Graduation Plan

Master of Science Architecture, Urbanism & Building Sciences

Graduation Plan: All tracks

Submit your Graduation Plan to the Board of Examiners (Examencommissie-BK@tudelft.nl), Mentors and Delegate of the Board of Examiners one week before P2 at the latest.

The graduation plan consists of at least the following data/segments:

Personal information	
Name	Lars Vedder
Student number	xxxxxxxxx

Studio		
Name / Theme	Building technology (computational design, Façade design)	
Main mentor	Michela Turin	Computational design
Second mentor	Arie Bergsma	Façade design
Argumentation of choice of the studio	Passionate about Façade design and want to learn more about computational design	

Graduation project	
Title of the graduation project	Optimizing Façade Design for Minimal Embodied Carbon and energy
Goal	
Location:	-
The posed problem,	Despite research studies on building energy performance, there is still a significant gap in understanding the embodied energy and carbon consequences of various façade typologies, especially in the early stages of design. Investigating the impact of various façade designs on embodied carbon and energy offers a chance to incorporate sustainability considerations into the architectural decision-making process from the start. As a result, this study intends to investigate the impact integrated dynamic design with façade typologies on embodied carbon and energy in mid to high-rise buildings, providing insights to drive sustainable design practices and reduce environmental impacts.

research questions and	"How do different dynamic façade variables influence the embodied energy and carbon footprint of mid to high-rise buildings during the early design phase, and what optimal combinations can be identified to minimize environmental impact while meeting regulatory standards?
design assignment in which these result.	

A literature review about high-rise and it's facades, their detailing, regulation and embodied energy and carbon.
A computational framework that calculates this
An optimization framework that can change materials and detailing to lower the emissions

Process

Method description

This study investigates the impact of high-rise and it's various façade typologies on the embodied carbon and energy of mid to high-rise buildings, focusing on the early design phase. By conducting computational simulations, the research tries to identify optimal combinations that minimize environmental impact.

Literature and general practical references

TU Delft Repositories
Google scholar
Research Gate
Science Direct

Bouwbesluit, 2012
BENG, 2017

Reflection

1. What is the relation between your graduation (project) topic, the studio topic (if applicable), your master track (A,U,BT,LA,MBE), and your master programme (MSc AUBS)?

The building technology studio has a focus on technology and sustainability. I think the topic of my thesis addresses both.

2. What is the relevance of your graduation work in the larger social, professional and scientific framework.

This research aims to make buildings more eco-friendly, especially in cities where urban growth adds to carbon emissions. By studying different building designs, it seeks ways to reduce their environmental impact, focusing on the materials used in their facades. Using new computer tools and optimization techniques, it aims to find practical solutions for architects and builders to create greener buildings. This not only helps combat climate change but also promotes sustainable urban development. The study fills gaps in existing research, providing valuable insights for future projects and advancing the field of sustainable architecture.

1 Introduction

1.1 Background

Population growth among people is a significant driving force behind environmental concerns such as global warming. Currently, 55% of the global population lives in cities, with that percentage expected to rise to 68% by 2050 (United Nations, May 16, 2018). This urban movement, along with a population prediction of 9.7 billion by 2050, increases demand for housing, deepening the concentration of structures within cities (United Nations, June 21, 2017).

This urban densification is predicted to have a significant impact on climate change, not only because of the built environment's energy demand over time, but also because materials' embodied energy and carbon emissions. Already today, the building sector consumes 35% of global resources, 40% of total energy, 12% of the world's drinkable water, and nearly 40% of global carbon emissions (Saint-Gobain, 22 August 2017).

The European Union is responsible for encouraging and putting in place mitigation measures to combat climate change. This effort includes developing energy reduction goals, as evidenced by the creation of the Climate Agreement (Arcadis, 2019).

For the built environment, Energieakkoord en de Europese richtlijn Energieprestatie van Gebouwen (EPBD) have been enacted. The main objective of the regulation is to cut greenhouse gas emissions by 85-90% by 2050, thereby keeping the temperature rise below 2 degrees Celsius (European Parliament and Council of the European Union, 2010).

Dutch regulations require all new buildings to be Nearly Zero-Energy by 2020 (Rijksdienst van Ondernemend Nederland. (n.d.)). This means that since January 1, 2021, all building permit applications must meet the requirements for almost zero-energy buildings (Rijksdienst van Ondernemend Nederland. (n.d.)).

These regulations primarily account for energy use during the use of the buildings. But as buildings become more energy efficient, embodied energy, encompassing production, transportation, construction, maintenance, and demolition/reuse, gains increased relative importance (Cabeza et al., 2014; Huang et al., 2018; Lolli et al., 2019).

These regulatory changes have an important effect on building industry operations. The Netherlands Enterprise Agency (Rijksdienst van Ondernemend Nederland) recommends evaluating energy performance during the early stages of design. This could also be applied to the embodied energy and carbon.

Compared to operational emissions, and despite their growing importance, legislation tackling embodied GHG emissions is uncommon (J. Steinmann et al. 2022). It is now anticipated that embodied GHG emissions in construction around the world must be cut back by at least 40% by 2030 in order to reach a net-zero carbon emission balance by 2050, as required by the Paris Agreement on Climate Change (UNEP, 2021).

It is critical for a developing team to determine early on whether the architectural characteristics of the proposed project will meet the required standards. An architect has to grasp the architectural concepts required to achieve energy performance standards.

1.2 Problem statement

While the global trend toward urbanization and vertical expansion increases, the sustainability of mid to high-rise buildings remains unsure. Existing research demonstrates an increasing worry about the environmental impact of tall structures, notably in terms of energy usage and carbon emissions. Studies by (Godoy-Shimizu et al., 2018). highlight the increased resource needs and energy intensity associated with higher structures. Recent research undertaken by the Energy Institute of the University College London supports this, indicating a significant increase in electricity demand, fossil fuel consumption, and CO_2 emissions in high-rise structures over 20 floors (Godoy-Shimizu et al., 2018).

Given the global growth of high-rise buildings and the need to address climate change through severe energy requirements, there is an urgent demand for sustainable design solutions that improve building performance. Architectural designs must adapt to environmental dynamics in order to maintain long-term viability and prevent negative consequences. While research emphasizes the importance of building orientation, shape, and envelope in impacting energy performance and occupant comfort (Raji, Tenpierik, & Dobbelsteen, 2017), urban restrictions frequently limit optimization choices.

Furthermore, unlike their low-rise counterparts, high-rise buildings come across additional environmental difficulties, such as differences in air temperature, wind speed, and daylight across levels. As a result, designing building envelopes is critical to tackling these difficulties and increasing energy efficiency.

Despite research studies on building energy performance, there is still a significant gap in understanding the embodied energy and carbon consequences of various façade typologies, especially in the early stages of design. Investigating the impact of various façade designs on embodied carbon and energy offers a chance to incorporate sustainability considerations into the architectural decision-making process from the start. As a result, this study intends to investigate the impact of integrated dynamic design with façade typologies on embodied carbon and energy in mid to high-rise buildings, providing insights to drive sustainable design practices and reduce environmental impacts.

1.3 Research objective

The aim of this study is to investigate the impact of different façade typologies on the embodied carbon and energy of mid to high-rise structures, with a particular emphasis on the early design phase. The study's goal is to uncover optimal combinations that minimize environmental effect by conducting extensive research and comparing different façade typologies using computational simulations. The goal is to provide designers, contractors, and other stakeholders with usable and concrete data that will allow them to make informed decisions early in the building design process. This study aims to contribute to the growth of sustainable design practices by facilitating the construction of structures that are both energy-efficient and environmentally responsible, thereby lessening the negative effects of urbanization on climate change.

1.4 Research questions

The aim of the paper is to answer the following research question:

"How do different dynamic façade variables influence the embodied energy and carbon footprint of mid to high-rise buildings during the early design phase, and what optimal combinations can be identified to minimize environmental impact while meeting regulatory standards?"

In order to answer this main research question, a series of sub-questions will help reach the goal of the project:

What is the definition of mid to high-rise, and what are the most prevalent facade typologies that apply to mid to high-rise buildings?

How do different façade materials and typologies affect the embodied energy and carbon footprint of mid- to high-rise buildings, taking into account production, transportation, and the end of the lifecycle?

What are the regulatory standards for façade design in terms of embodied energy and embodied carbon, and how do they relate to other building performance standards?

How is the integrated dynamic model established, and how does it perform compared to traditional software?

1.5 Methodology

During the background research, several issues were identified: population growth, urban densification, and global warming. This led to the Paris Agreement and the Energy Akk oord, since then regulations have been implemented to achieve zero energy design during the building's operational phase. The next step in this process involves reducing the embodied energy and embodied carbon of buildings and their materials. This study addresses these issues through a literature review, followed by a case study and an optimization study.

This study starts with a quantitative literature review to define the dimensions that characterize mid to high-rise buildings, considering both international standards and Dutch regulations. This phase establishes the definitions for mid to high-rise buildings by analysing existing literature and regulatory documents. It also involves identifying common façade typologies for these buildings using sources such as the SBR detail database and other government repositories.

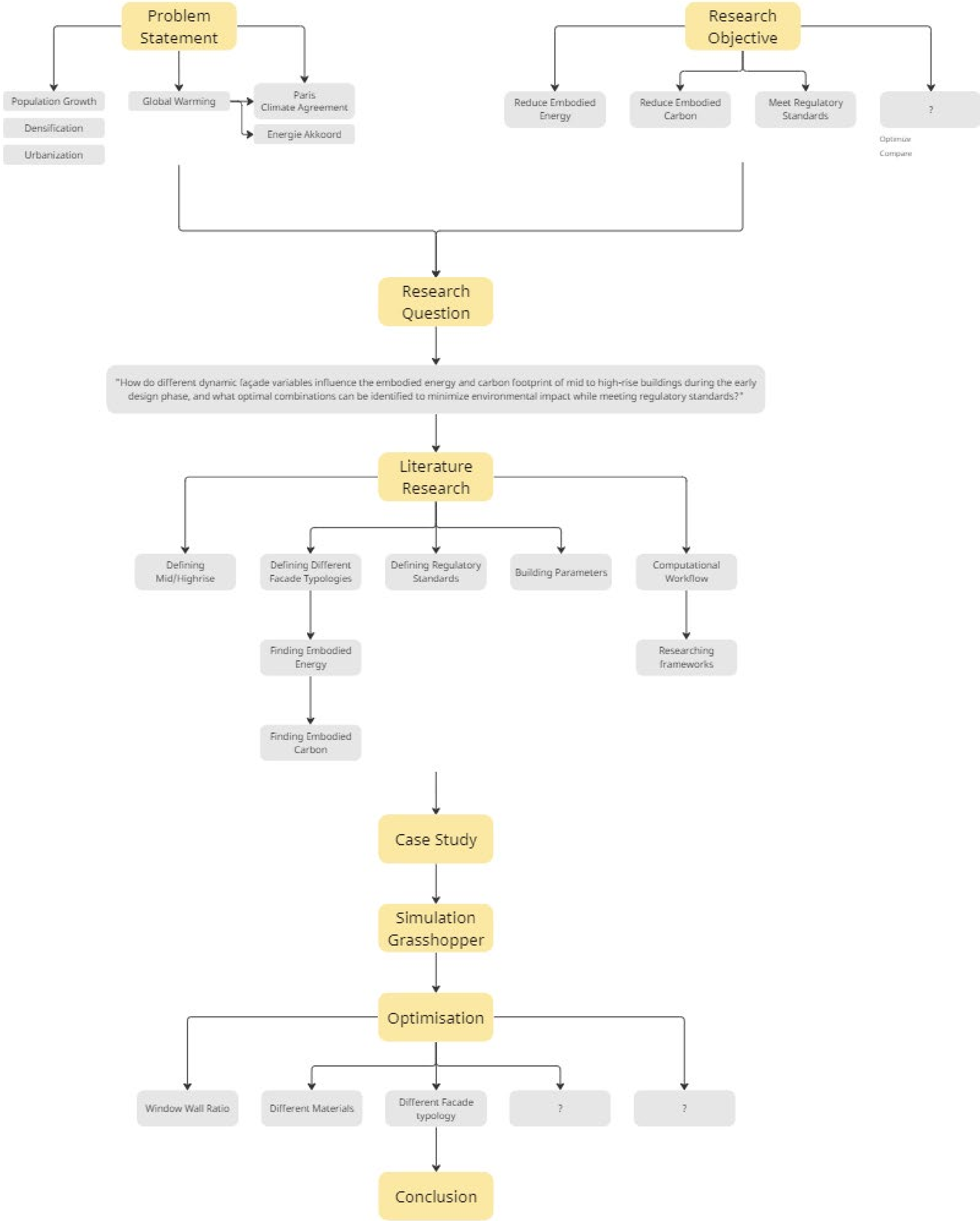
After this, the review focuses on analysing the materials used in each identified façade typology, finding their embodied energy and carbon footprint during the production, transportation, and installation stages, using quantitative literature sources and databases like Edupack.

Furthermore, the study investigates existing regulatory criteria for façade design, emphasizing embodied energy and carbon, and compares these criteria to other building performance standards to ensure compliance and relevance.

Following the literature review, a case study is done to apply insights to a real-world scenario. A computational workflow is then developed to model the building's façade typologies, utilizing frameworks that integrate dynamic modelling tools to ensure accurate simulation of embodied energy and carbon impacts. Grasshopper along with some plugins, a parametric design tool, is used to simulate the energy and carbon performance of different façade typologies.

The final phase involves an optimization study to identify the most sustainable façade designs. Optimization algorithms are implemented within the Grasshopper environment to explore various design alternatives, focusing on minimizing embodied energy and carbon while meeting regulatory standards. The performance of these optimized designs is analysed to determine the optimal combinations of façade materials and designs. The study evaluates these combinations against performance benchmarks and regulatory requirements, providing recommendations for architects, designers, and other stakeholders based on the optimized results. These recommendations aim to help the previously mentioned stake holders in the early design phases.

Summarizing, methodology combines literature review, regulatory analysis, case study, and computational simulation to comprehensively address the research question. By focusing on the embodied energy and carbon impacts of different façade typologies in mid to high-rise buildings, the study aims to contribute insights for sustainable architectural design. The findings will guide the development of energy-efficient, environmentally responsible buildings, aligning with global and national climate goals.



