POLITECNICO DI MILANO
School of Architecture urban planing and contruction engineering
Master of Science in Building and Architectural Engineering

Adaptable Modular Micro-Housing

Design and performance evaluation for a prefabricated building composed of customizable volumetric modules.

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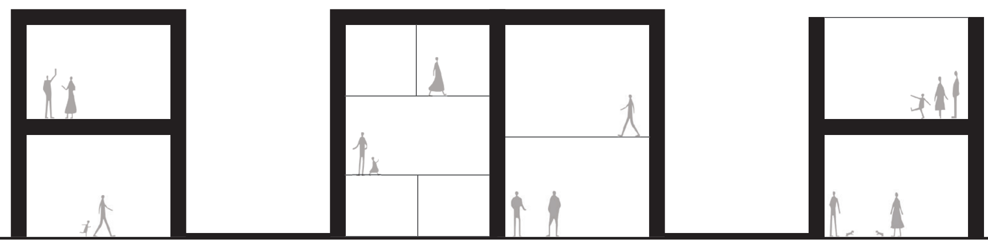

Polo Regionale di Lecco. May 2023

The Adaptable Modular Micro-Housing project seeks to revolutionize microhome design by integrating prefabricated construction and a mindset of minimalism. This innovative project offers various module options, showcasing its customizability and versatility in accommodating different household compositions. By aggregating these modules, a building is constructed, with Milan, Italy as the chosen location for this case study due to the city's high demand for housing. This project serves as an example of fast construction that can be adopted for future use.

By uniting the domains of architecture and engineering, this project aims to facilitate collaboration and produce a comprehensive design that encompasses all stages of the building process. Cutting-edge technologies will be utilized to design functional and adaptable spaces that can be tailored to meet the unique needs of the occupants. Environmental aspects and sustainability are also key priorities, with passive and active strategies in place to reduce CO2 emissions.

The Adaptable Modular Micro-Housing project places significant emphasis on achieving a harmonious balance between technology, functionality, and sustainability to deliver a high-quality end product that fully meets the needs of the residents. Overall, this project has the potential to transform the micro-housing industry by providing a flexible and customizable solution to the housing crisis while also prioritizing sustainability and environmental consciousness.

Keywords:

Housing, Micro-housing, Prefabricated modules, Modular construction, Volumetric prefabricated construction, Cross Laminated Timber, CLT, Adaptability, Micro-home.

ABSTRACT

Il progetto Adaptable Modular Micro-Housing cerca di rivoluzionare il design delle microcase integrando la costruzione prefabbricata e una mentalità minimalista. Questo progetto innovativo offre diverse opzioni di modulo, mostrando la sua personalizzabilità e versatilità nel soddisfare le diverse composizioni familiari. Aggregando questi moduli, viene costruito un edificio, con Milano, Italia come luogo scelto per questo caso di studio a causa dell'alta domanda di alloggi nella città. Questo progetto serve come esempio di costruzione rapida che può essere adottata per il futuro.

Unendo i domini dell'architettura e dell'ingegneria, questo progetto mira a facilitare la collaborazione e a produrre un design completo che comprende tutte le fasi del processo di costruzione. Tecnologie all'avanguardia saranno utilizzate per progettare spazi funzionali e adattabili che possono essere personalizzati per soddisfare le esigenze uniche degli occupanti. Gli aspetti ambientali e la sostenibilità sono anche prioritari, con strategie passive e attive in atto per ridurre le emissioni di CO2.

Il progetto Adaptable Modular Micro-Housing pone un'importante enfasi nel raggiungere un equilibrio armonioso tra tecnologia, funzionalità e sostenibilità per offrire un prodotto finale di alta qualità che soddisfi pienamente le esigenze dei residenti. Nel complesso, questo progetto ha il potenziale per trasformare l'industria delle microcase fornendo una soluzione flessibile e personalizzabile alla crisi abitativa, pur dando priorità alla sostenibilità e alla consapevolezza ambientale.

Parole chiave:

Alloggi, Micro-alloggi, Moduli prefabbricati, Costruzione modulare, Costruzione volumetrica prefabbricata, Cross Laminated Timber, CLT, Adattabilità, Micro-casa.

LESS IS MORE

Ludwig Mies van der Rohe

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Dina and Monika

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Dina

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Monika

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INTRODUCTION

1.1 PROBLEM STATEMENT

The housing crisis is a global issue, and the traditional methods of construction are not sufficient to address the current demand. Prefabricated modular architecture is gaining popularity due to its ability to provide quick and affordable solutions to housing needs. To address this issue, this research project will focus on developing a volumetric prefabricated modular architecture based on the concept of microhome that can be adapted to different situations.

Research Questions:

1. What is the concept of microhome, and how can it be applied in the design of volumetric prefabricated modular architecture?
2. How can the adaptability of volumetric prefabricated modular architecture based on the concept of microhome be optimized to meet the needs of different contexts, housing typologies, and household needs?
3. What are the sustainable aspects that should be taken into account when designing volumetric prefabricated modular architecture based on the concept of microhome?
4. How this kind of projects can be adaptable?
5. What are the different strategies to maximize the use of the internal spaces in Microhome and how can it be adaptable?
6. How can the structural aspects of volumetric prefabricated modular architecture be optimized to ensure durability and safety?
7. How can daylight studies be used to design volumetric prefabricated modular architecture based on the concept of microhome that promotes natural lighting and reduces energy consumption?
8. How can energy-efficient buildings studies be used to design volumetric prefabricated modular architecture based on the concept of microhome that reduces energy consumption and promotes sustainability?

Overall, this thesis project will investigate how the concept of microhome can be applied in the design of volumetric prefabricated modular architecture to address the current housing crisis by providing adaptable and sustainable housing solutions that meet the diverse needs of households in different contexts

1.2 OBJECTIVES

The objective of the project was the use of volumetric prefabricated modules to provide a high-quality, sustainable, and cost-effective housing solution that can be quickly and efficiently constructed in various locations. The building should be designed to meet the needs and expectations of modern living standards while minimizing the environmental impact and reducing construction time and costs. Additionally, the modular construction approach should enable flexibility in design and configuration, allowing for customized solutions that meet specific requirements of different users and locations. Ultimately, the objective is to provide a safe, comfortable, and functional living space that meets the needs of the occupants while providing a sustainable and efficient building solution.

The modules and the project are designed as a case study to be used as a model for different situations. It showcases the benefits of using modular construction techniques to meet the housing demands of different communities and locations and how modular construction can be utilized to efficiently build high-quality, sustainable, and social housing solutions in urban, suburban, and rural areas.

1.3 SCOPE AND PARAMETERS

The scope and parameters of an adaptable prefabricated modular microhome encompass various aspects that are crucial to its design, construction, and utilization. These parameters can be grouped into different categories such as:

- The population excluded from the market refers to individuals or households who face significant challenges in accessing affordable and suitable housing. Microhome design must take into account the needs of these marginalized populations and provide them with sustainable and accessible housing solutions.
- Housing situation refers to the current housing stock, housing demand, and supply in the local market. Understanding the housing situation is critical in identifying the housing needs of the target market and designing microhomes that can meet these needs. Milan housing situations refer specifically to the housing market in Milan, Italy. This market may have unique characteristics that require specific design considerations in the microhome.
- Housing typologies and household typologies refer to the different types of housing units and households that exist in the local market. Understanding these typologies is essential in designing microhomes that are suitable for different household sizes and preferences.
- Microhome standards and parameters refer to the different parameters that define the size, layout, and functionality of the microhome. Understanding these standards and parameters is essential in designing a microhome that can meet the needs of the target market.
- Climate conditions refer to the local climate and weather patterns that can affect the microhome's energy efficiency, and indoor air quality.
- Urban situation: refer to the location services and type of uses and the availability of public transportation.
- Site Regulations: Are referring to the local site regulations that need to be considered in the design of the microhome. This includes zoning laws, building codes, and environmental regulations.
- Adaptability considerations: such as the ability to modify the microhome to suit the changing needs of the occupants.
- Architectural solutions: it refers to project development, the use of multi-functional spaces and the optimization of natural light.
- Interior design: The thirteenth group of parameters includes the interior design of the microhome, such as the choice of materials, colors, and the use of smart furniture in the microhome, such as foldable beds and tables.
- Assembling solutions: Refers to the different solutions used in the construction of the microhome, such as prefabricated components and on-site assembly.
- Material study: refers to the study of different materials that can be used in the construction of the microhome. This includes the advantages and disadvantages of each material based on factors such as cost, durability, and energy efficiency.
- Daylight parameter: such as the SDA (Spatial Daylight Autonomy) and the ASE (Annual Sunlight Exposure). These factors are important in optimizing natural light in the microhome.
- Energy optimization: the microhome, such as natural ventilation, heating and cooling loads, and lighting consumption optimization.

