this site presents a proactive response to this current housing shortage.*

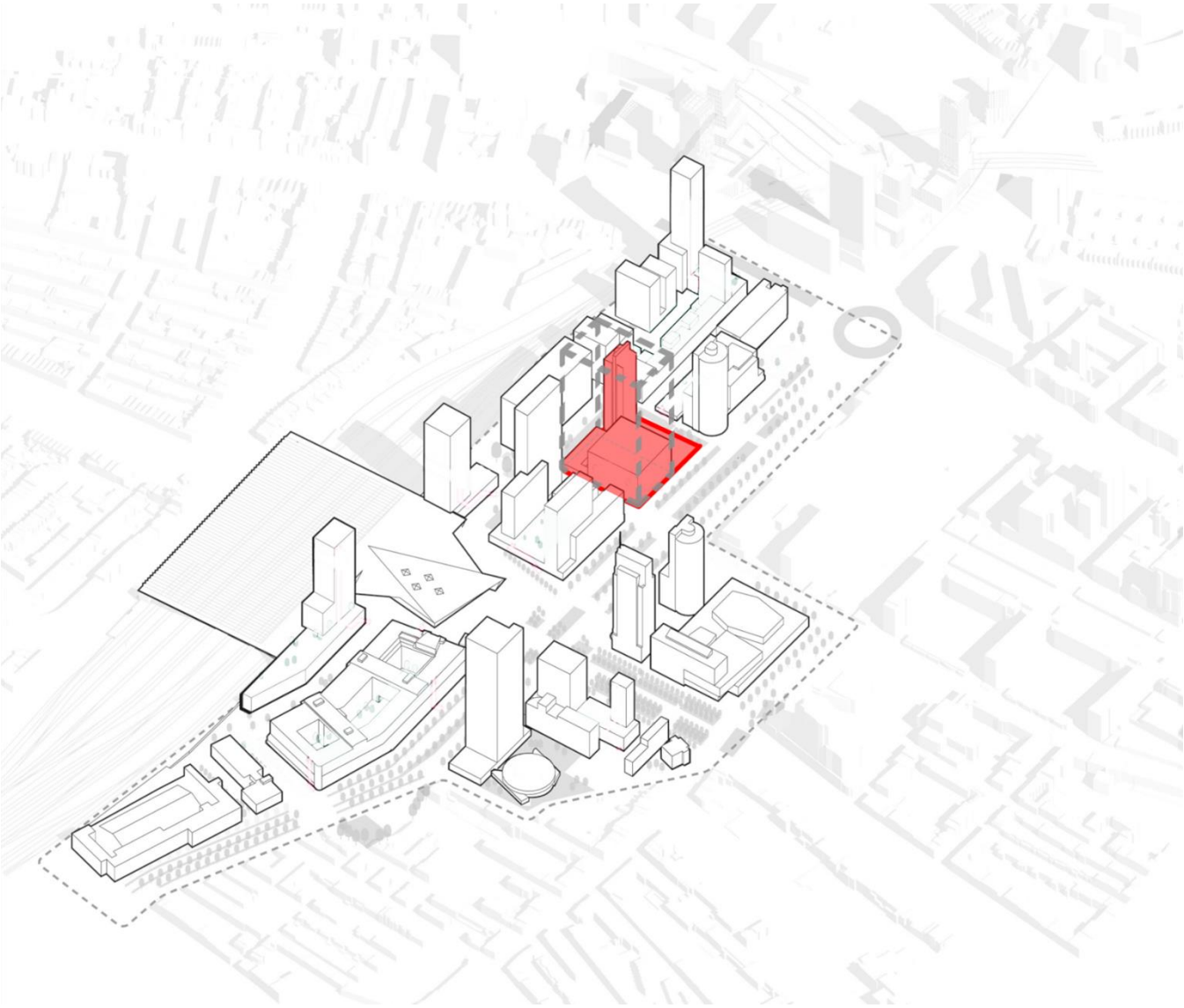

Figure 3: Selected project location within the RCD, including the Unileverplot and Weenacenterplot.
Source: Editted from https://delva.la/projecten/onderzoek/rotterdam-central-district/