Problem Statement
Population Growth
Densification
Urbanization
Global Warming
Paris Climate Agreement
Energie Akkoord
Research Objective
Reduce Embodied Energy
Reduce Embodied Carbon
Meet Regulatory Standards
?
Optimize
Compare
Research Question
"How do different dynamic façade variables influence the embodied energy and carbon footprint of mid to high-rise buildings during the early design phase, and what optimal combinations can be identified to minimize environmental impact while meeting regulatory standards?"
Literature Research
Defining Mid/Highrise
Defining Different Facade Typologies
Defining Regulatory Standards
Building Parameters
Computational Workflow
Finding Embodied Energy
Researching frameworks
Finding Embodied Carbon
Case Study
Simulation Grasshopper
Optimisation
Window Wall Ratio
Different Materials
Different Facade typology
?
?
Conclusion

1.6 Relevance

This research aims to make a difference at a societal level but also at an academic level. Society wise it addresses the need to combat climate change by reducing the environmental impact of buildings, particularly in the context of urban densification, which significantly contributes to global carbon emissions. The goal of the thesis is an attempt to find sustainable design solutions that can reduce the carbon footprint of mid to high-rise buildings, in this way contributing to global climate goals. As urban populations rise, the need for sustainable housing alternatives becomes more important. This study encourages more sustainable urban development by giving practical data into how different façade designs could reduce embodied energy and carbon. Additionally, the study provides architects, designers, and contractors with concrete data and recommendations, helping them to make informed choices early in the design process.

Scientifically, the study attempts to fill the gap in the existing literature by concentrating on the embodied energy and carbon implications of façade typologies in mid- to high-rise structures. It tries to improve the existing knowledge in this field and proposes new strategies, such as the use of computational tools like Grasshopper for dynamic modelling which are fairly new. The use of optimization algorithms to discover sustainable façade designs tries to offer a new standard for minimizing environmental impact. This project aims to promote sustainable architecture and building science by providing significant insights and approaches for future studies and practical applications in the field.

1.7 Boundary conditions

- The study focuses on residential mid to high-rises in a temperate climate.
- The study analyses the energy performance of a case study in the Netherlands, with a specified shape and orientation.
- Simulation settings are based on market-available technology.
- Facade designs are standardised from libraries. The study focuses on the embodied energy and embodied carbon of the façade elements rather than their influence on other factors such as the structure that supports the façade.

1.8 Boundary conditions

Arcadis. (2019). The Future Of The European Built Environment: A forward looking

Cabeza, L. F., Rincon, L., Vilarino, V., Perez, G., & Castell, A. (2014). Lifecycle assessment (LCA) and lifecycle energy analysis (LCEA) of buildings and the building sector: A review. Renewable and Sustainable Energy Reviews, 29, 394–416. https: //doi.org/10.1016/j.rser.2013.08.037

description of Europe in 2030 and 2050. Arnhem: Arcadis.

European Commission (2010). DIRECTIVE 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 May 2010 on the energy performance of buildings. Retrieved May 15, 2024 from http://data.europa.eu/eli/dir/2010/31/oj

gebouwen/wetten-en-regels/nieuwbouw/energieprestatiebeng

Godoy-Shimizu, D., Steadman, P., Hamilton, I., Donn, M., Evans, S., Moreno, G. & Shayesteh, H. (2018). Energy use and height in buildings, Building Research & Information, 46:8, 845-863. [online] Retrieved May 15, 2024 from https://www.tandfonline.com/doi/full/10.1080/09613218.2018.1479927

J. Steinmann, M. Röck, T. Lützkendorf, K. Allacker, X. Le Den, Whole Life Carbon Models for the EU27 to Bring Down Embodied Carbon Emissions from New Buildings. Review of Existing National Legislative Measures Funded, Tech. Rep., Ramboll, 2022, p. 43. Retrieved May 15, 2024URL https://c.ramboll.com/reducing-whole-life-carbon.

Raji, B., Tenpierik, M. and van den Dobbelsteen, A. (2016). A comparative study: design strategies for energy-efficiency of high-rise office buildings. Journal of Green Building, 11, pp.134-158.

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United Nations, (2017, June 21). World population projected to reach 9.8 billion in 2050, and 11.2 billion in 2100. Retrieved May 01, 2024 from https://www.un.org/development/desa/en/news/population/world-population-prospects-2017.html

United Nations, (2018, May 16). 68% of the world population projected to live in urban areas by 2050, says UN. Retrieved 01 may, 2024 from https://www.un.org/development/desa/en/news/population/world-population-prospects-2017.html

2.1 Defining mid to high-rise and it’s facades

2.1.1 Introduction

Chapter 2.1 investigates the characteristics of a mid- to high-rise building and the most common façade typologies used. The goal is to provide an answer to the question: “What is the definition of mid to high-rise, and what are the most prevalent facade typologies that apply to mid to high-rise buildings?” By doing this, a simple foundation is laid for understanding how these buildings are defined and what their exteriors often look like.

2.1.2 Short history of high-rise

Even before the middle ages there were ideas of constructing upward rather than outward. In Roman cities there were already some multi-story apartment complexes, then called “Insulae”. They were common in Roman cities; some of them were as many as ten floors (Aldrete, 2004). In the middle ages rich families built defensive towers throughout medieval Europe, as the 97.2-meter Asinelli Tower in Bologna, Italy (Behrens-Abouseif, 1992).

Thanks to developments in steel frame construction and Elisha Otis's discovery of the safety elevator in 1857, the modern era of high-rises started in the late 1800s. These developments made high-rise buildings more feasible and practical and this way realistic. The Home Insurance Building in Chicago, completed in 1885, is often cited as the first skyscraper due to its ten-story height and steel frame construction (Petruzzello, 2022).

After these developments, New York City and Chicago were the two leading cities in the building of skyscrapers. Steel frames were used in the construction of Chicago's skyscrapers, such as the Rand McNally Building and the Wainwright Building (Peterson, 1950). In that time, skyscrapers in New York City, like the American Surety Building and the Flatiron Building, fought to be the tallest structures in the world (Peterson, 1986).

The Great Depression and World War II slowed skyscraper construction. However, post-war advancements led to iconic structures like the Empire State Building in New York, which held the title of the world's tallest building for 40 years after its completion in 1931 (Hoffmann, 1969). The Soviet Union's "Seven Sisters" in Moscow and other Eastern Bloc skyscrapers reflected a different architectural style known as Socialist Classicism (Ambrose, Harris & Stone, 2008).

Fazlur Rahman Khan's tubular structural systems transformed skyscraper design in the 1960s, enabling for larger and more diversified building designs (Peterson, 1950). The completion of Chicago's John Hancock Center and Willis Tower represented important developments (Hoffmann, 1969). The global trend has changed toward building supertall skyscrapers, with cities in Asia, the Middle East, and other countries joining the race. The Petronas Towers in Kuala Lumpur and Dubai's Burj Khalifa are prime examples of this trend (Emporis, 2015).

2.1.3 Criticism of high-rise

High-rise is expensive to build and maintain. Materials, construction, and the operational phase maintenance of buildings is more expensive than the maintenance of low-rise buildings (Ali & Al-

Khodmany, 2012). Also, high-rise is often found in city centres where land values are high, making them economically viable primarily for office, commercial, and luxury residential usage, often eliminating cheap housing (Ali & Al-Khodmany, 2012). This makes High-rise buildings often appeal to high-income individuals and companies, which could worsen social hierarchies and gentrification by displacing lower-income residents and small businesses (Emporis, 2015).

Also, critics argue that these the tall buildings can disrupt the traditional urban fabric by overshadowing historical buildings and changing the character of neighbourhoods, resulting in the loss of human-scale environments (Peterson, 1950). Additionally, high-rise living may lead to isolated neighbourhoods with limited interaction at street level, producing a sense of split from the urban population (Ambrose, Harris & Stone, 2008). Visually, the worldwide style of high-rise buildings, defined by glass and steel façades, often results in homogeneity, reducing architectural variation and cultural identity (Petruzzello, 2022).

Furthermore, the construction of high-rise is extremely resource-intensive, requiring massive amounts of steel, concrete, and glass, resulting in enormous embodied energy. moreover, because of their size, large buildings use a lot of energy for heating, cooling, and lighting during the operational phase (Petruzzello, 2022). The usage of more mechanical equipment, such as elevators and HVAC systems, contributes to a larger carbon footprint. Despite advances in energy-efficient technology, the overall environmental impact is still high (Petruzzello, 2022).

2.1.4 Definition

The definition of high-rise is a bit subjective and varies based on different criteria. The Council on Tall Buildings and Urban Habitat (CTBUH, 2010) defines a tall building using a few aspects. One aspect requires that a structure have at least 14 floors or be more than 50 meters high. However, according to the CTBUH, this definition can vary depending on the context of the building ; for example, a 14-story structure may not be considered high-rise in the Netherlands but not in cities such as Chicago or New York. CTBUH also highlights proportion as an important metric because buildings with a big footprint may not appear taller despite their height. Another norm is the use of integrated technologies for high-rise such as advanced vertical transportation systems and wind bracing. These also play a role in defining a tall building (CTBUH, 2010).

According to Emporis, the term "high-rise" is generally applied to buildings with 12 to 39 floors or those standing 35 to 100 meters tall (Emporis, 2015). A skyscraper, even bigger than high-rise, refers to buildings with over 40 floors and standing taller than 150 meters (Skyscraper, n.d.). Buildings exceeding 150 meters are classified as supertall, while those reaching 300 meters and above are megatall (CTBUH, 2019).

In the Netherlands, high-rise buildings are defined as those above 70 meters (Bouwbesluit, 2012). Additionally, low-rise buildings are typically under five stories, not requiring elevator use, while mid-rise buildings range between five and ten stories (Davies & Jokiniemi, 2008; Designing Buildings Wiki, 2019). For this

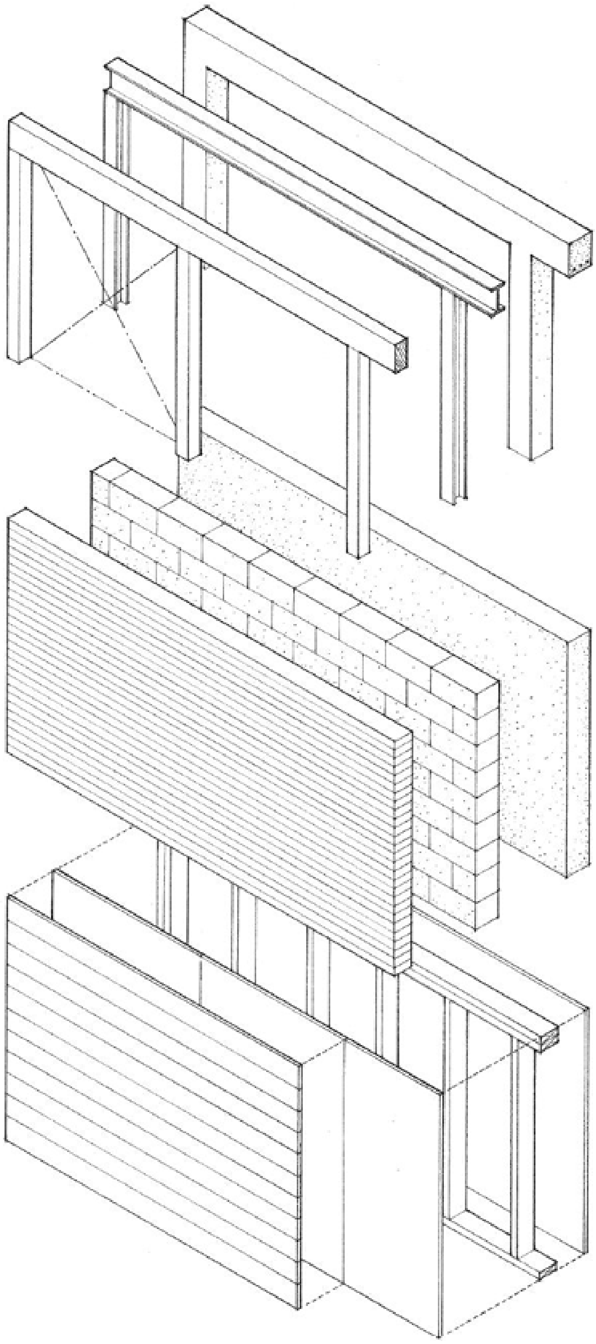
Summarizing, because of the varying definitions of 'mid to high-rise,' this study will use the following criteria: structures between 20 and 100 meters in height, or 5 to 40 stories, will be classed as mid to high-rise. Low-rise buildings are those that are under 20 meters or have fewer than 5 floors, whereas skyscrapers are those that are more than 100 meters tall.

2.1.5 Façade typologies introduction

Façade typologies play a significant role in building construction, influencing a structure's aesthetics, structural robustness, and functionality. Over the last decades, facade technologies have also evolved rapidly due to stringent energy requirements, higher comfort level standards demanded by users, and frequent unpredictable extreme climatic events associated with climate change. This evolution has led to the development of various facade typologies, which will be highlighted in this chapter.

In "Building Construction Illustrated" by Francis D.K. Ching, Three primary wall systems are identified by Ching: Structural Frames, Concrete and Masonry Bearing Walls, and Metal and Wood Stud Walls (Ching, 2014).