All these aforementioned parameters, englobe the hole criteria and the aim of the research and the develop of the case study project.

1.4 SITE SELECTION CRITERIA; SELECTION AND ANALYSIS.

Milan, the capital of Lombardy region in northern Italy, was chosen as a location for the project for several reasons. Firstly, Milan is one of the most populous and vibrant cities in Italy, with a growing demand for sustainable solutions. The city has been experiencing rapid urbanization and population growth, which has created a need for new housing that can be quickly and efficiently built to accommodate the increasing demand.

Secondly, Milan is known for its innovative and forward-thinking approach to architecture and urban design. The city has a long history of embracing new technologies and materials in construction, making it an ideal location to showcase the benefits of modular construction techniques.

Additionally, the rich cultural heritage and a diverse population, which creates an opportunity to design housing solutions that can accommodate different lifestyles, needs, and preferences. The modular construction approach allows for flexibility in design and configuration, which can be tailored to meet the specific needs of different users and communities.

Lastly, the study of Milan as a location for a housing project made of prefabricated volumetric modules is also driven by the need to address the challenges of sustainability and climate change. Modular construction is a more sustainable and efficient building solution compared to traditional construction methods, as it reduces waste, lowers energy consumption, and minimizes environmental impact. By choosing Milan as a location for the housing project, it is possible to demonstrate how modular construction can be used to create high-quality, affordable, and sustainable housing solutions that can meet the demands of modern urban living.

1.5 EXPECTED RESULTS

Designing a housing project with volumetric prefabricated modules is expected to produce several results that can benefit both the occupants and the environment Because the modules can be produced in a controlled factory environment, allowing for higher quality control and consistency in the finished product. This means that the finished product will be of a higher quality and built to last, leading to less maintenance and repair work for the occupants.

Secondly, the method and the materials used should result in much faster construction than traditional construction methods, which will significantly reduce the construction time and costs. This can result in faster delivery of housing projects, which can meet the growing demand for affordable and sustainable housing solutions.

Modular construction enables flexibility in design and configuration, allowing for customized solutions that can adapt to the specific requirements of different users and locations. The microhomes concept often focuses on maximizing space efficiency and multifunctional use of living areas, which can enable occupants to personalize and adapt the space to their needs and preferences.

Finally, the design of the project with volumetric prefabricated modules can serve as a case study for the wider adoption of modular construction as a viable and sustainable solution for meeting the global housing demand. The success of the project can inspire and encourage the wider adoption of modular construction, which can lead to more sustainable, efficient, and affordable housing solutions for communities worldwide.

2

LITERATURE REVIEW

Housing is a critical component of our built environment, providing shelter and security for individuals and families. However, the housing situation varies significantly across different regions and countries, with challenges ranging from affordability and availability to quality and sustainability. The housing market plays a crucial role in shaping the supply and demand for housing, with factors like interest rates, government policies, and economic conditions influencing the prices and availability of homes.

One potential solution to the housing crisis is prefabricated modular architecture, which allows for faster, more efficient construction of homes using factory-built modules that are assembled on-site. This approach can help reduce costs, improve sustainability, and increase flexibility in housing design.

Housing typologies refer to the different types of housing that exist, including single-family homes, apartments, and townhouses. Each housing typology has its own advantages and disadvantages, and the choice of typology often depends on factors like affordability, location, and lifestyle preferences.

Microhousing is a growing trend in urban areas, offering smaller, more affordable housing options for people who value convenience and access over space. These compact living spaces are typically designed to maximize efficiency and functionality, making them a popular choice for young professionals, students, and others who are looking for an affordable housing solution in high-cost urban areas.

Overall, addressing the housing crisis requires a multifaceted approach that incorporates innovative design, financing, and policy solutions to create safe, affordable, and sustainable housing for all.

2.1
CONTEXTUAL FRAMEWORK

2.1.1. HOUSING SITUATION

The housing situation is a complex and multifaceted issue that affects individuals and societies around the world. Generally speaking, there is a growing demand for affordable and adequate housing, particularly in urban areas where population density is high. However, this demand is often not met due to various factors such as rising housing costs, limited land availability, inadequate housing policies and regulations, and income inequality. As a result, many people are forced to live in substandard and overcrowded housing or become homeless. The housing situation is further complicated by factors such as demographic changes, climate change, and natural disasters. Addressing the housing situation requires a multifaceted approach that involves collaboration between policymakers, planners, developers, and communities to develop innovative solutions that ensure access to safe, affordable, and sustainable housing for all.

The global housing situation is diverse and complex, with significant variations in affordability, availability, and quality of housing across different regions and countries. Urbanization, population growth, and economic factors have led to a growing demand for housing globally, particularly in developing countries. However, in many places, the supply of affordable and adequate housing has not kept up with the demand, leading to housing shortages, overcrowding, and informal settlements. In some developed countries, the housing situation is characterized by high homeownership rates and stable rental markets.

In Europe, the housing situation varies widely, with some countries experiencing a shortage of affordable housing while others have a surplus. Countries like Germany and Austria have well-regulated rental markets, while other countries like Spain and Greece have high rates of homeownership but also high levels of mortgage debt. Italy faces significant housing challenges, with a high percentage of the population living in inadequate or overcrowded housing. The country has a large number of vacant properties, but they are often located in areas where there is low demand. There is also a shortage of affordable housing in major cities like Milan, where high rents and limited availability are major issues. In Milan, the housing situation is particularly acute, with a shortage of affordable housing and high rental prices. Many people are forced to live in small, cramped apartments or commute long distances from the suburbs. The city government has implemented various measures to address the housing crisis, including the construction of new social housing and the regulation of short-term rentals. However, the issue remains a significant challenge for the city and its residents.