Promoting Mixed-Use Synergy
Currently, the program on the Unilever Plot consists of offices, dwellings, and education, all housed in three separate monofunctional buildings. This segregation limits interaction and hinders the development of a lively urban environment. To address this, my proposal aims to transform the site into a dynamic, mixed-use environment by introducing functions such as hospitality, shopping, and social facilities. These added facilities will not only enhance the quality of life for the residents but also serve as catalysts for further area development. By providing amenities to the current and future inhabitants, this integrated approach will stimulate the growth of the area and act as a kickstart for the introduction of more housing units, creating a self-sustaining ecosystem.

Alignment with the 'Boulevard Model' Weena
The current program on the Unilever Plot does not align with the municipality's "Boulevard Model", an ambition document on Weena Street. This model emphasizes vibrant ground-level activities, leisure amenities, and an engaging streetscape (*Central District*, n.d.). *Unfortunately this never came into fruition. Therefore my design challenges to harmonize the new high-rise construction with this established urban planning guideline, fostering an active and dynamic street-level environment.*

In summary, the Unilever Plot presents an ideal canvas to address multiple urban challenges: densification, housing shortage, and alignment with the city's urban planning vision. By proposing a high-rise tower constructed through a sustainable method derived from my thematic research, I aim to not only enhance the physical landscape but also contribute to the vitality and liveliness of the Rotterdam Central District.

Overall Design Objective

The overall design objective of this graduation project is to densify and vitalize the Unilever plot in Rotterdam's Central District through redevelopment, utilizing a strategic approach to incorporate a 150m mixed-use residential tower in alignment with the max height of the area's Highrise vision. The project aims to significantly contribute to urban densification, aligning with the principles of the compact city, while also preserving the current program and expanding it with additional functions.

When redeveloping this plot, the existing buildings on this plot play a crucial role in the design process. Since demolition may not be best option in terms of sustainability, a careful evaluation between preservation and removal of current structures has to be conducted. This assessment considers its architectural and functional significance and explores and how these structures can be integrated into the new design, to contribute to the revitalization of the Unilever plot.

This project will focus on timber construction and will utilize the parametric design tool developed during the thematic research phase. The primary goal is to create a sustainable, high-rise architectural design that effectively addresses housing shortages, promotes mixed-use synergy in alignment with the city's 'Boulevardmodel', which is the urban planning vision for the Weena Street.

…

Overall design question

"How can the Unilever plot in Rotterdam's Central District be effectively revitalized and densified through redevelopment by incorporating a 150m mixed-use residential tower with timber as its primary construction material, while addressing sustainability concerns, housing shortages, promoting mixed-use synergy, and aligning with the city's 'Boulevard model' vision for the Weena Street?"

Reflection on the relevance

From a societal perspective, this graduation project addresses critical urban challenges by proposing a sustainable approach to high-rise construction. It tackles housing shortages, environmental sustainability, and efficient land use, aligning with global efforts to combat climate change. The redevelopment of the Unilever plot into a vibrant, mixed-use environment enhances urban quality of life by reducing car dependency and encouraging sustainable transportation.

From a user perspective, architects are the primary beneficiaries. The parametric design system empowers them to exercise creative freedom while working with sustainable timber-based high-rise construction, fostering innovative and efficient designs. Residents and urban dwellers benefit from improved access to amenities, job opportunities, and convenient transportation within high-rise communities, enhancing their overall living experience.

The project's emphasis on sustainability and efficient land use serves as a model for future high-rise construction projects, potentially reducing the carbon footprint of urbanization and addressing housing shortages in growing cities. It is both specific, focusing on the Unilever plot, and generic, with principles and tools applicable to various urban contexts worldwide. Architects, residents, and society at large stand to gain from the project's outcomes, making it socially and environmentally impactful.