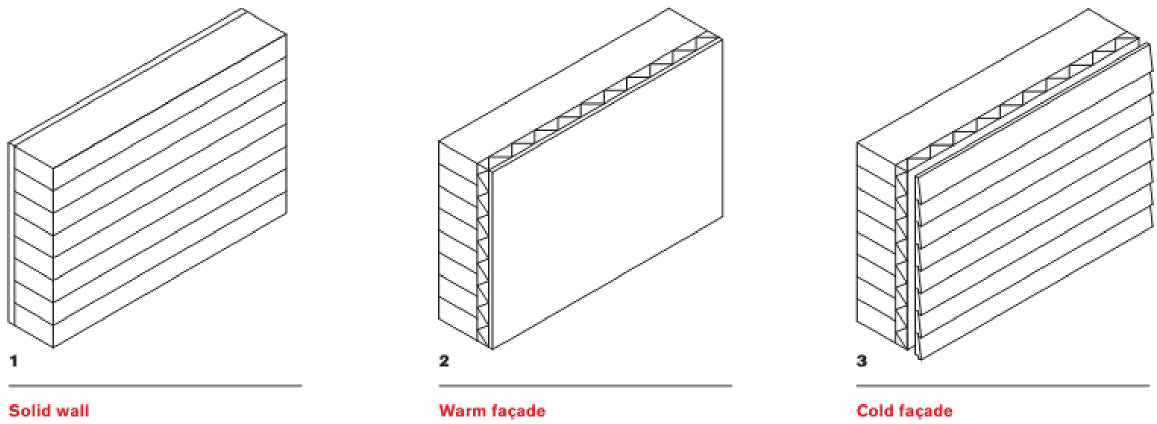
He starts with structural frames which can be made from concrete, steel or wood. Concrete frames are typically stiff and classified as fireproof, fire-resistant construction. Fireproof steel frames may use moment connections and require fireproofing to be classified as fire-resistant construction. Timber frames need to be braced or have shear planes for lateral stability. They also could be qualified as heavy timber construction if they are utilized with non-combustible, fire-resistive external walls and if the members fulfil the minimum size requirements stated in the building code. Steel and concrete frames can span bigger distances and support bigger loads than timber frames. . Structural frames can support and accept a range of non-bearing or curtain wall systems. The detailing of connections is crucial for structural and cosmetic reasons when the frame is left exposed (Ching, 2014).



Concrete and masonry bearing walls are already non-combustible constructions and they rely on their mass to carry loads. While concrete and masonry are robust in compression, they require reinforcement to withstand tensile stress. Wall design and construction rely heavily on the height-to-width ratio, lateral stability features, and precise positioning of expansion joints (Ching, 2014).

Metal or wood studs of cold-formed metal or wood are typically spaced at 400 or 600 on centre; this spacing is related to the width and length of common sheathing materials. Studs primarily carry vertical loads while sheathing or diagonal bracing stiffens the plane of the wall. Cavities within the wall frame can be used to accommodate thermal insulation, vapor retarders, and the distribution of mechanical and electrical services. Additionally, stud framing can accept a variety of interior and exterior wall finishes. The fire-resistance rating of the wall assembly is often determined by the finish materials used. Stud wall frames may be assembled on-site or panelised off-site, offering flexibility in construction methods. This flexibility is further enhanced by the workability of relatively small pieces and the various means of fastening available (Ching, 2014).

In "Façades: Principles of Construction" by Ulrich Knaack, Tillmann Klein, Marcel Bilow, and Thomas Auer (2007), three primary façade types are detailed: solid walls, warm façades, and cold façades. Solid walls, made of materials like stone or brick, are both durable and simple. Warm façades feature a thermal insulation layer put directly to the surface, either outdoors or inside, with the outside insulation being weatherproof. Cold façades have a ventilated space between the outside protective layer and the thermal insulation, this allows moisture to evaporate so that the insulation materials keeps the necessary insulation properties (Knaack et al. 2007).



(Knaack et al. 2007).

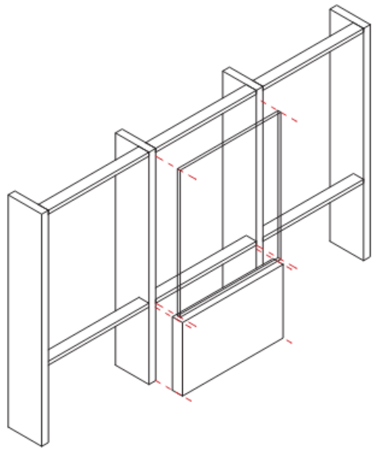
Summarizing, the evolution of facade typologies has impacted building construction, driven by increasing energy requirements, higher comfort standards, and climate change challenges. Structural frames, whether made of concrete, steel, or timber, offer versatile support for various non-bearing wall systems especially for mid to high-rise. On site built concrete and masonry bearing walls, are less suitable for high-rise structures due to their high mass and the need for reinforcement. Tough they are sometimes used as prefabricated elements. Similarly, the solid walls described in Principles of Construction, are impractical for high-rise applications because of their mass and shortcomings in todays' energy requirements. In contrast, warm and cold facades provide effective insulation solutions, with cold facades having better moisture management through ventilation.

2.1.6 Non-bearing façade typologies

In the lead-up to the Neoclassical era, architects separated the wall's functions step by step: bearing, sealing, and light transmission where being separated from each other. Technical constraints still necessitated some integration, but wide window openings were possible without the structural linkages found in older architecture. Neoclassical architects eventually detached the building's outer envelope from its loadbearing structure, using inner columns for support and allowing the façade to stand alone on the exterior (Knaack et al. 2007). This let to the following façade types:

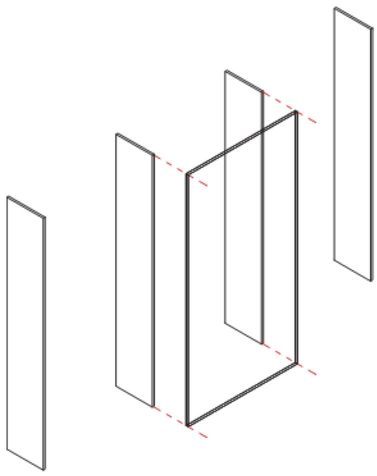
Post-and-beam façade

The post-and-beam façade was an evolutionary step in separating the building's outside wall from its load-bearing structure, which has led to modern glass buildings. This design employs storey-high poles connected by horizontal beams, with spaces between them for cladding, lighting, and ventilation. These façades not only convey wind stresses and structural weight to the ground, but they also support a variety of functional aspects. This design advances the breakdown of the monolithic outside wall, resulting in a more versatile and useful façade (Knaack et al. 2007).



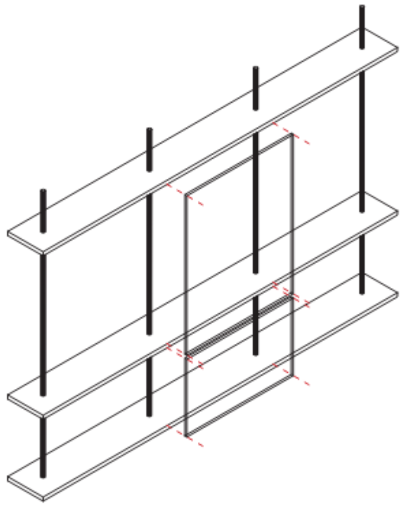
Post façade

Post systems, where tie rods are used to bear loads , are designed to improve structural transparency by enhancing openness. Structural constraints are defined by the maximum distance between posts, with storey-high posts distributing loads to earth (Knaack et al. 2007).



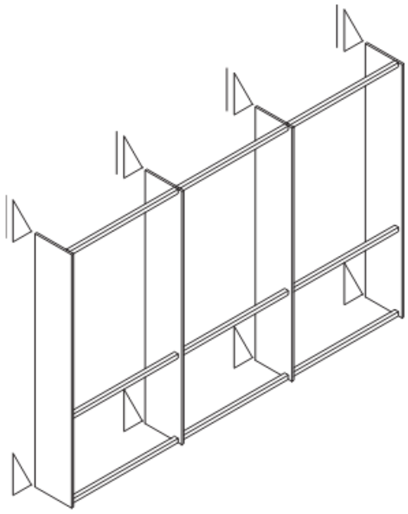
Beam façade

Using simply beams instead of posts results in a suspended façade system. beams, not posts, bear lateral forces, while vertical suspension systems and heavy-duty tie-rods near the roof support the façade's weight. This design reduces structural mass and prevents buckling, transferring wind loads to the ground via the beams (Knaack et al. 2007).



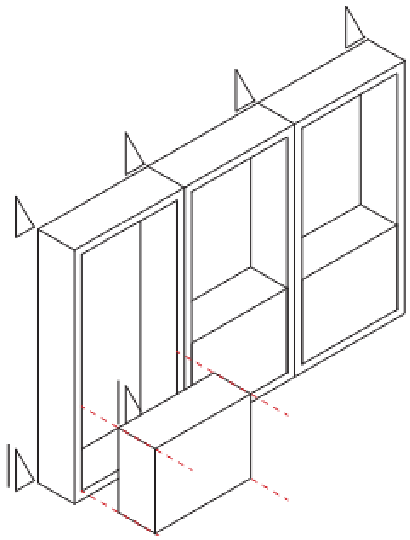
Standing post-and-beam façade

Standing post-and-beam façades usually consist of storey-high modules. However, the problem of the post being subjected to buckling has to be considered (Knaack et al. 2007).



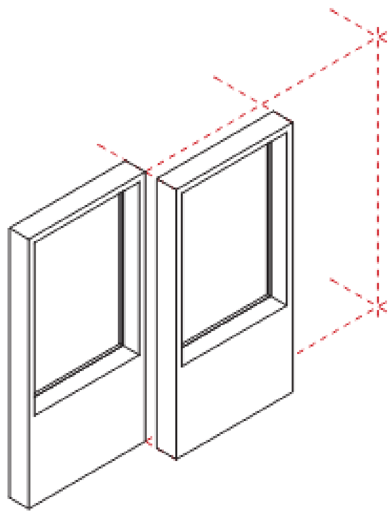
Curtain wall facade

Curtain walls, hanging from the roof via tie rods, evolved from earlier façade systems and are largely independent of a building's main structure. This design allows flexible partitioning and various cladding or glazing options. Vertical and lateral loads are transferred floor by floor, with special elements for longer spans, avoiding post buckling and enhancing design freedom (Knaack et al. 2007).



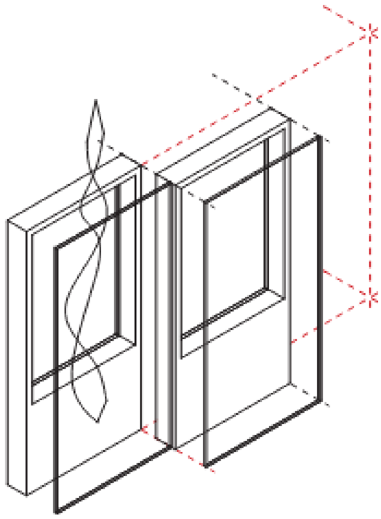
System façade

The curtain walls that are widely used can be divided into stick and unit systems. Elements can be prefabricated and assembled on-site, or entire walls can be prefabricated off-site and installed as a whole. Prefabrication can offer a lot of benefits like consistent quality, quick assembly, and low on-site labour, but it's typically used in high-rise buildings due to logistical demands, such as crane usage. System façades differ from post-and-beam systems by allowing complete prefabrication and minimal on-site labour (Knaack et al. 2007).



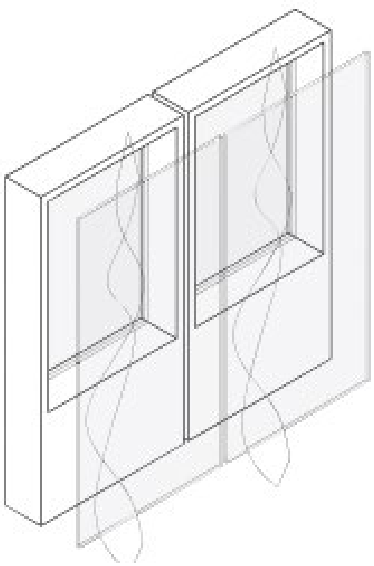
Double facades

Double façades add an extra glazing layer outside the façade for ventilation or soundproofing. This system has evolved from initial excitement to a more pragmatic use, addressing specific needs like high street noise, wind loads, or increased building height. Ventilation can occur between façade layers, often spanning multiple stories. Double façades are now implemented selectively, based on the functional and technical requirements of the building.



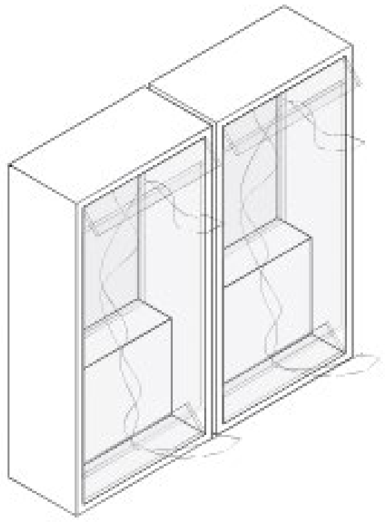
Second skin facade

A second-skin façade adds an external glass layer over the building's inner façade, offering technical simplicity and minimal moving parts. Ventilation is provided only at the top and bottom. While easy to construct, it has limited interior environment control and a risk of overheating. This design balances ease of implementation with basic ventilation needs but may not suit buildings requiring precise climate management (Knaack et al. 2007).



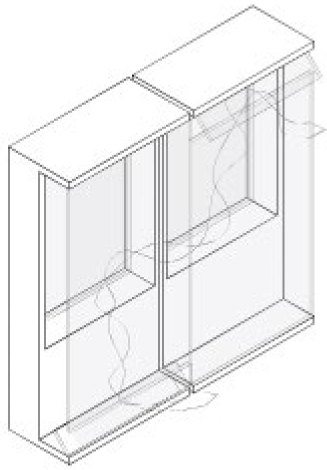
Box-window façade

The box-window façade includes storey-high elements that individual users can open at the top and bottom, allowing personal control of the internal environment. However, this freedom can negatively impact other occupants, as exhaust air from one floor may affect the floor below. Staggering ventilation inlets and outlets can mitigate this issue. This design contrasts with the second-skin façade, which adds an external glass layer for simpler construction and basic ventilation (Knaack et al. 2007).