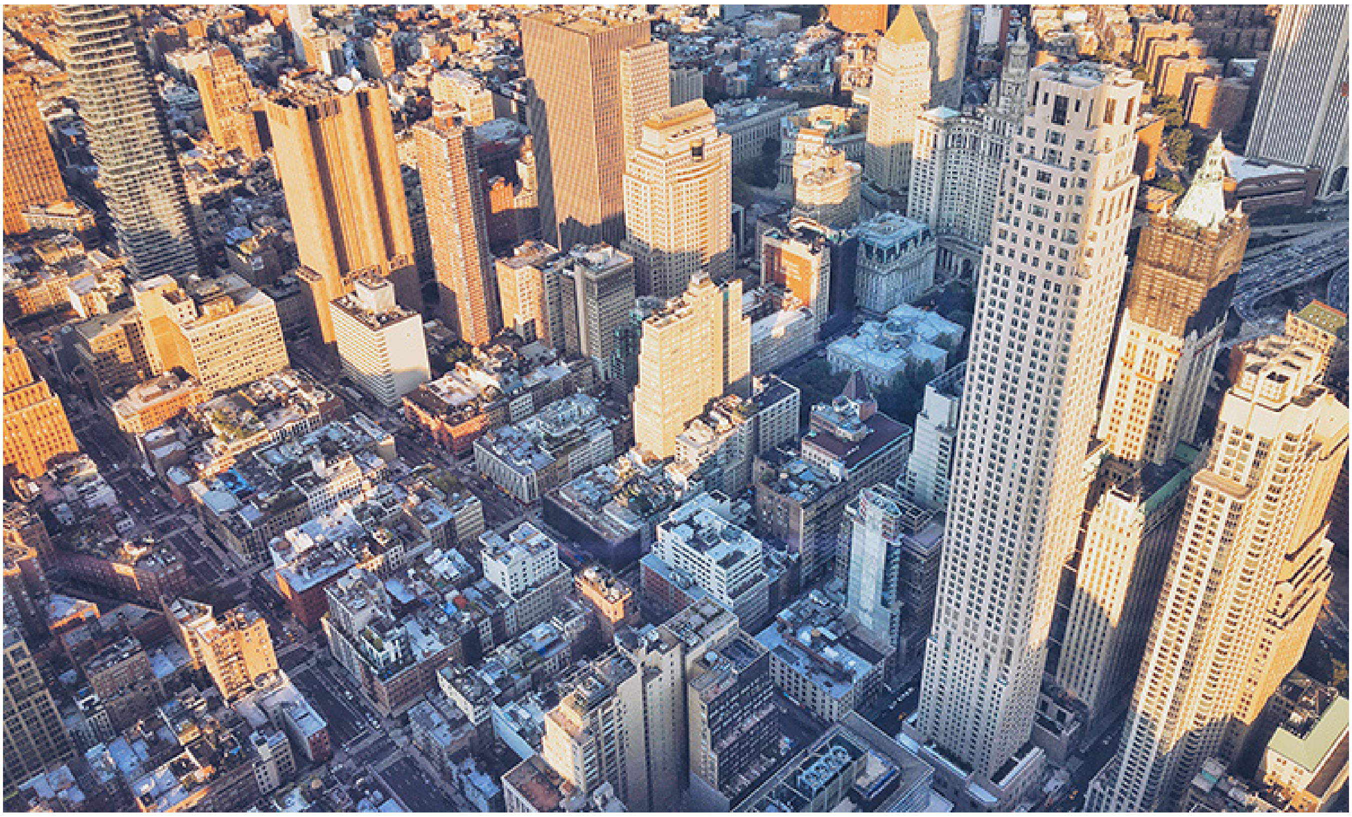


Fig. 01. City view. Source: www.shareable.net/

2.1.1.1 GLOBAL SITUATION

The global housing situation is complex and varies significantly depending on geographic region, economic development, and local policies. However, there are some overarching trends and challenges that are affecting the availability, affordability, and quality of housing worldwide.

According to Wallace (2021), the world's urban population is growing rapidly at a rate of 1.5 million people per week, primarily due to urbanization. Since 2008, the number of people living in cities has significantly increased, with a 50 percent rise in urban population. Experts predict that this trend will continue, and the urban population is projected to increase to 68 percent by 2050, adding 2.5 billion people (Hove, 2012).

McRae (2022) suggests that it is necessary to shift housing systems globally from prioritizing financial gain to treating housing as a social good and basic human right. This involves creating deeply affordable housing options while also achieving environmental targets, with a focus on prioritizing the health and well-being of marginalized communities over profit. To achieve these objectives, it is crucial for states and institutional investors to collaborate and develop housing that complies with international human rights laws. This recognition of the challenges at hand presents an opportunity and an urgent need for action.

The Bank for International Settlements and World Economic Outlook chart (Fig. 1 and Fig. 2) depicts a steady increase in the global real house price index over the last five years, which has persisted during the pandemic. However, experts argue that the primary cause of the ongoing crisis is the combination of economic prosperity and growing inequality, rather than a shortage of resources or an economic downturn. Regulations, legislation, and policies in each country are limiting the well-being of citizens. Furthermore, the housing market is now considered a significant market and is used as a financial instrument rather than being recognized as a fundamental human right and a cornerstone of a dignified life.

On the other hand, the United Nations Sustainable Development Goals (SDGs) include a target to ensure access to adequate, safe, and affordable housing for all by 2030. However, achieving this target will require significant efforts from governments, private sector actors, and civil society organizations, as well as innovative approaches to housing provision and financing.

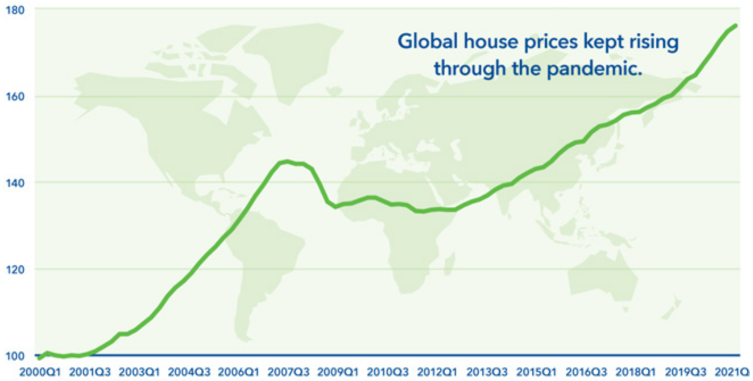


Fig. 02. Global house prices. Source: Bank for the international settlements and world economic outlook.

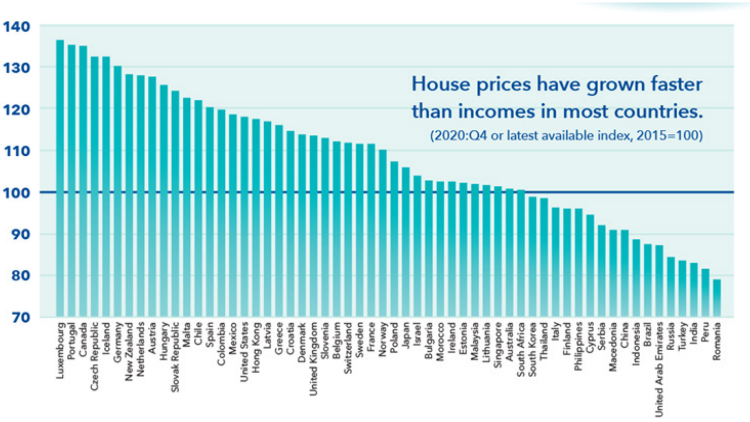


Fig. 03. House price to income ratio around the world. Source: Bank for the international settlements and world economic outlook.

THE GLOBAL HOUSING CRISIS

It refers to the shortage of affordable and adequate housing in many parts of the world. This crisis affects millions of people, particularly those in developing countries, low-income earners, and vulnerable populations such as refugees and the homeless.

The global housing crisis affects over 1.8 billion people, with 15 million being forcibly evicted and 150 million living in homelessness. In India, 24 people are evicted every hour, with over 1 million facing evictions from 2017-2022 and 15 million under threat daily. In Los Angeles, homelessness grew by 25% from 2018-2020, with deaths among the homeless rising 56% from 2020-2021. The lack of affordable housing and wage stagnation are cited as root causes. Despite this, residential real estate is worth an estimated $260 trillion and continues to generate significant profits for investors. This juxtaposition makes it increasingly difficult for those in need to access housing. Swift intervention is needed to prevent mass evictions in many cities worldwide.

Fig. 04. SDG 11. Source: sdgs.un.org

50%

Rising in urban population, since 2008

+1.8

Billion people affected by the housing crisis.