Thematic Research Objective

My thematic research's primary goal is to develop a parametric design tool tailored for architects working on timber-based high-rise projects. This design system will provide architects with the necessary parameters and tools to enable design freedom within sustainable timber construction within the constraints and challenges posed by sustainable timber construction in high-rise buildings.

The objective is to empower architects to create remarkable and efficient high-rise designs that significantly reduce the carbon footprint while contributing to sustainable architectural practices. Ultimately, the goal is to revolutionize the field of high-rise architecture by promoting timber construction for its sustainability while still enhancing design freedom contributing to eco-conscious urban development.

To realize this goal, I will leverage the capabilities of parametric design by developing a parametric tool for architects to aid them in their design process. This tool will allow designers to input parameters such as building height, facade divisions, column or floor spacing, and other relevant variables. It can generate design options and recommend structural details, such as column and floor thicknesses, to ensure the feasibility of the design.

Allowing designers to adjust parameters, it spares them from the complex related structural constraints. As a result, they can fully focus on the creative aspects of their designs, with the tool guiding them within what is structurally possible. In essence, this parametric approach empowers architects to harness the full potential of timber construction for sustainable, innovative, and efficient high-rise designs.

Thematic Research Questions

Main question:

> *"How can a parametric design system be developed and utilized effectively to enable to empower architects in optimizing sustainable timber-based high-rise design, overcoming constraints, and fostering design creativity, thereby shaping the future of architectural practices?"*

Sub-questions:

1. *What are the fundamental constraints and challenges in timber-based high-rise construction?*

2. *What will be the key features, functionalities, and software platforms be for the parametric design tool, and how will these contribute to its effectiveness in enabling architects to optimize sustainable timber-based high-rise designs?*

3. *What are the most significant challenges and obstacles faced in architectural practice related to timber-based high-rise construction in architectural offices?*

Reflection on the relevance

The thematic research objective of developing a parametric design system tailored for architects engaged in timber-based high-rise projects holds paramount societal and scientific significance. In a world grappling with climate change, the project's focus on sustainability aligns with global environmental concerns. Timber-based construction offers a greener alternative to traditional concrete methods, addressing carbon emissions and resource depletion.

The research's applicability extends beyond mere specificity, as it equips architects with a versatile toolset for sustainable design across various projects. This generality fosters widespread adoption of sustainable practices, promoting eco-consciousness in architectural endeavors.

Scientifically, the research delves into intricate architectural parameters and quantifies environmental implications. The findings contribute to a burgeoning field of sustainable construction, allowing for objective comparisons between timber and concrete methods.

Ultimately, architects, urban planners, policymakers, and the environment will benefit. Architects gain innovative tools, urban planners access sustainable urban solutions, policymakers leverage eco-friendly policies, and the environment gains respite from resource-intensive construction practices.

Thematic Research Methodology

1. Laying the research foundation via Literature Study

To develop a comprehensive understanding of high-rise construction, parametric design, and urban planning principles, I will start with an literature study that I will build upon key components previously outlined in the problem statement, which are:

Urbanization and High-Rise Demand

As established, urbanization in the Netherlands has led to a growing urban population, predominantly concentrated in cities, such as Rotterdam. This urban shift necessitates sustainable high-rise construction to accommodate the growing demand for housing and workspaces in densely populated areas. This part of the literature study will delve deeper into the urbanization trends, compact city concepts, and the need for high-rise buildings, aligning with the principles of a compact city.

Sustainable Urban Development

The compact city concept, emphasizing dense and proximate development patterns, urban connectivity through public transport systems, and accessibility to local services and jobs, is pivotal in promoting sustainable urban development. The literature study will further explore this and related concepts in the context of high-rise construction, highlighting how vertical urbanization can reduce carbon emissions and support sustainable ways of transportation.