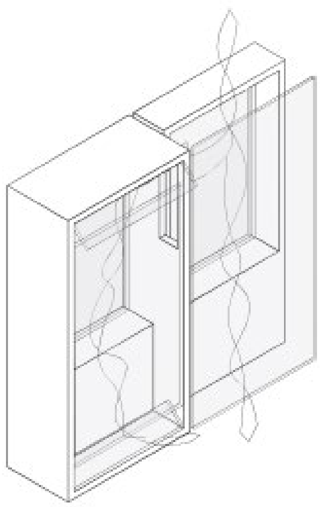
Corridor façade

The corridor façade tries to address ventilation interference by using staggered air inlets and outlets and vertical baffles between the façade layers to prevent horizontal air flow and noise interference. However, the installation of these baffles is not always possible due to the need for horizontal connections. This design connects neighbouring double-façade elements to achieve controlled, staggered ventilation between the two layers, improving noise and air quality management (Knaack et al. 2007).



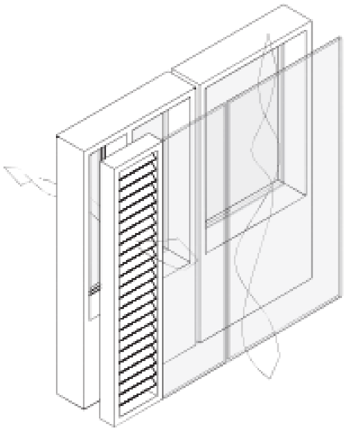
Shaft-box façade

The shaft-box façade, the most effective but complex double façade variant, involves discrete box windows releasing exhaust air into a multi-floor shaft mounted on the façade. This design enhances thermal efficiency through a stack effect, promoting vertical air movement in the shaft. While offering superior performance, it requires significant construction and control-engineering efforts, making it a high-efficiency but challenging double façade system to implement (Knaack et al. 2007).



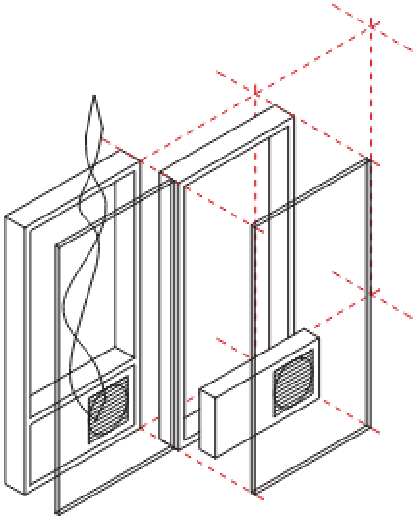
Alternating facade

Alternating façades offer a solution to variable ventilation needs by combining single-skin and double façade benefits. Essentially single-skin constructions, they can locally convert to double façades by adding a second skin. This approach aims to merge the simplicity of single-skin façades with the buffering effect of double façades, providing flexibility and efficiency in managing ventilation requirements within specific areas of the building (Knaack et al. 2007).



integrated façade

The integrated façade advances the concept of the double façade by incorporating functions beyond ventilation, such as air-conditioning and lighting control. Also known as a 'modular' or 'hybrid' façade, this system can potentially centralize all environmental-engineering functions within the façade itself, redefining building design by transferring essential functions from the building core to the façade. This approach promises a new synergy between façade construction and internal environmental control, revolutionizing building design principles (Knaack et al. 2007).



2.1.7 Façade typologies available on ISSO

ISSO-SBR offers detailed drawings and specifications for various façade typologies that are designed to meet Dutch building norms and performance standards. These tools are invaluable to architects, engineers, and builders who design and construct structures. The façade typologies offered on ISSO are classified according to their construction methods, materials, and functionality.

The ISSO database has the following Façade typologies:

01 Curtain wall (Vliesgevel)

02 Structural glazing

03 Masonry with wooden inner cavity wall

04 Profiled sheet with steel box

05 Sandwich panel

06 Profiled sheet with steel frame inner cavity wall

07 Cladding with steel frame inner cavity wall

08 Prefabricated concrete with cladding

09 Ceramic tiles with wooden inner cavity wall

10 Masonry, cavity insulation, stone inner cavity wall

11 Natural stone with...

12 Second skin façade

14 Ceramic tiles with steel inner box

15 Load-bearing structure for the façade, steel inner box with profiled sheet

16 Masonry, cavity insulation, stone inner cavity wall

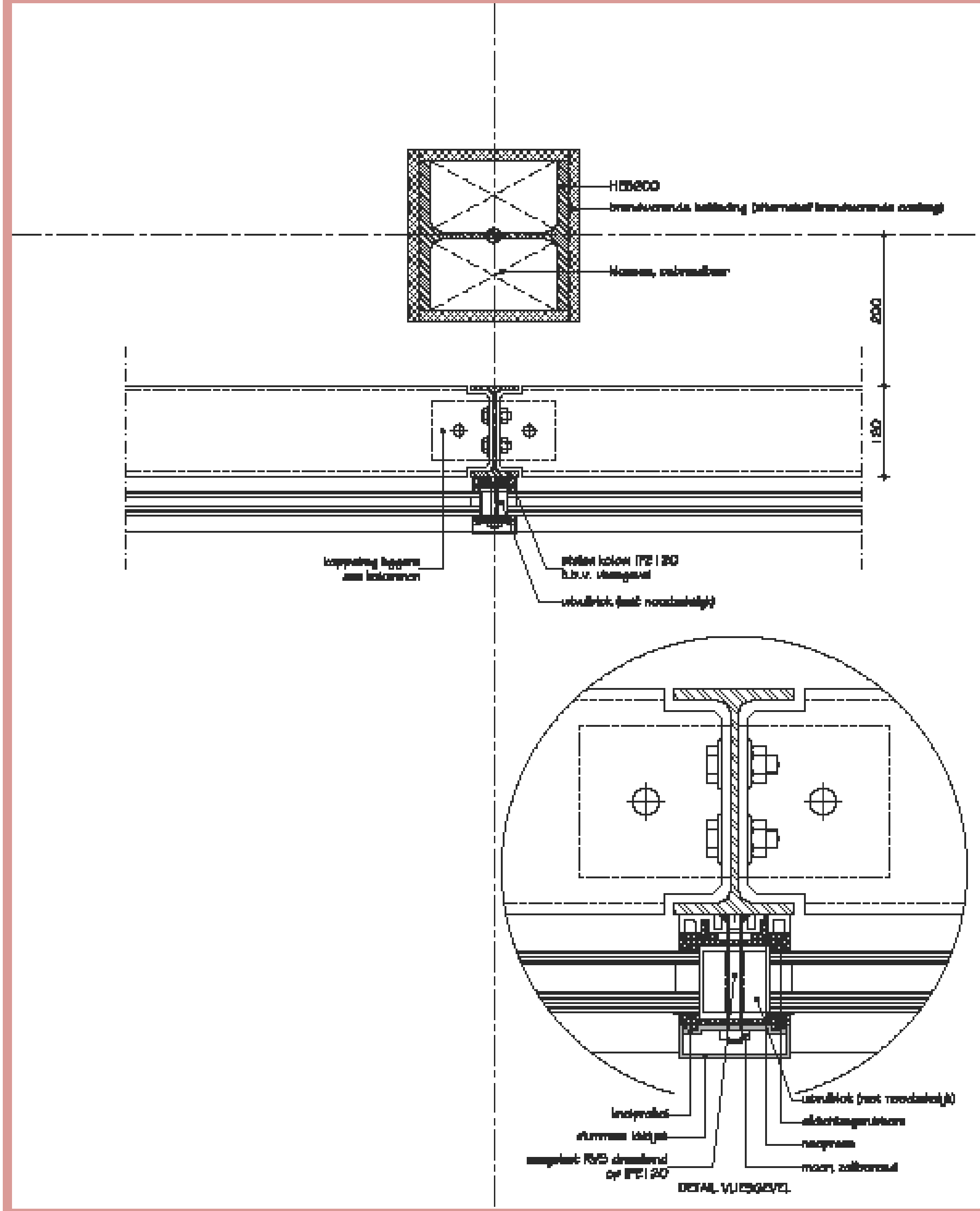
Geveltype

01 vliesgevel	45
02 structural glazing	6
03 metselwerk met houten binnensppouwblad	13
04 geprofileerde plaat met stalen binnendoos	35
05 sandwichpaneel	10
06 geprofileerde plaat met staalframe binnenspouwblad	10
07 beplating met staalframe binnenspouwblad	11
08 prefab beton met voorzetwand	8
09 keramische tegels met houten binnenspouwblad	12
10 metselwerk, spouwisolatie, steenachtige binnenspouwblad	9
11 natuursteen met..........	9
12 tweede huid façade	10
14 keramische tegels met stalen binnendoos	11
15 draagconstructie voor de gevel, stalen binnendoos met geprofileerde plaat	10
16 metselwerk, spouwisolatie, steenachtig binnenspouwblad	8

Select the details I want to analyse, Floor detail, shared wall detail, window opening horizontal and vertical for every typology. These can then be modelled and analysed for embodied energy and embodied carbon.

Draagstructuur : stalen draagstructuur
Gevelopbouw : vliesgevel
Vloertype : holle staalplaat-beton vloer
Variant-detail : vliesgevel met stalen draagconstructie

S.01.03.204.1



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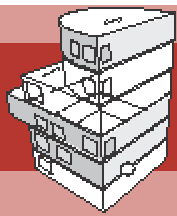
Omschrijving begrippen: zie begrippenlijst

Draagstructuur : stalen draagstructuur
Gevelopbouw : vliesgevel
Vloertype : holle staalplaat-beton vloer
Variant-detail : vliesgevel met stalen draagconstructie



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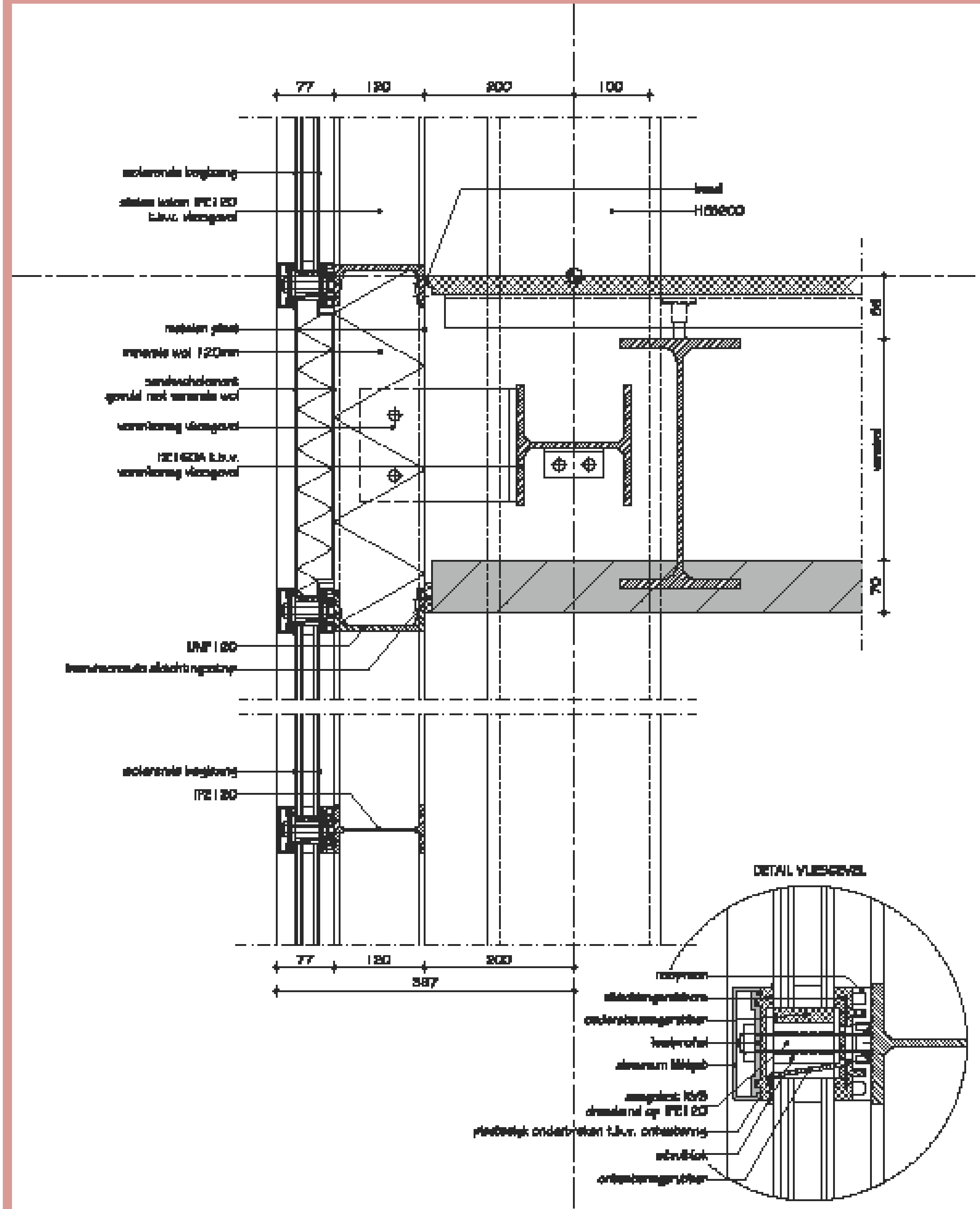

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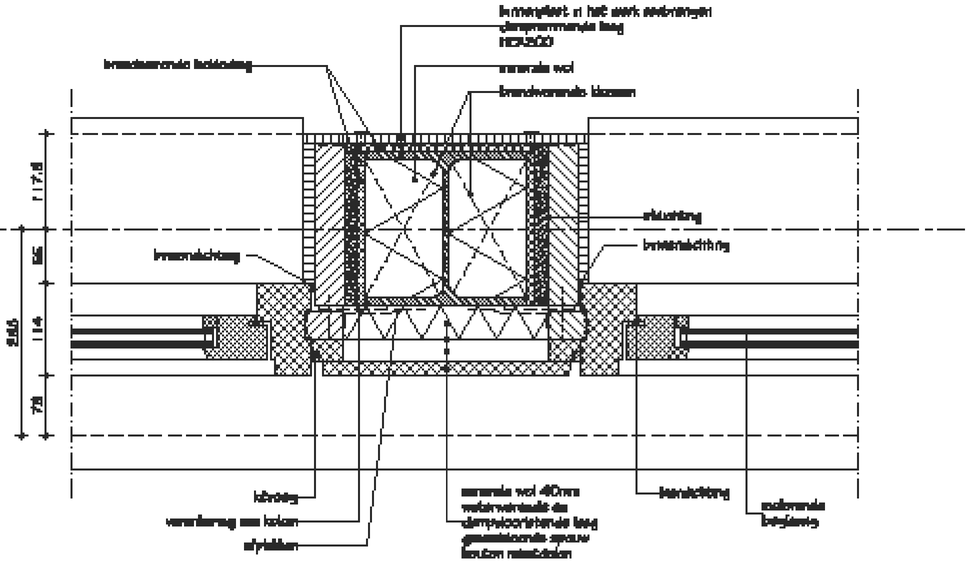
Omschrijving begrippen: zie begrippenlijst