+150

Million people living in homelessness

Fig. 05. Target SDG. Source: sdgs.un.org

Some of the key factors contributing to the global housing crisis include rapid urbanization, population growth, inadequate housing policies, rising property prices, and a lack of investment in affordable housing by governments and the private sector.

Based on the article "The Global Housing Crisis: A Crisis Unlike AnyOther " McRae (2022) mentions that, in 2020, the built environment was responsible for 37% of annual global greenhouse gas emissions. The world has around 255 billion square meters of buildings, and 5.5 billion square meters are constructed each year, equivalent to building a city like Paris weekly. This trend is rapidly exhausting the global carbon budget, with the depletion expected within 11 years. The challenge is that governments must ensure access to adequate housing for everyone while limiting global warming to under 1.5 degrees Celsius. These crises are closely linked and cannot be resolved through mere policy solutions. Significant systemic change prioritizing health, well-being, and climate resilience over profit is necessary.

The COVID-19 pandemic has further highlighted the importance of safe and secure housing, with lockdowns and social distancing measures making it clear that inadequate housing can exacerbate health and social issues.

CHALLENGES

One of the main challenges is the lack of affordable housing, which is a problem in both developing and developed countries. According to the United Nations, over 1.6 billion people worldwide lack adequate housing, and around 100 million people are homeless. The situation is particularly acute in urban areas, where demand for housing often outstrips supply, leading to rising prices and overcrowding.

- Another challenge is the quality of housing. Many homes around the world lack basic amenities, such as running water and sanitation, which can have serious health consequences. Poor-quality housing is also a risk factor for a range of other health problems, including respiratory illnesses, lead poisoning, and injuries
- There are also concerns about the environmental impact of housing, particularly in terms of energy use and greenhouse gas emissions. Buildings are responsible for a significant proportion of global carbon emissions, and improving the energy efficiency of homes and reducing their carbon footprint is an important challenge.
- To address these challenges, a range of policies and initiatives are being implemented around the world. For example, some countries have introduced rent control measures to make housing more affordable, while others are investing in social housing programs to provide homes for low-income households. There are also efforts to improve the quality and energy efficiency of housing, such as through building codes and energy performance standards.

CONSEQUENCES

The ramifications of the housing crisis are severe and far-reaching. Homelessness and inadequate living conditions can lead to physical and mental health problems, social exclusion, and reduced economic opportunities. In addition, the housing crisis can exacerbate inequality and contribute to social unrest.

In some developed countries, the housing situation is characterized by high homeownership rates and stable rental markets. However, even in these countries, there are concerns about housing affordability, especially in major cities where housing costs can be prohibitively high.

Here are some examples of solutions that can be applied:

1. Increase affordable housing supply: Increasing the supply of affordable housing is one of the most effective ways to address the housing crisis. Governments, NGOs and private entities can play a role in the provision of affordable housing. This can be done through building new homes or renovating existing ones.

2. Promote innovative housing solutions: Innovative housing solutions such as modular housing, micro-housing, co-housing and community-led housing. Micro-housing is a form of affordable housing that consists of small, efficiently designed units. This can be a cost-effective solution to the housing crisis, especially in areas with high population density.

3. Address legal and regulatory barriers: Legal and regulatory barriers can limit the supply of affordable housing, such as zoning regulations and land use restrictions.

4. Increase funding for housing: Increased public and private investment in affordable housing can help to address the shortage of affordable housing, and provide a stable foundation for families and communities.

5. Addressing the root causes of homelessness: Homelessness is often caused by a combination of economic, social, and personal factors. Addressing these root causes, such as unemployment, poverty, and mental health issues, can help prevent homelessness and reduce the demand for affordable housing.

Overall, addressing the global housing crisis requires a concerted effort from governments, private entities and civil society. Through a combination of policy changes, innovative solutions and increased investment, progress can be made towards more adequate and affordable housing for all.

Fig. 06. City view. Source: https://immigrantinvest.com/insider/eu-house-prices-index-en/

2.1.1.2. EUROPE SITUATION

The housing situation in Europe can vary widely depending on the country and region. In general, the cost of housing tends to be higher in larger and more developed cities, such as Milan, London, Paris, and Berlin, compared to smaller or less developed cities.

However, there are some common issues and trends that are affecting the overall housing situation in Europe. Here are some key points:

1. Affordability: Housing affordability is a major issue in many European countries, particularly in urban areas. According to a report by the European Federation of National Organisations working with the Homeless (FEANTSA), in 2020, more than 700,000 people were homeless in the European Union, and over 70 million people were living in precarious housing conditions.
2. Housing crisis: Some European countries, such as the UK, Spain, and Ireland, have experienced a housing crisis in recent years, with high demand for housing, limited supply, and rising prices. According to a report by the European Parliament, the housing crisis is affecting both renters and homeowners, with many people struggling to find affordable housing.
3. Social housing: Social housing plays an important role in many European countries, providing affordable housing to low-income and vulnerable groups. However, in recent years, social housing has been underfunded and in some cases, sold off to private developers. According to a report by the European Federation of Public, Cooperative and Social Housing (CECODHAS), social housing accounts for less than 10% of the total housing stock in many European countries.
4. Sustainability: Sustainable housing is becoming increasingly important in Europe, with many countries setting targets to reduce carbon emissions from buildings. According to a report by the European Environment Agency, buildings are responsible for 36% of the EU's carbon emissions.

The housing situation in Europe is complex and multifaceted. While some countries and cities have successfully implemented initiatives to address the shortage of affordable housing, others continue to struggle with high costs and low availability of housing.

According to the State of Housing in Eruope, 2021; before the COVID-19 pandemic, Europe was already experiencing a housing affordability crisis with 17.2% of the EU-27 population living in overcrowded homes and a housing cost overburden rate of 9.4% for the overall population. Low-income individuals were particularly affected with a housing cost overburden rate of over 35.4%. Tenants, especially those renting at market prices, were more affected than owners, and housing cost overburden was highest in cities. While housing quality has improved over the last decade, 4% of the EU-27 population still lived in poor quality dwellings in 2019. Homelessness has also been on the rise with at least 700,000 people sleeping rough or in emergency or temporary accommodation in the EU, 70% more than a decade ago.

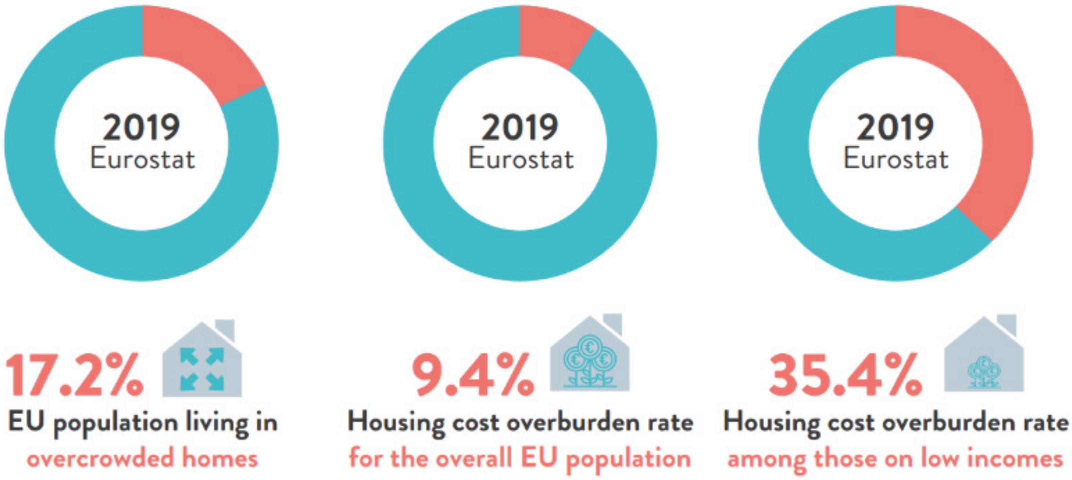


Fig. 07. Housing Europe, The State of Housing in the EU, 2019. Source: Eurostat SILC.