Challenges with Conventional High-Rise Materials

The literature study will also delve into the environmental challenges associated with conventional high-rise construction materials, particularly concrete. Notably, it will focus on the significant carbon footprint of concrete production and its environmental impact. Insights from the literature will be used to underscore the urgency of rethinking high-rise construction for sustainability.

Emergence of Timber in High-Rise Construction

In response to the environmental challenges posed by traditional materials, there is a notable shift towards incorporating timber in high-rise construction projects. The literature will provide an overview of this trend, showcasing successful timber-based high-rise projects globally. It will highlight how timber's emergence offers a sustainable alternative to traditional materials and contributes to eco-conscious urban development.

This comprehensive literature study forms the basis for my thematic research and allows for a deeper exploration of high-rise construction, parametric design, and the potential of timber as a sustainable alternative.

2. Case-Study Analysis
Before conducting interviews, I will start with examining high-rise projects that are based on, or closely related to timber-based construction methods. I have selected these projects based on criteria such as project height, location, and architectural firms involved. These selected projects are momentarily at the forefront of timber-based high-rise construction.

Projects selected for analysis:

Project:	**Height:**	**Type:**	**Location:**	**By:**
W350	*350m*	*Timber*	*Tokyo*	*Sumitomo Forestry and Nikken Sekkei*
Oakwood Timber Tower	*300m*	*Timber*	*London*	*PLP Architecture*
C6	*191m*	*Timber*	*Perth*	*Fraser and Partners*
The Dutch Mountains	*133m, 96m*	*Timber hybrid*	*Eindhoven*	*Marco Vermeulen and Arup*
HOHO Wien	*81m*	*Timber hybrid*	*Vienna*	
HAUT	*73m*	*Timber hybrid*	*Amsterdam*	*Team V and Arup*
Treehouse	*130m*	*Timber hybrid*	Rotterdam	PLP*, Zus, Provast*

The information collected will I use to prepare myself before conducting interviews with experts in the sector.

3. Interviews with Industry Experts And Field Research
I will conduct interviews with companies and experts experienced in utilizing timber in high-rise design and construction. These interviews will provide valuable real-world input for my the parametric design tool that I aim to develop. In these interviews, I aim to find out what the different constraints are within timber in high-rise design and construction, forming the basis for the digital design tool.

Selected companies and experts I aim to interview:

Company:	**Explanation:**
Powerhouse	*Architectural firm where I used to work, former colleagues can share their insights on high-rise construction, timber-based mid-rise, and other relevant topics.*
Team V	*An architectural office that designed the tallest timber-based tower in the Netherlands.*
Pieters Bouwtechniek	*A structural engineering company with expertise in timber construction.*
Arup	*Engineering and sustainability consultants, designers, and architects who worked on Dutch timber-based high-rise projects such as HAUT and The Dutch Mountains.*
Arcon	*Experts in timber construction who visited the timber-based high-rise project HOHO Wien.*
Elephant	*An architectural firm with expertise in Parametric Design.*

4. Developing the Parametric Design tool

In this phase, I will focus on the development of a parametric design tool. This tool aims to enable architects to navigate the complexities of timber-based high-rise construction, emphasizing design freedom and structural feasibility. By harnessing the insights gathered from the literature study, case-study analysis, and interviews with industry experts, I will create a digital design tool that streamlines the architectural process and promotes sustainability.

Before doing so, I will also evaluate and select the appropriate software to create this design tool. The chosen software will play a pivotal role in the effectiveness and functionality of the tool. Considerations for software selection will include compatibility with parametric design principles, user-friendliness, and the ability to integrate the unique aspects of timber-based high-rise construction. The development of this tool is critical to bridging the existing knowledge gap within the architectural field regarding timber-based high-rise construction. Through this digital solution, I aim to facilitate the incorporation of timber as a preferred choice in high-rise building projects.

5. Validation of the Parametric Design tool via Design Study

The design study on the Unilever plot in Rotterdam's Central District, where I will incorporate a 150m mixed-use residential tower with a focus on timber construction, will serve as a case study to validate the effectiveness of the parametric design system I aim to develop. The selection of this location aligns with my research objectives and provides an ideal setting for the study.