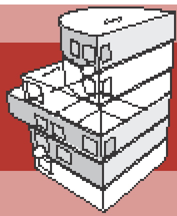
Masonry with wooden inner cavity wall

Draagstructuur : stalen draagstructuur
Gevelopbouw : metselwerk met houten binnensppouwblad
Vloertype : holle staalplaat-beton vloer
Variant-detail : gevelkolom, houten kozijn

S.03.03.204.1



Draagstructuur : stalen draagstructuur
Gevelopbouw : metselwerk met houten binnensppouwblad
Vloertype : holle staalplaat-beton vloer
Variant-detail : houten kozijn, oplegging vloer op stalen IPE - ligger



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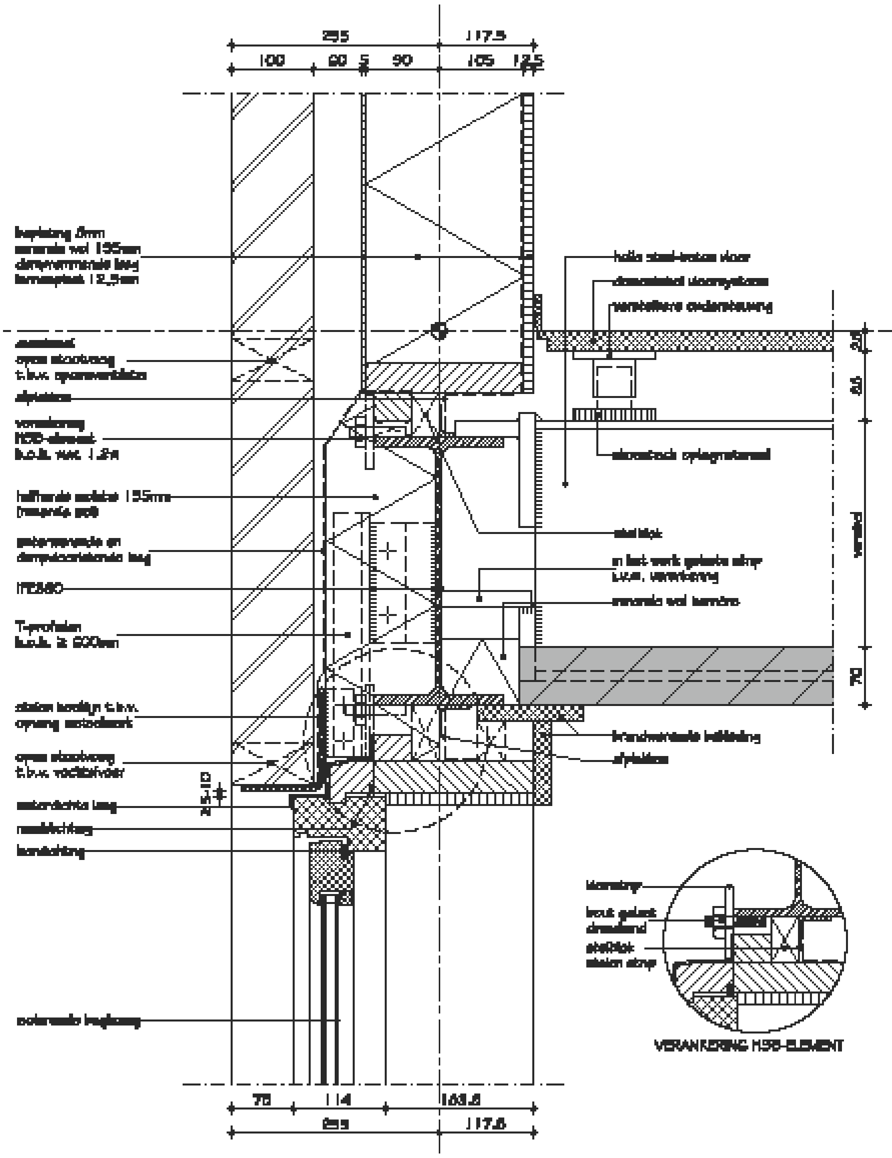

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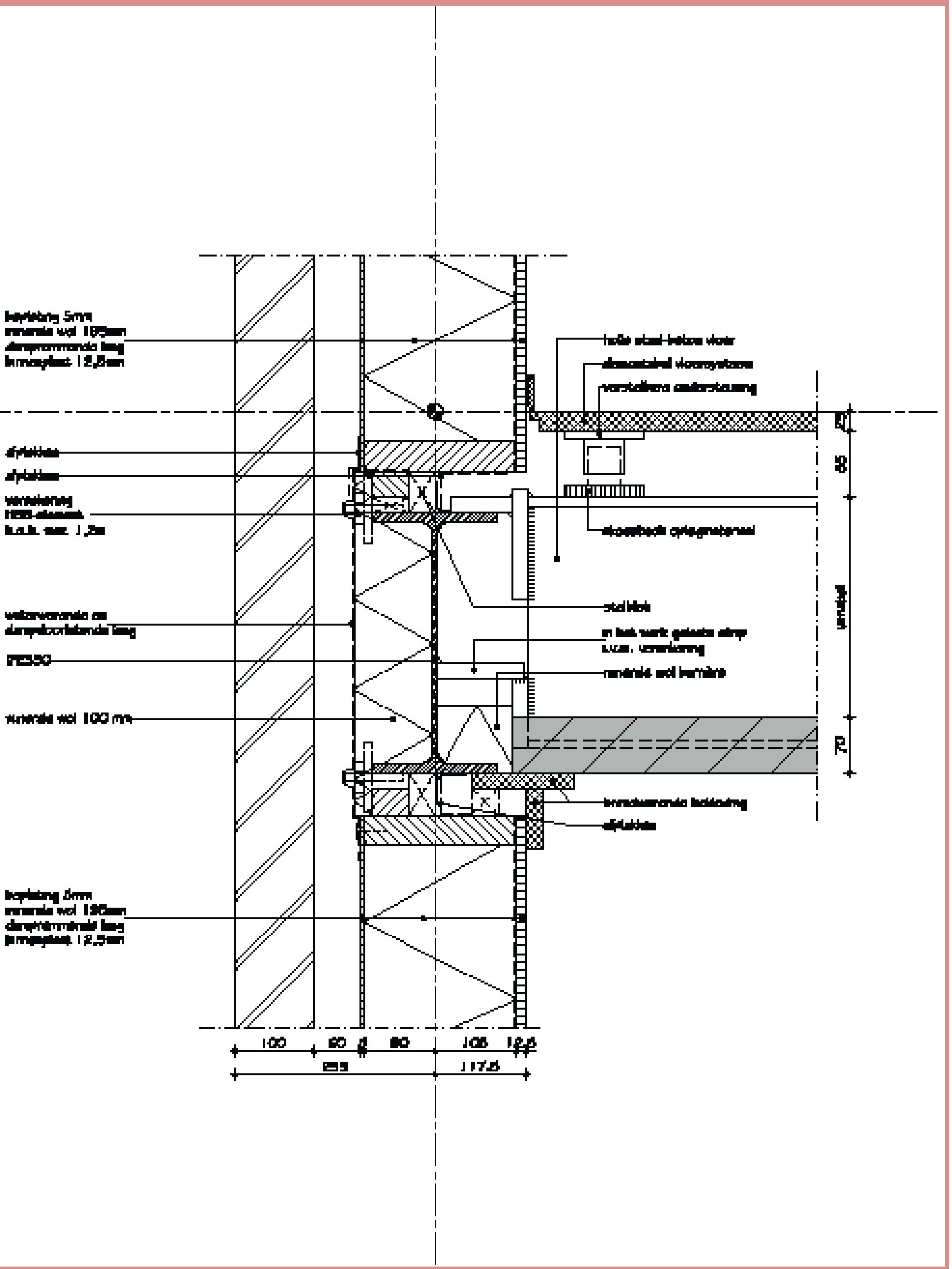
Omschrijving begrippen: zie begrippenlijst

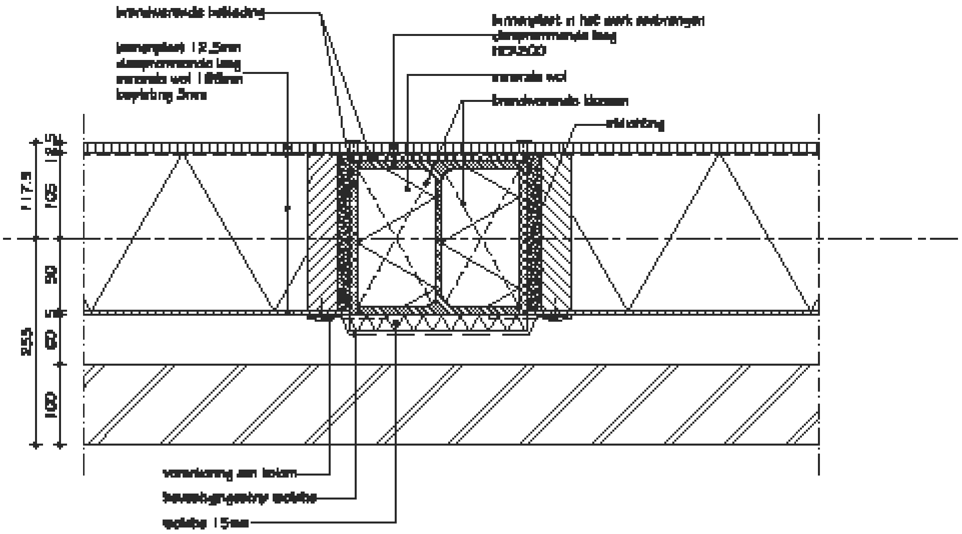
Draagstructuur : stalen draagstructuur
Gevelopbouw : metselwerk met houten binnensppouwblad
Vloertype : holle staalplaat-beton vloer
Variant-detail : stalen IPE - ligger

S.03.03.301.1



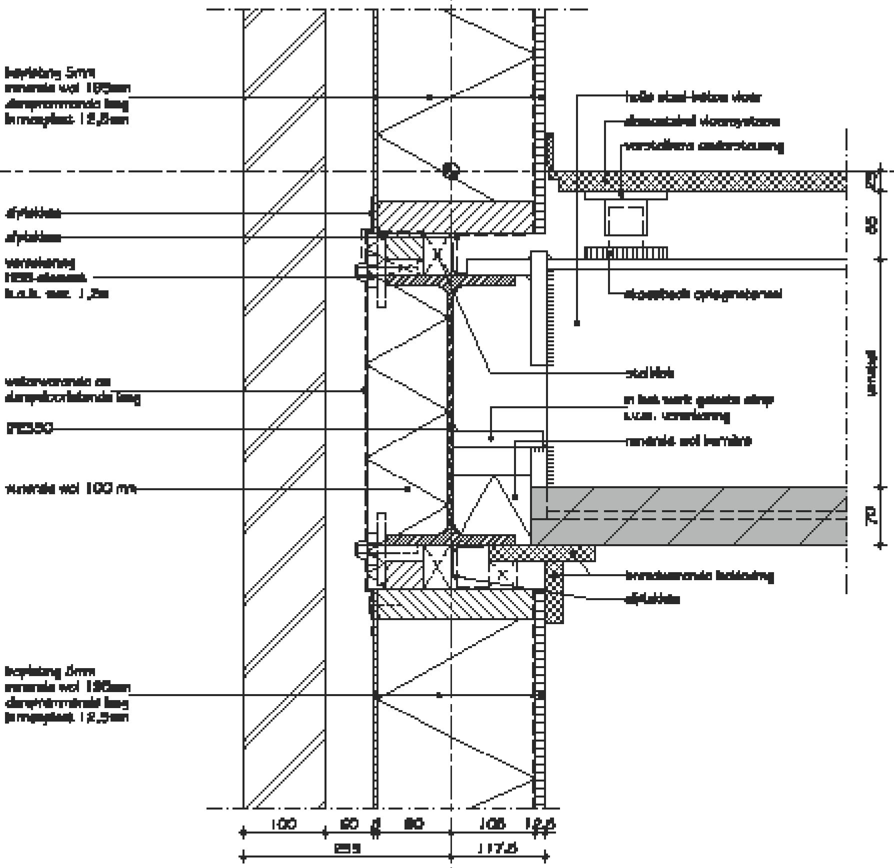
Draagstructuur : stalen draagstructuur
Gevelopbouw : metselwerk met houten binnensppouwblad
Vloertype : holle staalplaat-beton vloer
Variant-detail : gevelkolom

S.03.03.203.1



Draagstructuur : stalen draagstructuur
Gevelopbouw : metselwerk met houten binnensppouwblad
Vloertype : holle staalplaat-beton vloer
Variant-detail : stalen IPE - ligger