Housing markets in Europe had recovered strongly after the global financial crisis, with house prices increasing rapidly. This growth in house prices has outpaced increases in household incomes, affecting even those on middle-incomes, especially younger workers. The 'financialisation' of housing is a significant factor contributing to this trend, especially in high-demand urban areas. Rents have also increased significantly, especially in cities and high-demand areas, with short-term lettings supported by online platforms driving this phenomenon. However, the post-COVID period has seen a decline in the volume of available short-term rentals in major European cities, and some cities are launching programs to encourage short-term landlords to rent their apartments on a long-term basis.

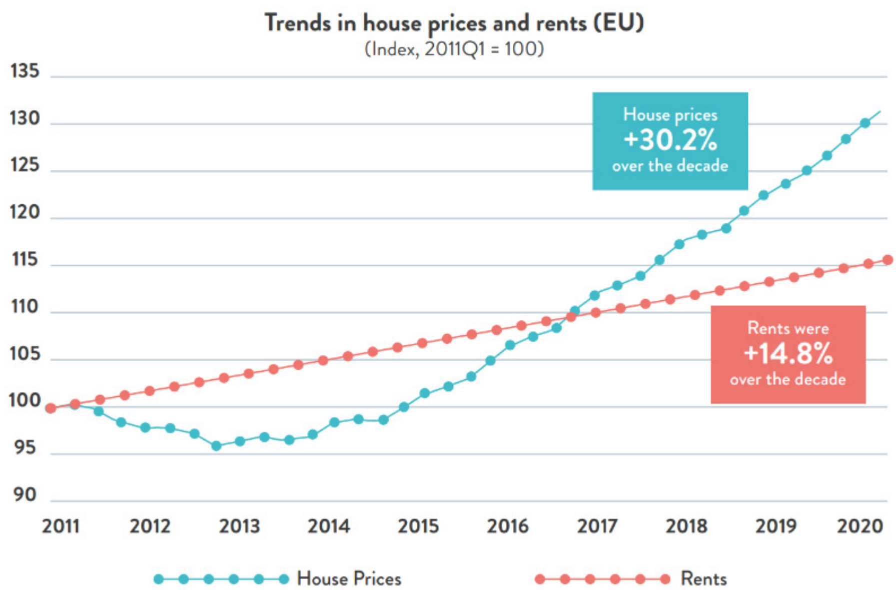


Fig. 08. Trends in house prices and rents (EU). Source: Eurostat SILC.

The decreasing availability of affordable housing is partly due to a shift from investment in social housing to providing income support for low-income households, which can drive up prices. The share of public and social rental housing has been decreasing for decades, and other affordable housing solutions have been hindered by increasing land and construction prices and tightening lending conditions. Unmet housing needs were already a challenge prior to the pandemic, and recent indications suggest the need for social and affordable housing will only grow. Many countries are experiencing significant housing shortages and waiting lists, with some facing housing deprivation and rent payment arrears. The next table summarizes current gaps in housing supply compared to housing needs in selected countries.

COUNTRY	TOTAL PRESENT UNMET HOUSING NEED	OF WHICH: TOTAL UNMET SOCIAL & AFFORDABLE HOUSING NEED	AVERAGE ANNUAL DELIVERY (2017-2019) New homes	AVERAGE ANNUAL DELIVERY (2017-2019) New social housing	MAIN ISSUES DRIVING UNMET NEED
ENGLAND	Around **3.5 million** households have some form of unmet housing need	Around **1.6 million**	169,000	31,000	• Insufficient supply • High volume of young people still living with their parents • Strong population growth
GERMANY	Roughly **1 million homes**	At least **225,000** units	288,000	26,280	• Strong population growth • Insufficient supply • 'Secular shrinkage' of the social housing sector
IRELAND	At least **165,000**	At least **80,000**	17,800	7,500	• Consistent shortfall in new construction compared to underlying need • High volume of young people still living with their parents • Insufficient supply of new social housing
LUXEMBOURG	Difficult to estimate due to high volume of cross-border workers - **35,000-** unit shortfall in recent years	Difficult to estimate due to high volume of cross-border workers – **c.6,000** on official waiting lists	4,050	65	• Strong population & economic growth • Insufficient new supply
NETHERLANDS	**331,000**	At least **110,000**	67,000	20,135	• Strong population growth • Insufficient supply
SLOVENIA	No reliable estimates available	Around **10,000**	3,165	75	• Insufficient supply in urban areas • Internal migration related to economic pull factors (i.e. rural to urban)

Fig. 09. Table current gaps in housing supply compared to housing needs in selected countries. Source: The State of Housing in Europe' questionnaire, November 2020- January 2021.

The long-term impact of COVID-19 is uncertain, but it could result in a shift towards teleworking and changes in demand for housing and commercial real estate. Income loss could exacerbate housing affordability issues for many, with an expected increase in poverty and inequality in Europe. Low-wage and precarious workers are expected to bear the brunt of the economic downturn, with a potential increase in demand for affordable and social housing. Experts are calling for increased investment in affordable housing as a key part of economic recovery efforts. The report will explore recent policy developments in this area.

Europe is currently experiencing a housing crisis, which is affecting a growing number of people throughout the EU. The cost of housing is increasing in cities like Paris, Warsaw, Dublin, and Athens, making it difficult for many to afford. Even before the pandemic, a significant proportion of Europeans were spending more than 40% of their income on housing. In urban areas, the situation is particularly dire, and people are being forced to leave the city. Additionally, the quality of housing is often substandard, with many people living in overcrowded and poorly insulated homes that are expensive to maintain. In response to this crisis, the European Parliament adopted a report in January entitled Access to decent and affordable housing for all. The report emphasizes that access to housing is a fundamental right that should be guaranteed at the EU level. However, it is clear that current European rules often prioritize the interests of those profiting from the housing market over those in need of housing.

Overall, the housing situation in Europe is complex and multifaceted, and requires ongoing attention and action from policymakers and stakeholders to ensure that everyone has access to safe, affordable, and sustainable housing.


Fig. 10. City view. Source: https://www.lawyersitaly.eu/purchasing-a-property-in-italy

2.1.1.3. ITALY SITUATION

The housing situation in Italy can be explained by various economic and social factors. One of the primary factors is the country's slow economic growth and high unemployment rate, which makes it difficult for people to afford housing.

According to a report by the European Commission, the average income in Italy is below the European Union (EU) average, and this has contributed to a shortage of affordable housing in the country. Additionally, Italy has a high rate of poverty, which makes it difficult for many people to find suitable housing. Another factor contributing to the housing situation in Italy is the country's aging population. According to the Italian National Institute of Statistics, over 22% of the population is over the age of 65. This has led to a decrease in the number of households and an increase in the demand for smaller, more affordable housing units.

Additionally, the country's complex bureaucracy and regulations have made it challenging for developers to build new housing units. This has resulted in a shortage of available housing units, particularly in urban areas.

In Italy, housing affordability is a major concern, particularly in urban areas where over 60% of households spent more than 30% of their income on housing, as stated by a report from the Italian National Institute of Statistics in 2020.

The quality of housing stock in Italy is generally low, with a considerable number of buildings requiring renovation and modernization, according to a report by the Italian Ministry of Infrastructure and Transport. Over 36% of residential buildings in Italy were constructed before 1960, and 17% were built before 1919.

Housing plays a critical role in social exclusion, which is a significant problem in Italy. Over 10% of Italian households lived in overcrowded or substandard housing, and over 3% were either homeless or living in emergency housing, as noted by a report from the Italian National Institute for Economic Research in 2020.