Expected results of thematic research and design implementation

Based on my research objectives and the nature of your thematic research, here's what the expected results might be:

Parametric Design System
The primary expected result is the development of a parametric design system tailored for architects working on timber-based high-rise projects. This system should provide architects with the necessary parameters and tools for sustainable timber-based high-rise construction, empowering them to create innovative and efficient high-rise designs.

Increased Timber Usage
My research aims to promote the use of timber as a primary construction material in high-rise buildings. The successful application of the parametric design system and the dissemination of research findings will encourage the architectural community to embrace timber construction, leading to increased adoption of this sustainable material in high-rise projects.

Closing the knowledge gap
Ultimately, my thematic research and design implementation will bridge the existing knowledge gap in timber-based high-rise construction, offering a practical solution and empowering architects to design and build more sustainable, functional, and creative high-rise structures, aligning with contemporary environmental and urban development objectives.

Planning

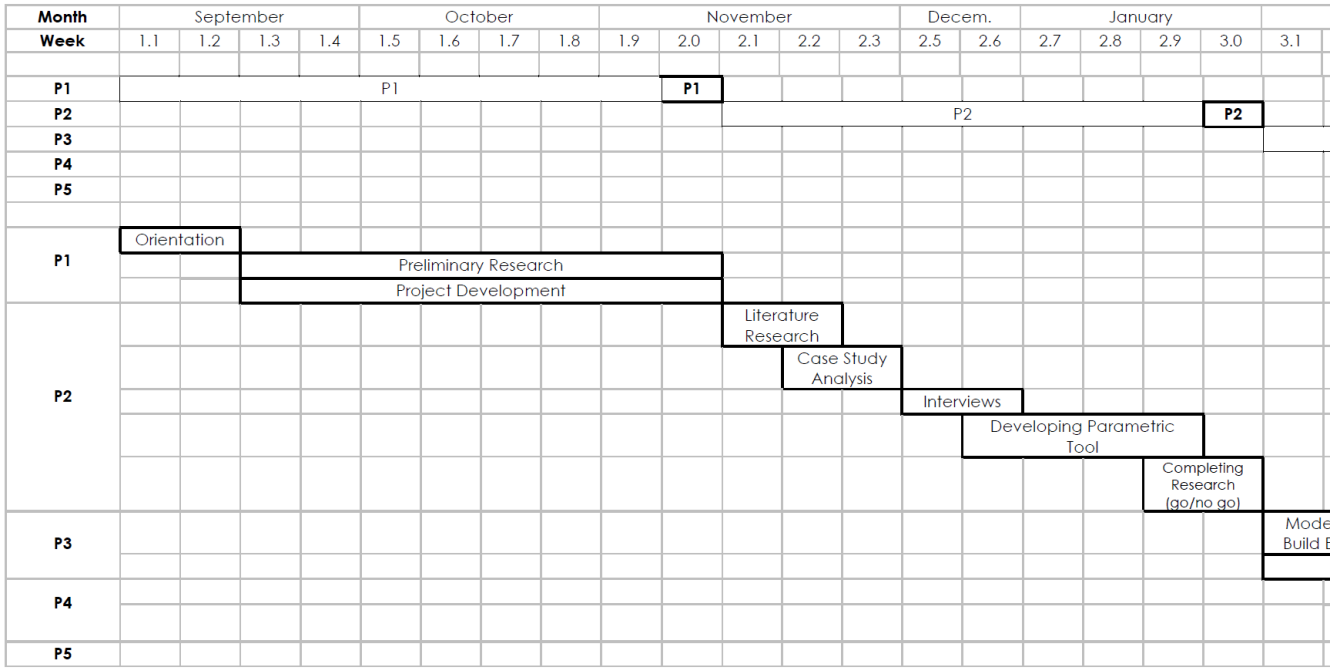

Figure 4: Planning Msc 3
Source: Authors own work

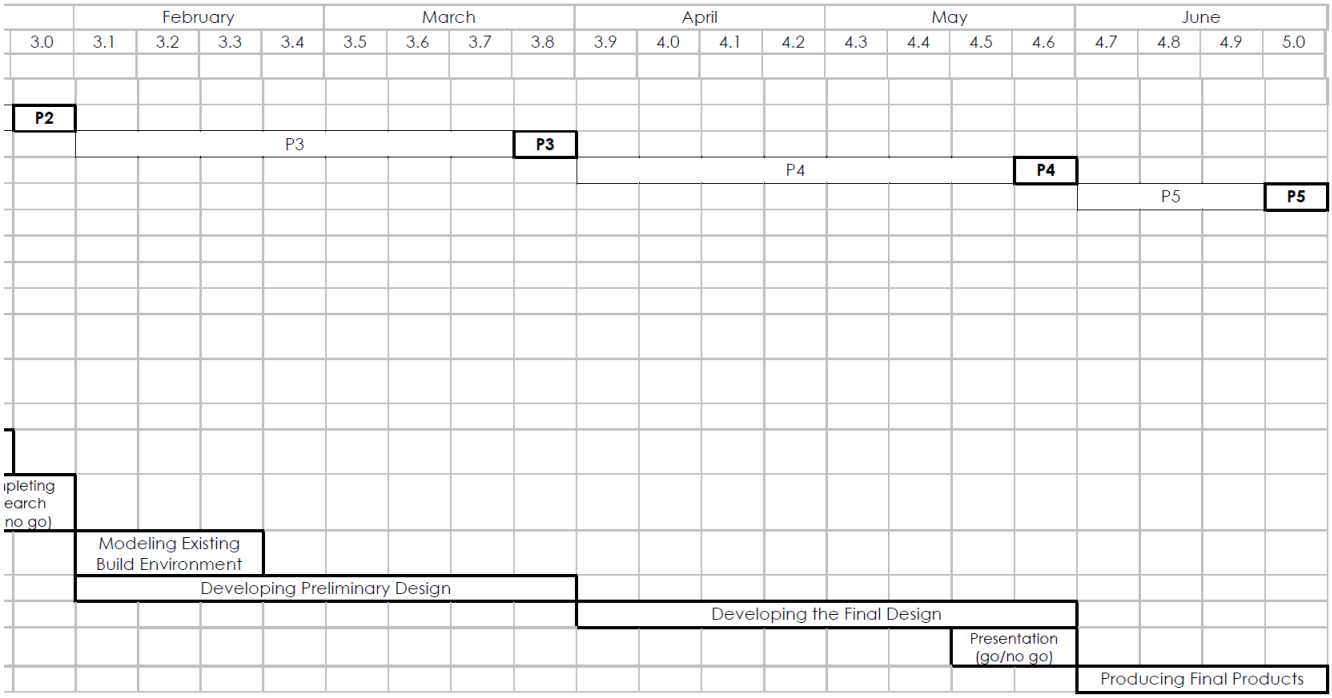

Figure 5: Planning Msc 4
Source: Authors own work

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Visual translation of the research plan into a diagram