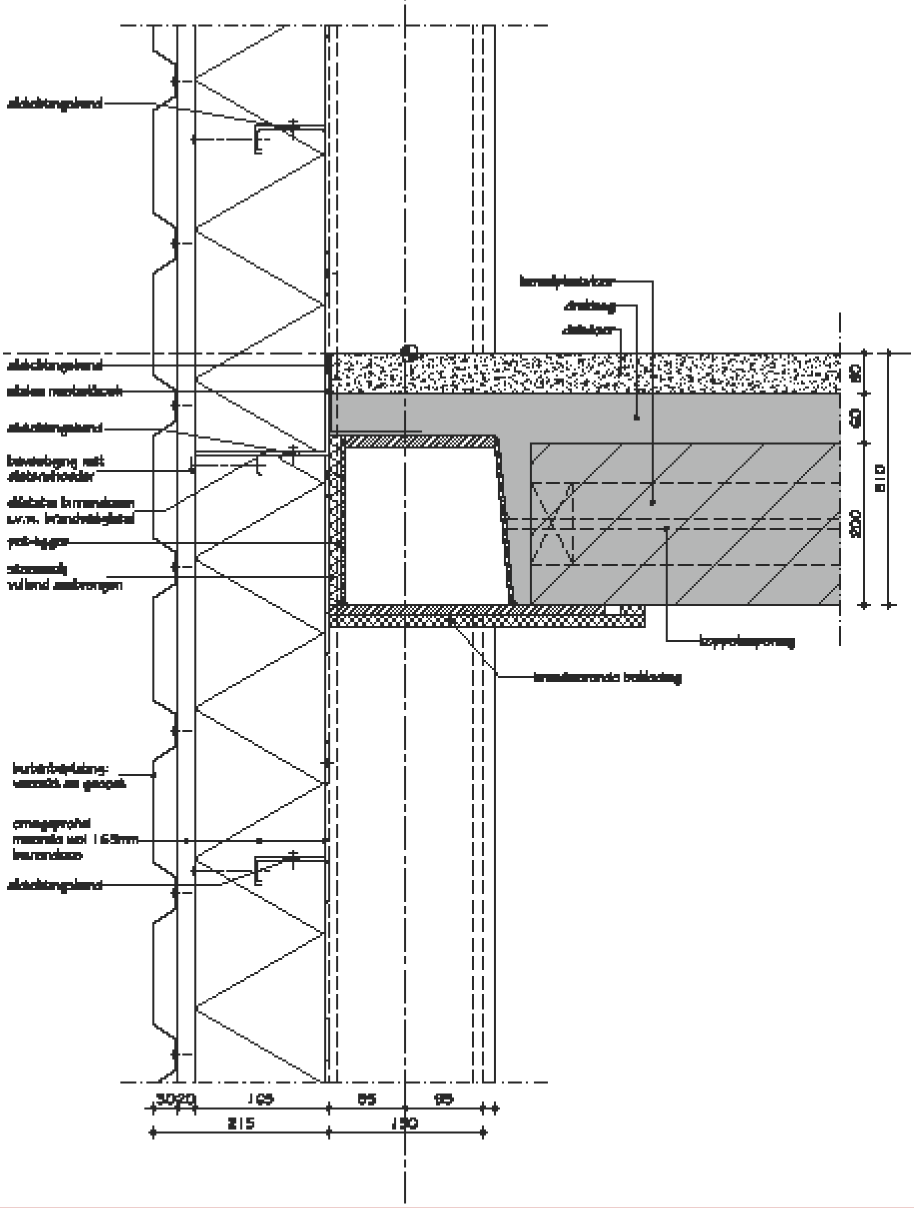
S.03.03.301.1



Profiled sheet with steel box

Draagstructuur : stalen draagstructuur
Gevelopbouw : geprofileerde plaat met stalen binnendoos
Vloertype : kanaalplaatvloer
Variant-detail : horizontale gevelbeplating, pet-ligger

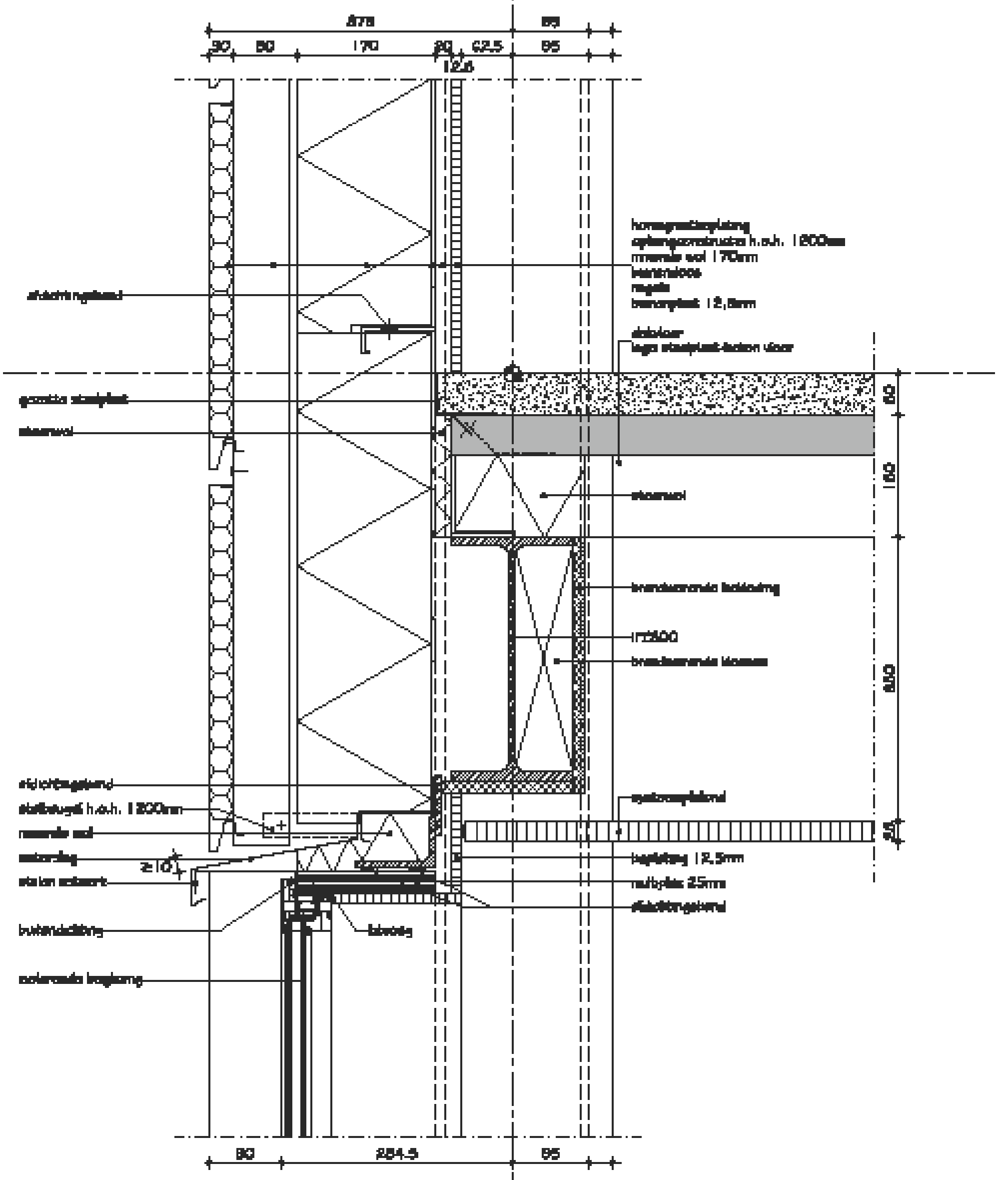
S.04.01.301.1



schaal 1:7 afhankelijk van uw printerinstellingen
Omschrijving begrippen: zie begrippenlijst

Draagstructuur : stalen draagstructuur
Gevelopbouw : geprofileerde plaat met stalen binnendoos
Vloertype : lage staalplaat-beton vloer
Variant-detail : honingraatbeplating, aluminium kozijn

S.04.05.303.1



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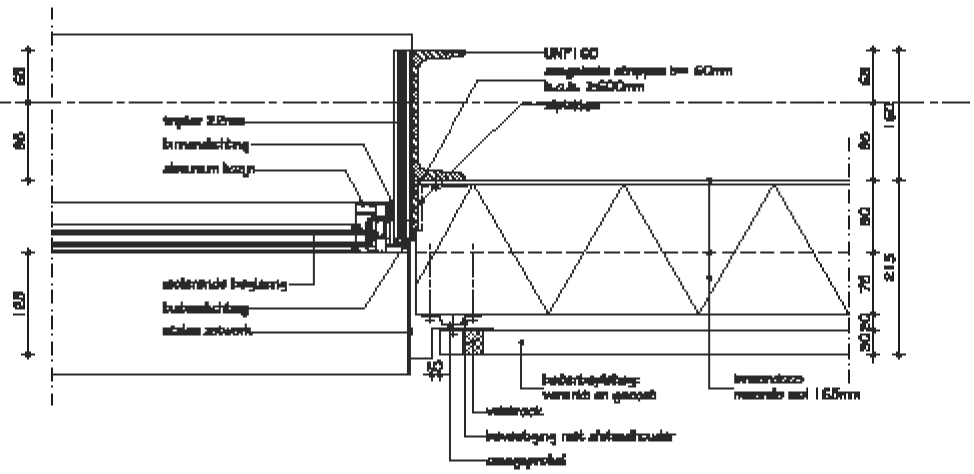
Omschrijving begrippen: zie begrippenlijst

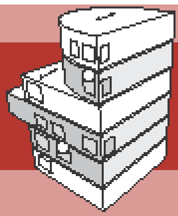
Draagstructuur : stalen draagstructuur
Gevelopbouw : geprofileerde plaat met stalen binnendoos
Vloertype : kanaalplaatvloer
Variant-detail : horizontale gevelbeplating, aluminium kozijn

S.04.01.207.1



schaal 1:7 afhankelijk van uw printerinstellingen
Omschrijving begrippen: zie begrippenlijst

Draagstructuur : stalen draagstructuur
Gevelopbouw : geprofileerde plaat met stalen binnendoos
Vloertype : kanaalplaatvloer
Variant-detail : horizontale gevelbeplating, aluminium kozijn



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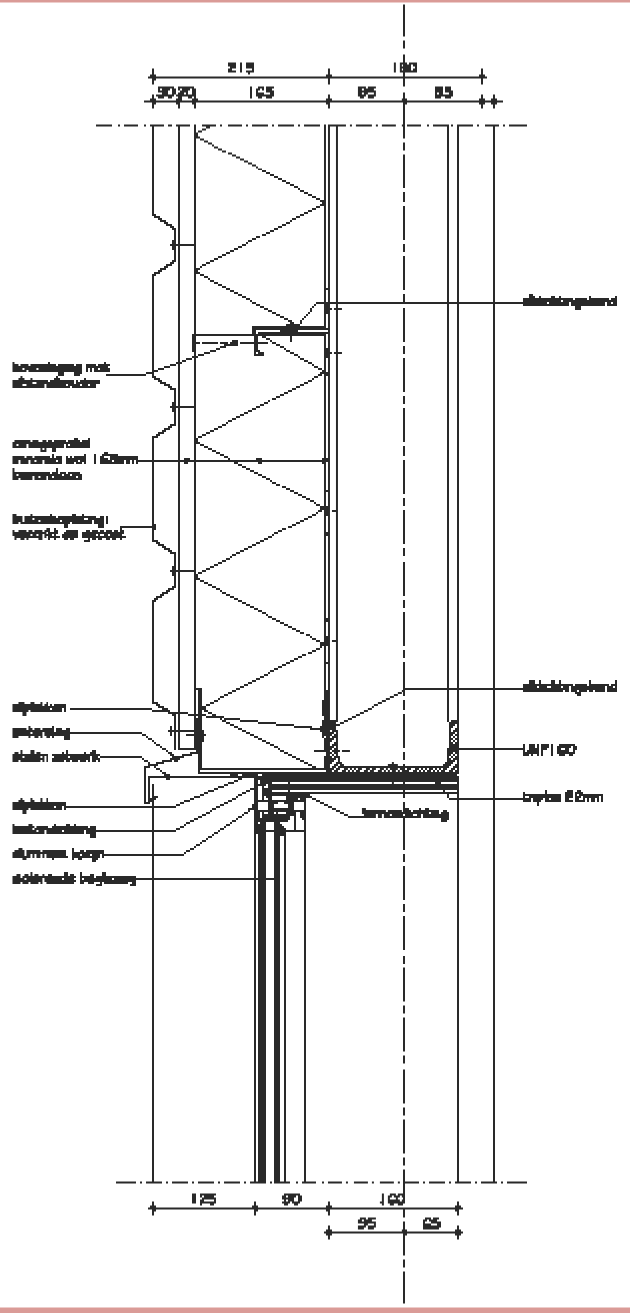
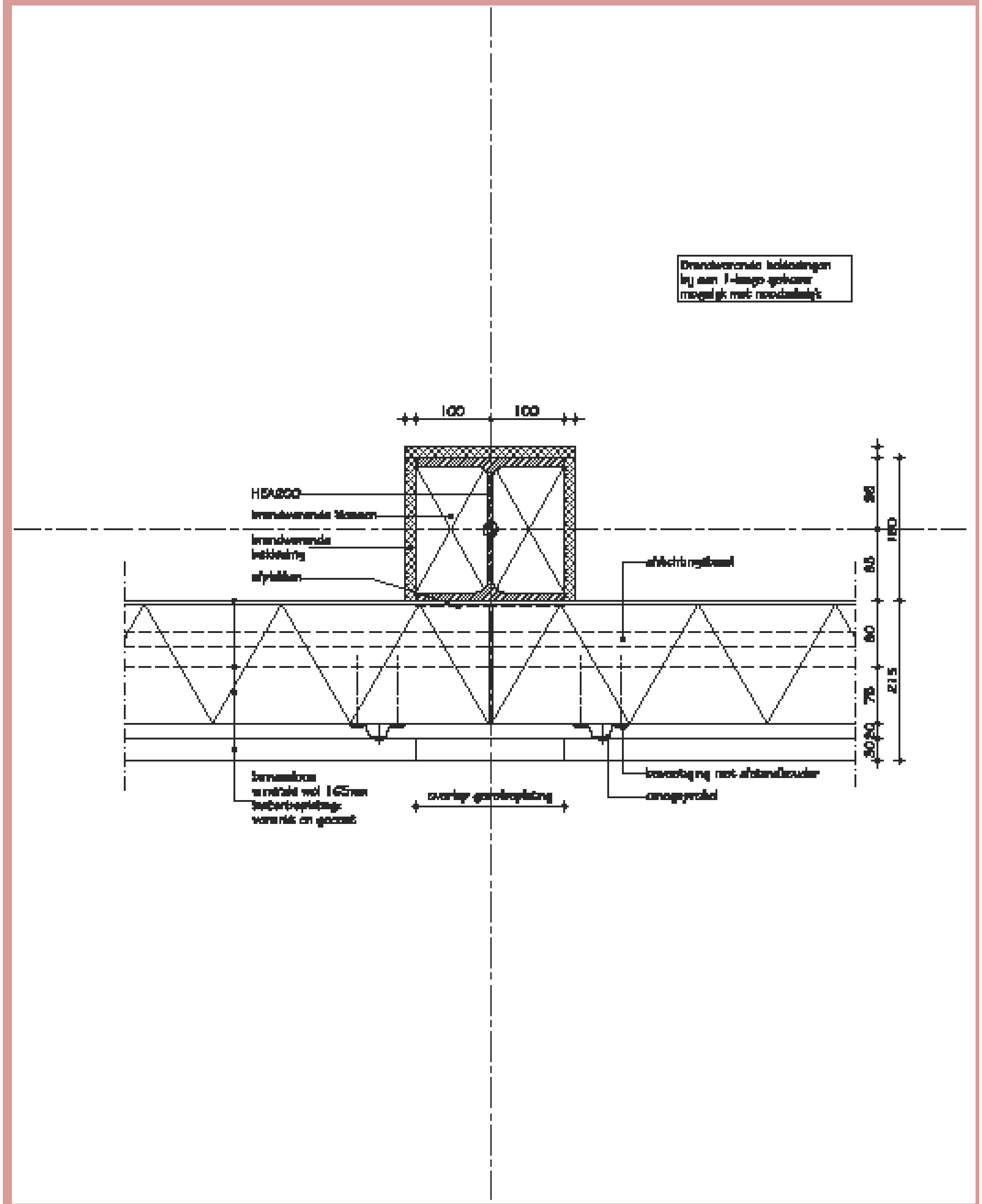


schaal 1:7 afhankelijk van uw printerinstellingen
Omschrijving begrippen: zie begrippenlijst