There is a rent control system in Italy that restricts the amount that landlords can charge for rent. However, this system has been criticized for discouraging investment in the rental market and reducing the availability of rental housing.

Italy is a strong advocate for EU intervention and is set to benefit from funding allocated from Next Generation EU. The national recovery and resilience plan includes a 'Safe, green and social' program with a budget of 2 billion Euros dedicated to public housing. The plan allows for the renovation of approximately one fifth of the public housing stock, with a focus on energy retrofit and anti-seismic measures. Additionally, a measure called 'Superbonus 110%' was implemented in July 2020 to support energy retrofit, anti-seismic renovation, and installation of photovoltaic panels and structures/chargers for electric cars. Private households, condominiums, cooperatives, public providers, NGOs/associations are among the beneficiaries. A national program to enhance housing quality was approved at the end of 2019, and 50 million euros were added to the Fund for rent arrears in 2021 to help households cope with financial hardship.

The requirement for housing is a significant issue in Italy. While Italy has a high number of dwellings per inhabitant, experts predict that only 1.2 million housing units will be constructed in the next ten years, which is insufficient to accommodate new household formation. Moreover, the social housing sector is quite small, representing less than 4% of the total housing stock, resulting in housing deprivation for one million households not in social housing. The COVID-19 pandemic has further exacerbated the situation, with a decrease in incomes and a steep increase in rent arrears for private rental households and mortgage payment defaults. There is also a rising demand for housing for students, youth, and the elderly, necessitating innovative housing solutions such as intergenerational and co-housing.

On the other hand, knowing the housing needs in Italy and according to the Italian National Institute of Statistics (ISTAT), the average purchase value per unit of residential property in Italy as of the second quarter of 2021 was around €1,617 per square meter. However, it's important to note that this value can vary significantly depending on the location and type of property you're looking for. For example, properties in major cities such as Rome, Milan or Florence, or in prime locations such as the Amalfi Coast, Tuscany or Lake Como, can be significantly more expensive.

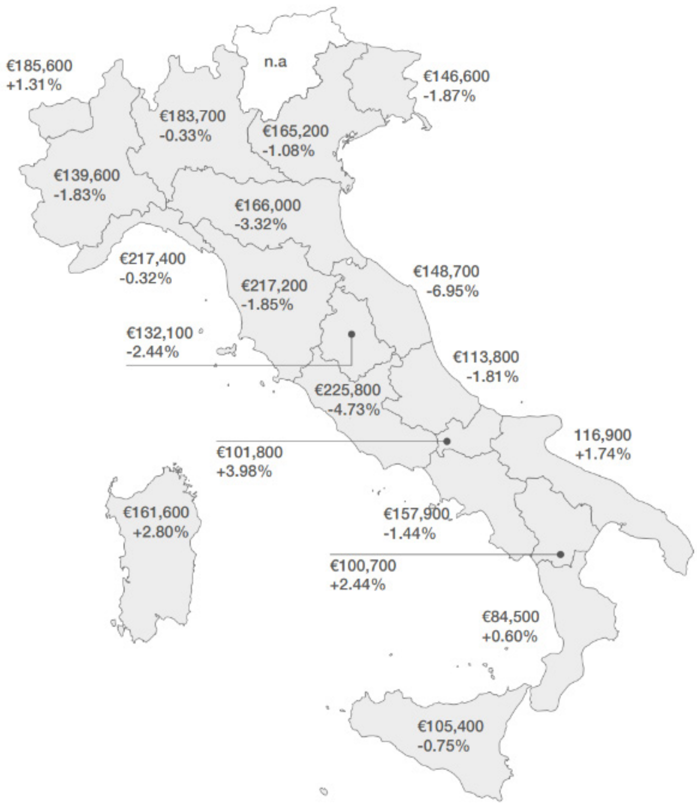


Fig. 11. 2016 average residential purchase value per unit by region and variation compared to 2015 Source: PwC analysis on data provided by Italian IRS

This diagram shows the average residential purchase value per unit by region and variation in 2016 compared to 2015.

Estimated by the Italian IRS (Agenzia delle Entrate): based on the estimated surface area and the average municipal price from the OMI database, total residential purchases in terms of monetary volume were estimated. The total and average surface area for residential units transacted were estimated based on the number of rooms on the cadastral survey (vani catastali) and the average room (vano) size in the respective municipality.

The chart below illustrates the housing stock situation in Italy in 2011 divided into 4 categories to highlight the occupied typographies.

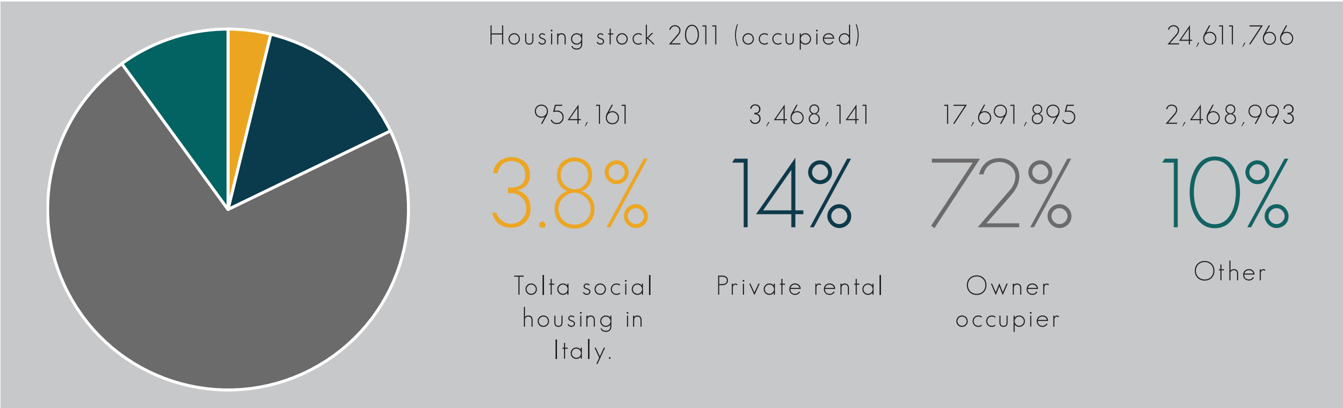


Fig. 12. Housing stock 2011 (occupied). Source: Istat, 2011 Population and Housing Census http://daticensimentopopolazione.istat.it/Index.aspx?DataSetCode=DICA_FAM_CARATT1; Ministero infrastrutture e trasporti. Decreto 16 marzo 2015. "Criteri per la formulazione di un programma di recupero e razionalizzazione degli immobili e degli alloggi di edilizia residenziale pubblica" (GU Serie Generale n.116 del 21-05-2015).

Over the past year, Italy has been trying out the "Housing First" (HF) method, with 28 projects spread throughout 10 regions of the country, from Turin to Agrigento in the southernmost part of Sicily. While still in the experimental phase, the HF approach provides a new direction for policies aimed at addressing poverty and severe marginalization in Italy. The crucial point is to encourage the spontaneous bottom-up process of change that is already happening among public and private social service providers in the areas of housing, poverty, and homelessness.

In conclusion, the housing situation in Italy presents a multifaceted issue with several challenges that require significant attention and investment from both the government and the private sector. The shortage of affordable housing, high demand for rental properties, and poor conditions of many existing properties all contribute to the complexity of the situation. While the Italian government has implemented various measures to address these issues, including tax incentives, subsidies, and investments in social housing projects, there is still much work to be done to ensure that everyone in Italy has access to safe, affordable, and quality housing. Despite the challenges, there is hope for improvement with continued efforts and investments to address the root causes of the housing crisis in Italy.