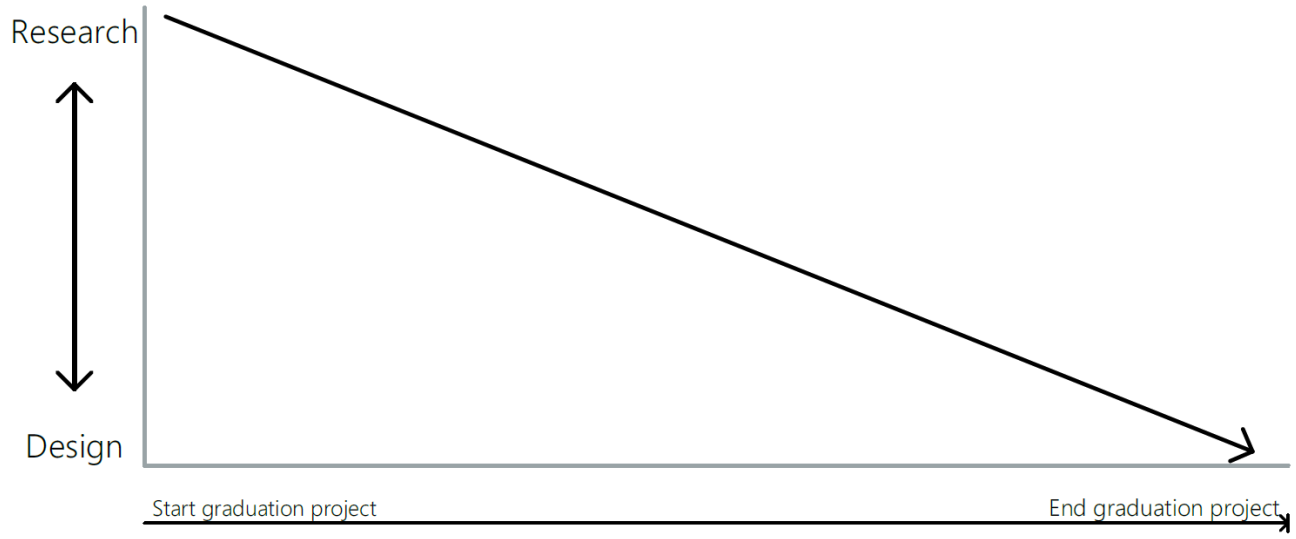

Figure 6
Source: Authors own work

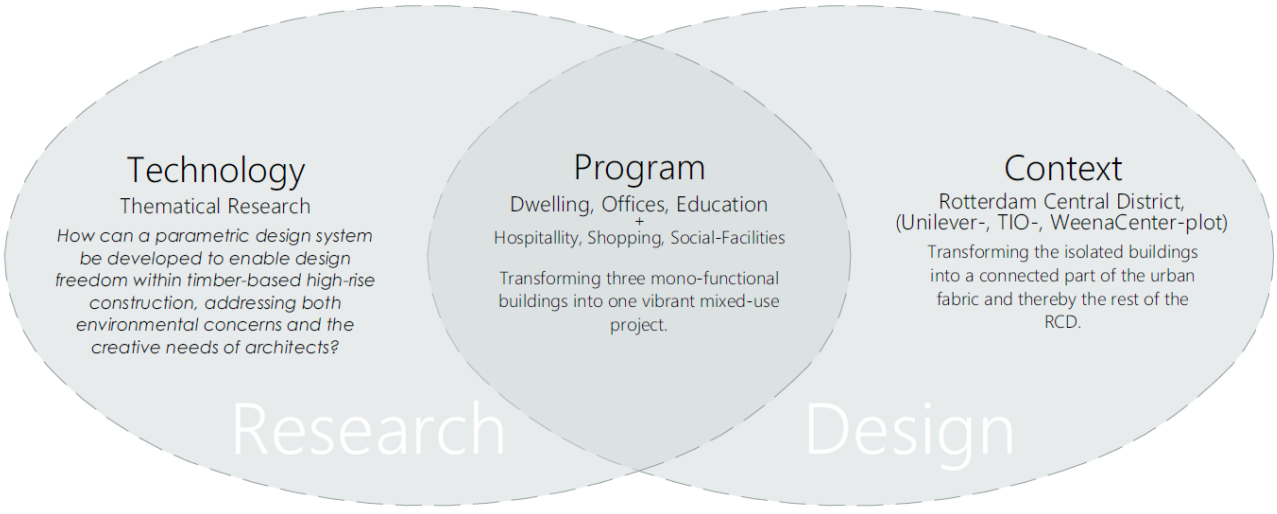

Figure 7
Source: Authors own work