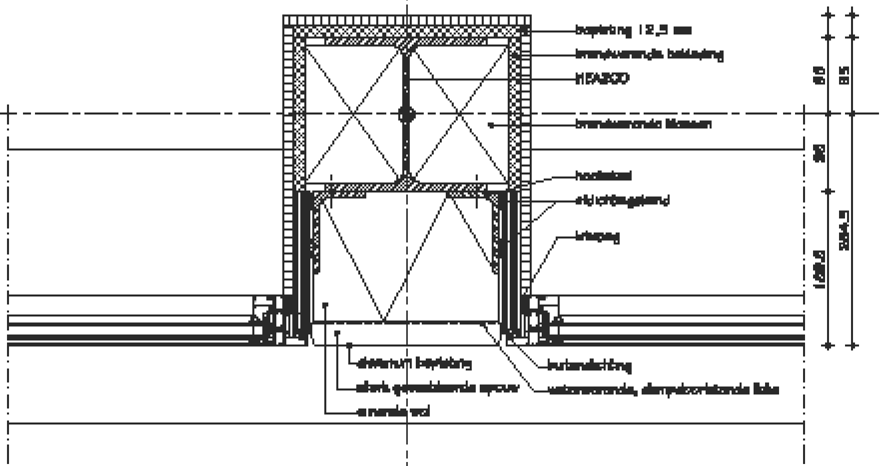
Draagstructuur : stalen draagstructuur
Gevelopbouw : geprofileerde plaat met stalen binnendoos
Vloertype : kanaalplaatvloer
Variant-detail : horizontale gevelbeplating

S.04.01.203.1



Draagstructuur : stalen draagstructuur
Gevelopbouw : geprofileerde plaat met stalen binnendoos
Vloertype : lage staalplaat-beton vloer
Variant-detail : honingraatbeplating, aluminium kozijn

S.04.05.204.1



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Sandwich panel

Retrieve from ISSO

Profiled sheet with steel frame inner cavity wall

Retrieve from ISSO

Cladding with steel frame inner cavity wall

Retrieve from ISSO

Prefabricated concrete with cladding

Retrieve from ISSO

Ceramic tiles with wooden inner cavity wall

Retrieve from ISSO

Masonry, cavity insulation, stone inner cavity wall

Retrieve from ISSO

Natural stone with…

Retrieve from ISSO

Second skin façade

Retrieve from ISSO

Ceramic tiles with steel inner box

Retrieve from ISSO

Load-bearing structure for the façade, steel inner box with profiled sheet

Retrieve from ISSO

Masonry, cavity insulation, stone inner cavity wall

Retrieve from ISSO

2.1.8 Conclusion

What is the definition of mid to high-rise, and what are the most prevalent facade typologies that apply to mid to high-rise buildings?

Add text...

2.1.9 Sources

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2.2 Embodied energy & embodied carbon

2.2.1 introduction

Add text...

2.2... Definitions

Add text...

2.2... Conclusion

What is the definition of mid to high-rise, and what are the most prevalent facade typologies that apply to mid to high-rise buildings?

Add text...

2.2... Sources

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2.3 Regulations

2.3... introduction

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2.3... Definitions

Add text...

2.3.... Conclusions

How do different façade materials and typologies affect the embodied energy and carbon footprint of mid- to high-rise buildings, taking into account production, transportation, and the end of the lifecycle?

Add text...

2.3... Sources

Add text...

2.4 Dynamic models

2.4.1 introduction

Simulating building performance needs technical expertise in design, engineering, construction, operations, and management. The goal is to predict a building's behaviour from design to demolition using different disciplines including as physics, mathematics, material science, and human behaviour. The idea of developing performance simulation algorithms and forecasts stretches back several decades and the area is constantly evolving. Recent improvements in building simulation settings demonstrate the incorporation of research findings into current design and construction methods. (Malkawi, 2004)

This chapter tries to investigate how this dynamic model compares to traditional software, assessing its effective it is in predicting and optimizing building performance across various contexts. The goal of studying the development and performance of dynamic models is to show how they help make modern building practices more efficient and sustainable.

2.4.2 Definitions

Important ideas and techniques that are essential to the discipline of computational design are covered in this part of the literature review. Traditional software, parametric and computational design, visual programming languages, integrated dynamic models, Building Information Modelling (BIM), and Building Performance Simulation (BPS) are a few examples. The section provides a basis for comprehending each term's contribution in current building practices by identifying them.

Traditional software (CAD & BIM*)*

Computer-Aided Design (CAD) software has been essential in the architecture, engineering, and construction (AEC) industries for decades. Traditional CAD systems help designers create, modify, analyze, and optimize designs. These systems produce detailed drawings and specifications, improving precision and efficiency compared to manual drafting.

Key features of traditional CAD software include:

- 2D and 3D Drafting: Create and visualize both two-dimensional and three-dimensional models.
- Precision and Accuracy: Tools for exact measurements and adjustments.
- Documentation: Generate comprehensive documentation such as plans, elevations, sections, and details.
- Interoperability: Support various file formats and integrate with other software for seamless collaboration.

However, traditional CAD primarily focuses on geometric representation and cannot dynamically simulate or predict building performance. This limitation has led to the development of more advanced methodologies that incorporate performance analysis early in the design process.

Building Information Modeling (BIM) is a digital representation of the physical and functional characteristics of a facility. BIM serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions throughout its lifecycle, from conception to demolition.

Key characteristics of BIM include:

- Integrated Data: Combines geometric data with detailed information about building components.
- Collaboration: Facilitates collaboration among all stakeholders (architects, engineers, contractors, and owners) through a unified model.
- Visualization: Enhances visualization of the design through 3D models, making it easier to communicate ideas and detect potential issues before construction begins.
- Lifecycle Management: Supports the entire lifecycle of a building, from design and construction to operation and maintenance, improving efficiency and reducing costs over time.

BIM differs from traditional CAD by managing building information in a digital environment, allowing more comprehensive analysis and control. This fosters better decision-making and more sustainable building practices.

Building Performance simulation (BPS)

Building Performance Simulation (BPS) refers to the use of computer-based models to predict and evaluate the performance of buildings in terms of energy consumption, indoor environmental quality, and other critical factors. BPS tools enable designers to assess various design alternatives and their impact on a building's performance, promoting more informed decision-making.

Building Performance Simulation (BPS) is defined in this research as the scientific prediction of specific building performances using mathematical models based on fundamental physical principles. BPS relies on computer-controlled calculations and is considered essential for supporting and assessing the design of high-performing buildings (Malkawi, 2004).

The use of BPS enables the design team to make informed decisions during the exploration of architectural expressions and concepts throughout the design phases. Providing project-specific data on design performance can help improve the quality of the design (Negendahl, 2016).

The use of BPS for demonstrating building performance is not a new concept in itself. However, there has been an increasing use of BPS in recent years. This is because of stricter requirements created by new regulations or an increasing demand for high-performing buildings from the market, particularly in the context of sustainability (Negendahl, 2016).

Computationeel- en parametrisch ontwerpen

Parametric design has, in a short time, opened the door to groundbreaking new possibilities for design methodologies and their corresponding architectural designs (Harding, Joyce, Shepherd, & Williams, 2013). Today, it is well established within the so-called "computational design" community. Parametric design does not explicitly include the role of computation (calculations) or the type of process the designer uses it for. It simply means design as "a process where a problem is described using variables" (Hudson, 2010). Similarly, the term generative just describes something "with the power or function of generating, producing, or reproducing" (Merriam-Webster 2017). Both terms can be applied to most, if not all, design processes.

Computational design encompasses a range of methodologies that use algorithms and computational processes to enhance design creativity and efficiency. It involves the application of advanced computational techniques to generate, analyze, and optimize complex designs. Parametric design, a subset of computational design, utilizes parameters and algorithms to control and manipulate design elements. This approach allows for the creation of flexible and adaptable models where changes to input parameters automatically update the design.

Within the domain of computer science, the process of applying an algorithm to input data to obtain an output is called computation ("Wolfram|Alpha," n.d.). In this research, computation is defined as the process of applying an algorithm to input to obtain output (that is, step-by-step procedures designed to solve a problem or complete a task) and their practical implementation in a computer program (Holden, 2020). Parametric design is defined in this research as "a design process in which a description of a problem is formulated using variables" (Hudson, 2010).

In mathematics, a graph is an abstract construction consisting of objects (nodes), some pairs of which are connected by links (edges). If the edges of the graph have a corresponding direction, the graph is a directed graph. The so-called directed graph is the fundamental data structure on which the most popular parametric modeling environments, such as McNeel's Grasshopper, Bentley's Generative Components, and Autodesk's Dynamo, are based. Within these parametric modeling environments, the user constructs components via a graphical interface, which are relationally connected with each other through wires. In this way, the directed graph is constructed. According to Davis, these environments are referred to as Visual Programming Languages (VPL).

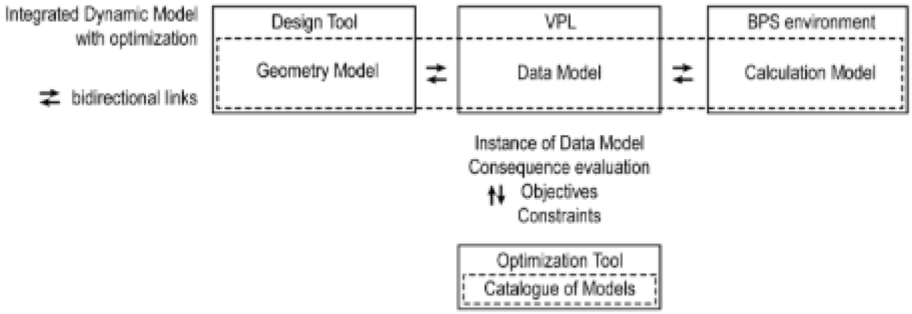
Key characteristics of parametric design include:

- Flexibility: Enables designers to explore multiple design variations quickly by adjusting parameters.
- Efficiency: Reduces the time and effort required to make changes, as the model updates automatically based on predefined rules and relationships.
- Optimization: Facilitates the exploration of optimal design solutions by analyzing various scenarios and performance criteria.
- Integration: Combines geometric design with performance analysis, allowing for more holistic and sustainable solutions

“Conventional CAD systems focus design attention on the representation of the artifact being designed. Currently industry attention is on systems in which a designed artifact is represented parametrically, that is, the representation admits rapid change of design dimensions and structure. Parameterization increases complexity of both designer task and interface as designers must model not only the artifact being designed, but a conceptual structure that guides variation. (Aish & Woodbury, 2005) “

The integrated dynamic model

In a recent review, Negendahl (2015) defines an integrated dynamic model as a special case of a distributed model. An integrated dynamic model is a combined model composed of a geometric model controlled in a design tool dynamically coupled to a visual programming language (VPL), which is again dynamically coupled to a building performance simulation (BPS) environment. The middleware can be operated by either the simulationist (Bleil de Souza, 2012), or the building designer, both of them or by a third, undefined operator.



VPL’s such as Grasshopper (Robert McNeel & Associates, 2013b), Dynamo (Autodesk, 2013a), GenerativeComponents (Bentley, 2013), Digital Project (Gehry Technologies, 2013), and Yeti (Davis, 2013b) are examples of some of the scripting tools, designers and architects are using to automate form generation. Arguably, VPLs are able maintain the design variables as open and parametric, and code instructions are more user-friendly than those provided by lower level programming languages such as Java, RhinoScript, etc. As the VPLs are run-time coupled to the design tool, the coupling can be defined as dynamic in the way Zhai (2003) categorizes the couplings between BPS tools. Also the integrated dynamic model method can be used for multi domain (performance) evaluations, hence the model can be categorized as integrated, much like Citherlet et al. (2001) categorizes multi domain BPS tool couplings.

VPLs can in some cases be considered as design tools themselves, mainly because of the heavy use of geometric modeling functionalities. The reason why these tools are categorized differently than traditional CAD tools, is their ability to handle non-geometric data, and let operators create their own algorithms (Negendahl, 2015a). The VPL is coupled bi-directionally with one or more design tools, e.g. Rhino, Revit and MicroStation (Bentley, 2014) and has direct run-time access to the design tool functions. VPLs coupled to design tools are able to formalize to the exchange of data consisting of collections of geometric primitives, and the geometric-content-based data exchange of a VPL is in opposition to BIM’s ‘assigned-attribute-based’ data structures (Davis and Peters, 2013).