Fig. 13. Milan city view. Source: https://www.yesmilano.it/en/living-in-milano

2.1.1.4. MILAN SITUATION

The housing situation in Milan, Italy, has been a topic of concern for many years, with a shortage of affordable housing being a major issue. According to a study by the Milan-based research institute CRESME, there is a shortage of approximately 150,000 housing units in Milan, with the highest demand being for affordable rental housing. Milan has experienced a rapid increase in property prices in recent years, which has made it more difficult for people to find affordable homes. This has been particularly challenging for low-income families, students, and young professionals.

The problem is exacerbated by a high demand for housing due to Milan's status as an economic and cultural hub, as well as a popular destination for international students and expats. The city's population has been steadily growing, but the construction of new housing units has not kept up with the pace of demand.

Milan is currently facing several issues, including high housing costs and shortages, aging buildings and infrastructure, limited new construction, gentrification, and a lack of sustainability (fig. 14). These problems can lead to social and economic inequality, overcrowding, homelessness, displacement of long-term residents, and the loss of community character. To address these challenges, there is a need for more affordable and sustainable housing options, as well as a focus on preserving the unique character of Milan's neighborhoods.

The prevalence of unregulated or poorly regulated short-term rentals is a significant challenge contributing to the housing crisis in Milan. These rentals have reduced the availability of long-term housing options for residents and have also caused prices to soar in certain neighborhoods. As a result, low-income residents are the hardest hit by the crisis and often have to contend with overcrowded or substandard living conditions, or risk being priced out of the city entirely. This has created growing inequality and social unrest, as many residents feel marginalized by Milan's economic growth and development.

The map in fig. 15, illustrates the division of Milan into 55 zones by the agency, including 10 central, 12 semi-central, 29 peripheral, and 4 suburban areas . The central area commands the highest mean rent (€_month/sq.m) at 19.42, followed by semi-central at 10.19, peripheral at 7.45, and

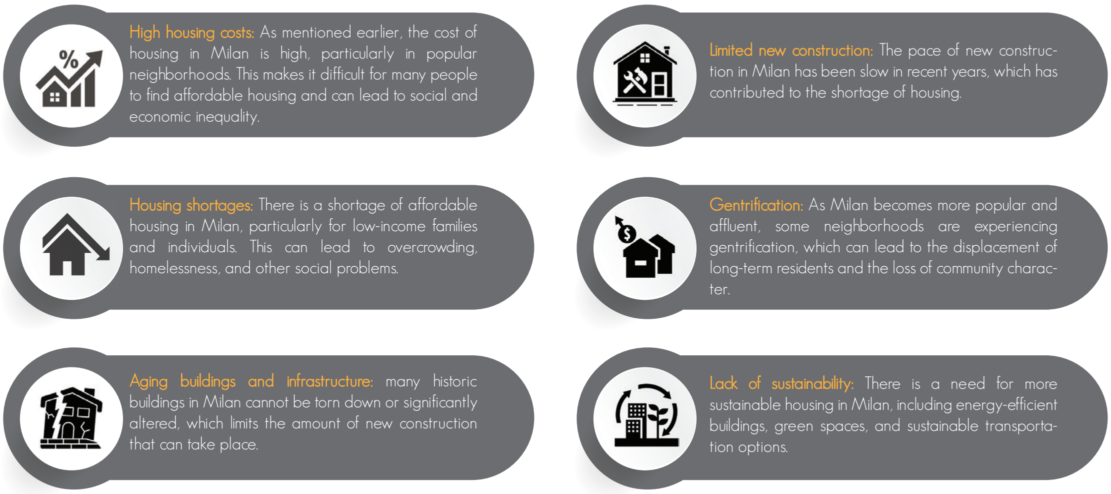


Fig. 14. Some of the current issues Milan is facing.

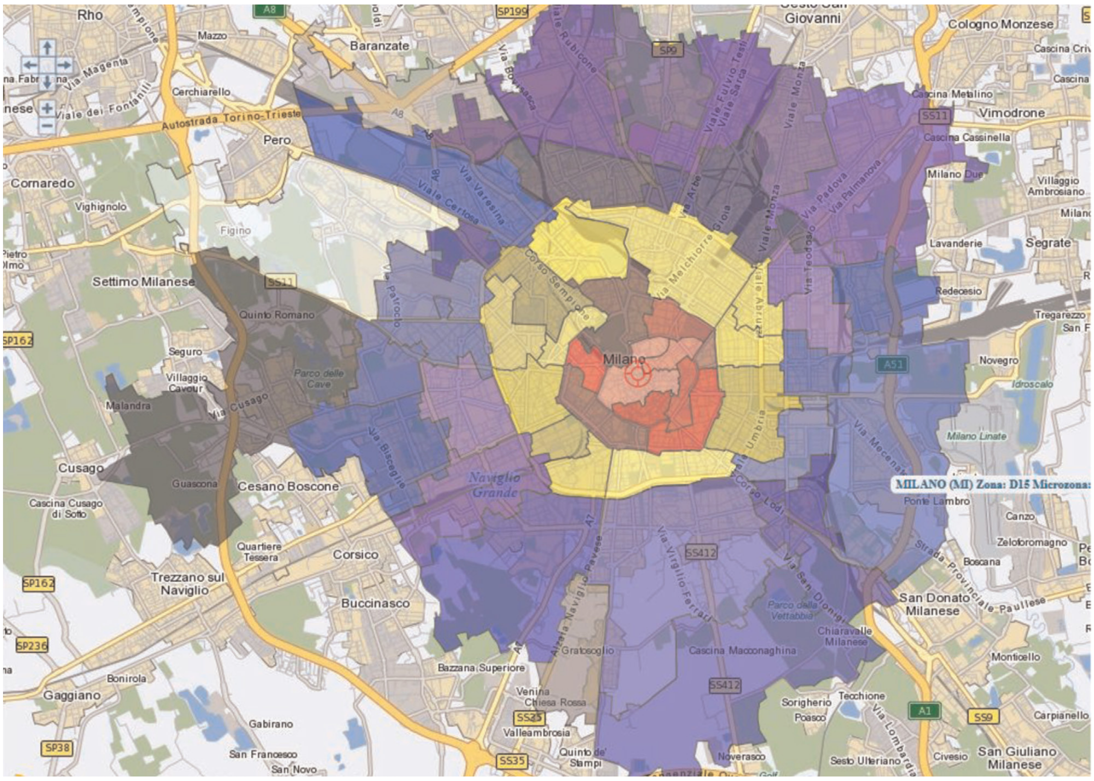


Fig. 15. Housing market zones in Milan. Source: *Housing rent and road pricing in Milan: Evidence from a geographical discontinuity approach.* (D'Arcangelo & Percoco, 2015)

suburban at 7.02, resulting in an average of 10.19 euros per square meter per month for the entire city. Notably, D'Arcangelo found that as the distance from the city center increases, the average rent of houses decreases.

Overall, addressing these housing problems will require a comprehensive approach that includes investment in affordable housing, sustainable development, and community-based planning processes. Various initiatives have been launched in recent years, including the construction of new social housing units and the regulation of short-term rental platforms such as Airbnb. Additionally, the City of Milan has implemented a number of policies and initiatives aimed at addressing the housing crisis. These include the creation of new affordable housing units, the renovation of existing buildings to increase the number of available units, and the implementation of rent control measures to prevent excessive rent increases. The city has also worked to encourage the development of cooperative housing and social housing projects, which prioritize the needs of low-income families and individuals.

2.1
CONTEXTUAL FRAMEWORK

2.1.2. HOUSING MARKET

The housing market refers to the buying and selling of residential properties, including houses, apartments, and condominiums. It is a crucial component of any economy, as it provides people with a place to live and can serve as a valuable investment opportunity. The housing market is affected by a variety of factors, including economic conditions, population growth, and government policies.