Optimization

Optimization covers a wide range of processes in building design from manual and heuristic attempts to full automation of optimization processes and workflows in large teams. To limit the discussion of optimization within the scope of the thesis objectives, optimization is defined as computer automated building performance optimization in the early design stage.

There are a wide range of optimization algorithms available for building designers and simulationists today. In the following, some of the most frequently used algorithms are briefly reviewed. All algorithms are available for integrated dynamic models, either through dedicated optimization tools (plugins) for the VPL for example: Galapagos (Rutten, 2010), Octopus (Vierlinger, 2014) and Goat (Simon Flöry et al., 2015), or through generic optimization tools such as MATLAB (Tonel, 2007).

in general terms there are two types of optimization algorithms; deterministic and stochastic algorithms. The deterministic algorithms such as brute force search methods are much slower than the stochastic methods. Stochastic search methods rely on random elements to generate unique outcomes of complex, multi-parameter problems. The randomness may result in unique outcomes with no guarantee of finding the exact optimum. Non-stochastic methods, on the other hand, are entirely deterministic in their nature. They are generally more reliable for finding the precise optimum since they do not get stuck within local minima or maxima. There is no degree of creativity or serendipity in the outcome of deterministic optimization (Wilkinson, 2011). Wilkinson (2011) even argues that stochastic search methods are more applicable to the design world, whereas deterministic optimization methods suit the engineering side. In the combined effort of a design team, this author argues that both deterministic and stochastic optimization have their justification in the early design stage.

Deterministic search methods Deterministic search methods include heuristic search, complete enumeration, and random search techniques. Heuristic optimization is often associated with manual optimization where the user changes parameter settings and design variables and then makes a simulation. This process continues until the analyst believes that the output has been optimized. One example of such a method is described and discussed by Petersen 2011 using the BPS iDbuild (Petersen and Hviid, 2012). Random search techniques often utilize uniform or normal Consequence based design 81 distributions that center a symmetric probabilistic density function. Deterministic search methods are also sometimes known as Brute force techniques.

Direct Pattern search methods Direct Pattern search methods neither compute nor explicitly approximate derivatives of cost functions. Thus, the unifying theme that distinguishes pattern search from other (direct) methods is that each of them performs a search using a “pattern” of points independent of the cost functions (Torczon, 1997). The best known Direct Pattern search algorithm is Hooke-Jeeves (Hooke and Jeeves, 1961). Variations of this algorithm are found in many implementations such as MOBO, MATLAB, and GenOpt. Under the assumption that the cost function is continuously differentiable, all accumulation points constructed by the Generalized Pattern Search algorithms are stationary (Wetter, 2011a).

Newtonian search methods The (Damped) Newton approaches are often used in discretization of large systems of nonlinear algebraic equations (Dirkse and Ferris, 1996). In the cases where the convergence of the Newton scheme is attainable only for very small time steps, methods for the enforcing of the convergence are often applied. An example of a Damped Newton search method in combination with optimization of building design performance is showcased by

(Pedersen, 2006), who also concluded that the inclusion of damping terms can reduce the number of iterations significantly.

Evolutionary search methods Evolutionary search methods, also known as Genetic Algorithms (GAs) and Simulated Annealing algorithms (SAs), are some of the widely used optimization methods in building design. The algorithms are versatile but can be difficult to predict because of the many hyper parameters that control them. SA borrows its basic ideas from statistical mechanics: A metal cools, and the atoms (design variable vectors) align themselves in an “optimal state” for the transfer of energy. In general, a slowly cooling system, left to itself as it eventually finds the arrangement of atoms, which has the lowest level of energy state. The “cooling” behavior is what motivates the SA, as it converges towards an optimum. GAs are probabilistic optimizing algorithms that like SAs do not require mathematical knowledge of the response surface of the system. They borrow the paradigms of genetic evolution in nature, and utilize the hyper parameters: selection, crossover, and mutation.

- Selection: The current solutions are defined by points in hyperspace and ranked in terms of their fitness by their respective response values. A probability is assigned to each point proportional to its fitness, which determines a portability to mate the most promising solutions in pairwise configurations (selection of the fittest parents).
- Crossover: The new point, or offspring, is chosen, based on various combinations of the genetics (combinations of design variable vectors) of the two parents.
- Mutation: The offspring is also susceptible to mutation, a process that occurs with probability ⍰. In this case, the offspring is replaced randomly by new combinations of variable vectors.

Agent based search methods Agent-based models (ABMs) for optimization and Particle Swarm Algorithms (PSAs) are not as commonly used in building design as e.g. genetic algorithms. However, agent based search methods have gained increased interest in other design areas such as in transportation and manufacturing industries (Barbati et al., 2012). ABMs and PSAs are often said to be inspired by the social behavior of organisms such as fish schooling and bird flocking. Kennedy and Eberhart (1995) explains the agents as particles assigned with flocking behavior in hyperspace to look for the optimal position to settle. Each individual, namely particle, is assigned with a randomized velocity flown through hyperspace. PSAs are almost identical with ABMs. However, PSA agents are individual solutions roaming in a competitive space of solutions, whereas ABM agents are usually competing in same-state solution space. Nowadays, PSAs and ABMs have gained much attention and wide applications in solving continuous non-linear optimization problems (Eberhart and Yuhui, 2001). However, the performance of PSAs greatly depends on their hyper parameters, and similar to GA and SA, they often suffers from being trapped in local optimum (Liu et al., 2005).

Rewrite

2.4.3 Why computational design

“The truth of sustainable design is that approximately 80% of the design decisions that influence a building's energy performance are made by the architect in the early design stages, the remaining 20% are made by engineers at the later stages of design.” (Solar Heating & Cooling Programme, 2010).

Most experts believe that decisions made during the early design stage have the biggest effect on the final design output. However, few building designs have been backed by early stage performance evaluations in areas of building energy consumption and interior environment (Augenbroe, 2002; Kanters et al., 2014).

In this part, the focus is on understanding why energy use, indoor environment, embodied energy, and embodied carbon are usually not considered together in the early stages of building design. The introduction of "parametric modelling" and the idea of using dynamic models to integrate these factors will be explored for a more complete understanding of building sustainability.

NL is using many types of incentives and regulatory methods to improve building energy performance; a few examples are:

- Energie-investeringsaftrek: This incentive allows businesses to deduct a percentage of their investment costs in energy-saving equipment and sustainable energy from their taxable profits. It encourages companies to invest in energy-efficient technologies and renewable energy sources.
- BENG (Bijna EnergieNeutrale Gebouwen): As of 2021, all new buildings in the Netherlands must comply with the BENG standards, which require buildings to have very low energy consumption, make extensive use of renewable energy, and meet strict requirements for insulation and energy performance. This regulation aims to significantly reduce the energy use and carbon footprint of new buildings.
- Investeringssubsidie duurzame energie en energiebesparing: This subsidy provides financial support to homeowners, businesses, and nonprofit organizations for the purchase of renewable energy systems such as solar panels, heat pumps, and biomass boilers, promoting the adoption of sustainable energy solutions.
- Energielabel C verplichting voor kantoorgebouwen: By 2023, all office buildings in the Netherlands must have at least an energy label C. This regulation pushes property owners to improve the energy efficiency of their buildings to meet this minimum requirement, thereby enhancing overall building performance.

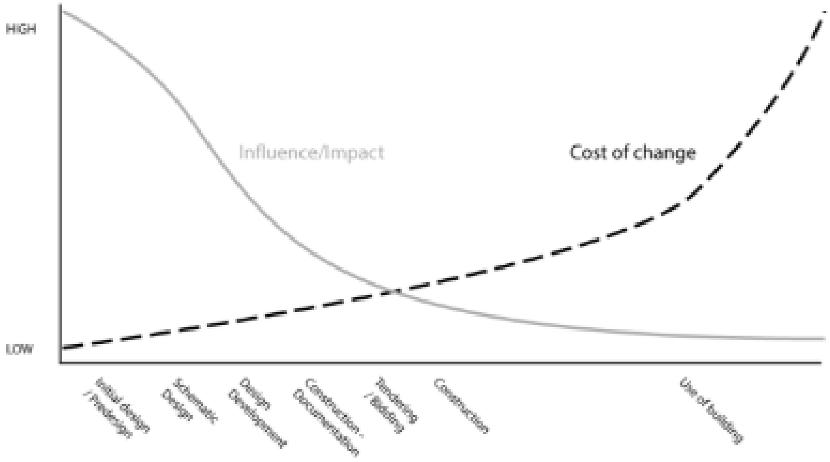
Most European countries have these incentives and they can be seen as "distant future goals," which are good ideas but hard for all countries to follow equally (Laustsen et al., 2011). Countries are at different stages of meeting these less strict requirements. For example, "nearly zero energy buildings" (NZEBs), or in the Netherlands BENG, are required by 2021 for all buildings and by 2019 for public buildings (Sutherland et al., 2013). The "Energy Efficiency Obligation" asks each country to save 1.5% of annual energy sales through efficiency measures. Countries like Germany and Denmark often set higher goals. The "20-20-20" targets aim for 20% cuts in emissions, 20% renewable energy, and 20% better energy efficiency by 2020 (European Parliament, 2009).

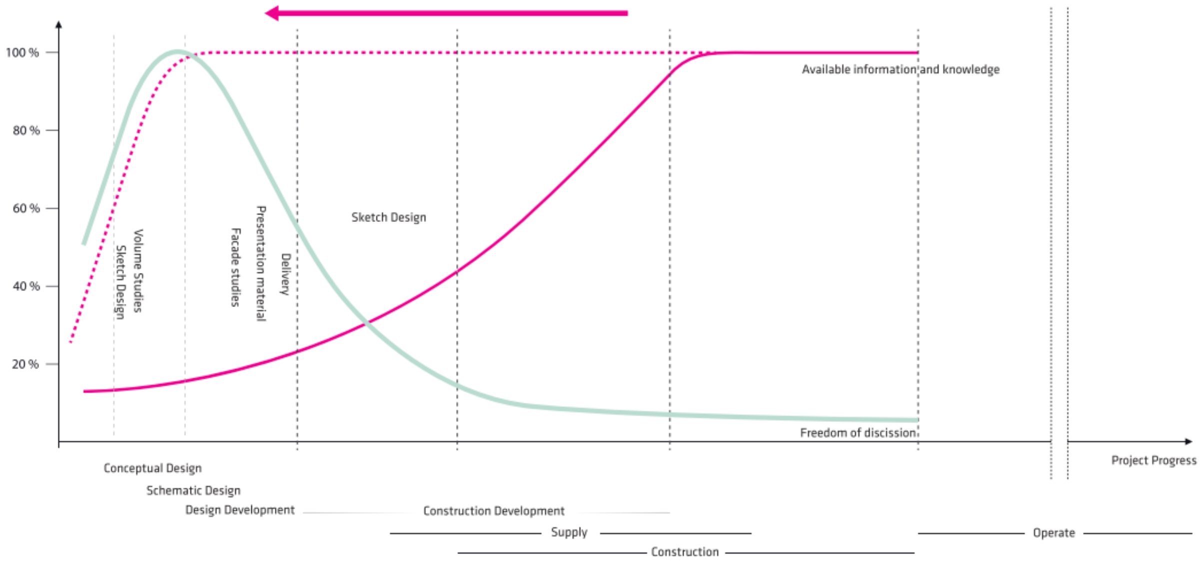
Also, many architectural studios and consulting engineers claim to be pioneers in sustainable design, often showing their design concepts online. However, there is a substantial gap between these objectives and the actual buildings built over the last decade. Building codes alone are insufficient (Laustsen et al., 2011) to ensure high-performance buildings, and 30% of modern buildings do not provide a healthy indoor environment (EPA, 1991). One issue is cost; clients may choose lower construction expenses to long-term operational expenditures. However, the issue is more complex than simply client preferences.

The cost of change

It's surprising that evaluations of life-cycle costs, energy use, and indoor environments are often left out of the early design stage in most building projects. These analyses are seen as costly because they require time and human resources, unlike physical upgrades like better ventilation or more insulation. Clients need to be convinced that these evaluations have value and can improve the building. They should invest wisely to make their buildings more efficient, green, and healthy in the most cost-effective way.

Often, the cheapest and best ways to improve a building are overlooked. One way to understand this is by looking at the cost of changes during design. MacLeamy (2013) explains that changes are expensive, but they cost less if made early in the design stage. Reducing changes early on can lower overall costs. MacLeamy's main point is to "contain changes as early in the design stage as possible." This means investing in thorough evaluations early to achieve cost-effective, high-performance building designs.





Parametric modelling has revolutionized building design by allowing new geometries to be generated quickly (Harding et al., 2012). These models are often created using Visual Programming Languages (VPL), enabling users to link parameters and geometric functions to model designs within constraints. Adjusting parameters takes a top-down approach, where the model's intent is built into the model itself, and changes rely on feedback from the model. According to Davis (2013a), the main motivation for introducing parametric modelling was to reduce the cost of making changes during the design process.

"In theory, a parametric model helps lower the cost of change if the manipulation of the model's parameters and explicit functions rebuilds the geometry with less effort than would otherwise be required from a designer." (Davis 2013a)

Parametric modeling not only reduces the cost of changes but also transforms the design process. It is used to analyze aspects from building envelopes and forms to materials and structures inspired by nature (Courtney L. Fromberg et al., 2015). Marcello and Eastman (2011) note that architectural expertise often relies on "rules of thumb" from past experiences. Parametric objects can incorporate this knowledge to create more precise solutions. Davis (2013a) argues that instead of making early decisions to avoid costly changes later, parametric modelling allows for delaying critical decisions until they are better understood. This approach lowers the cost of changes, making the design process more flexible and efficient. By front-loading changes as suggested by Paulson (1976) and MacLeamy (2013), the cost and complexity of design alterations can be minimized (Davis 2013a)

2.4... Conclusions

How is the integrated dynamic model established, and how does it perform compared to traditional software?

2.1... Sources

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