On a global scale, the housing market has experienced significant fluctuations over the past few decades. The global financial crisis of 2008 caused a major slowdown in the housing market in many countries, with prices dropping and sales slowing down. However, in recent years, the market has rebounded in many regions, with prices and sales increasing. In Europe, the housing market has also been subject to various challenges and opportunities. Italy, in particular, has experienced some difficulties in recent years due to economic struggles and political instability. According to a report by the Bank of Italy, the Italian housing market has experienced a prolonged period of stagnation, with low demand and limited new construction. However, there are signs that the market may be starting to recover, with some regions seeing an increase in demand and prices.

In Milan, the housing market has historically been one of the strongest in Italy, with high demand for properties in the city center and surrounding areas. However, the COVID-19 pandemic has had a significant impact on the market, with sales slowing down and prices decreasing. Despite this, there are still opportunities for buyers and investors, particularly in the luxury market.

In conclusion, the housing market is a complex and ever-changing aspect of the global economy. While it can be affected by various external factors, it remains an important investment opportunity for many individuals and organizations. In Italy and Milan, the market has faced challenges in recent years, but there are signs that it may be starting to recover. As always, careful research and analysis are key to making informed decisions in the housing market.

Potential features that could be observed in the housing market present in the market over the past few years, based on current trends.

High demand of homes

Rising home prices

Tight supply of homes

More competition

Remote work impact

The current state of the residential market highlights the need for a paradigm shift towards home ownership as a key element of societal development. Solutions should be developed that are accessible to a wide range of people without infringing on public finance requirements. Public housing resources have been in decline due to the abandonment of structural policies in favor of one-off interventions and the transfer of implementing powers to the regions. Inefficiencies in the management and sale of public property have hindered the generation of sufficient resources for affordable housing.

RETHINKING THE RESIDENTIAL MARKET

The residential market is constantly evolving, and with it, the need for new approaches to housing design, development, and financing. Rethinking the residential market involves exploring innovative strategies that can make housing more affordable, sustainable, and accessible to a wider range of people. This requires collaboration among developers, policymakers, and community stakeholders to find solutions that address the challenges facing the housing market. From mixed-income communities to transit-oriented development and infill development, new approaches to housing development are emerging that prioritize affordability and inclusivity. In this context, it is crucial to examine how financing mechanisms can be reimagined to support these new models of housing development, ensuring that housing is available to all members of society.

In 2020, the McKinsey Global Institute published a report called "The Future of Housing: Meeting the Challenges of the 21st Century," which analyzed the worldwide housing market and identified growing demand for multifamily housing, energy-efficient buildings, and smart homes. However, it also recognized significant challenges, such as the lack of housing supply, the affordability crisis, and the need for more sustainable and resilient housing. The Urban Land Institute's 2016 report "Rethinking Housing: New Directions for Sustainable Communities" similarly proposes a new approach prioritizing affordability, sustainability, and inclusivity. The report suggests innovative models like mixed-income communities, transit-oriented development, and infill development as effective solutions. It also highlights the importance of engaging community stakeholders in the planning process and overcoming regulatory barriers to innovative housing development.

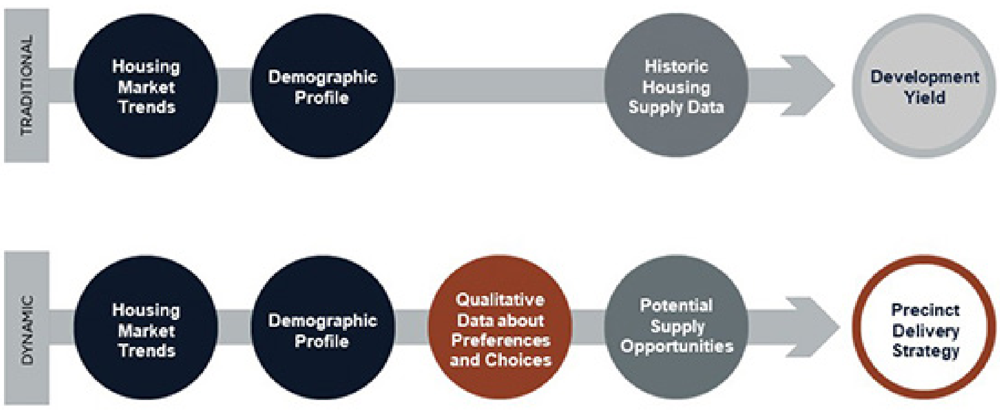


Fig. 16. We need to rethink demand. Source: https://www.cbre.co.nz/insights/articles/resi-advantage-2021

The Figure. 16, depicts a shift in mindset towards housing demand, emphasizing the importance of reevaluating conventional approaches. Such traditional methods tend to produce a development yield, whereas a more dynamic approach incorporating qualitative data can result in a precinct model that better serves the intended audience. To promote affordability, various models such as supported rental, rent-to-buy, build-to-rent, co-living, co-housing, and shared equity are necessary. Rental cooperatives, equity cooperatives, and community land trusts are increasingly popular in other countries, and community land trusts, in particular, are effective in eliminating land costs.

2.1.2.1. SOCIAL HOUSING

Social housing refers to publicly subsidized housing for low-income households, typically provided by government or non-profit organizations. The goal of social housing is to provide affordable and safe housing for those who may not otherwise be able to afford it in the private rental or ownership market. There are different types of social housing, including public housing, nonprofit housing, and cooperative housing. In public housing, the government owns and manages the housing units, while in nonprofit housing, a non-governmental organization (NGO) owns and manages the units. Cooperative housing is where residents collectively own and manage the housing units. Each type will be explained as described as follows:

Public housing, also known as council housing in the UK, is one of the most common forms of social housing. In public housing, the government owns and manages the housing units, and tenants pay a subsidized rent that is based on their income. This type is usually targeted towards low-income households, and tenants may be subject to income restrictions and other eligibility criteria.

Nonprofit housing is owned and managed by non-governmental organizations (NGOs). Nonprofit organizations can include charities, housing associations, and community groups. These organizations may receive government funding or subsidies to provide affordable housing, and tenants may still pay subsidized rent that is based on their income. Nonprofit housing may also include supportive housing, which provides additional services and support to tenants who may have specific needs, such as the elderly or people with disabilities.

Cooperative housing is a form of social housing where residents collectively own and manage the housing units. In a cooperative housing scheme, tenants may own shares in the cooperative and participate in the decision-making process. At the same time this typology can provide an affordable housing option for people who want more control over their living environment, but it requires a high level of cooperation and collaboration among tenants.

Social housing is a critical issue that affects millions of people worldwide. According to the United Nations, access to adequate housing is a fundamental human right, yet many people are unable to afford safe and decent housing. It aims to provide affordable housing for low-income families, the elderly, and those with disabilities.

It has a long history, dating back to the 19th century when governments first began to build public housing for the poor. However, the concept of social housing has evolved over time, and today it encompasses a wide range of housing options, including cooperative housing, community land trusts, and housing vouchers. One of the primary goals of it is to address the affordable housing crisis that many countries face. The lack of affordable housing is particularly acute in cities, where demand is high, and prices are skyrocketing. In the United States, for example, more than 10 million low-income households spend more than half their income on housing, leaving little money for other necessities such as food, healthcare, and education (National Low Income Housing Coalition, 2021).

Social housing has the potential to help alleviate this crisis by providing safe and affordable accommodation for those in need. Studies have shown that it can have a positive impact on the health, education, and overall well-being of low-income households (Desmond et al., 2015; Metropolitan Housing and Communities Policy Center, 2013). Social housing can also stimulate economic growth by creating jobs in construction and related industries. However, social housing faces many challenges, including funding constraints, regulatory barriers, and political opposition. Many governments are reluctant to invest in social housing, citing concerns about the cost and potential impact on the private housing market. Some critics argue that it is a form of welfare that creates a culture of dependency and discourages self-sufficiency (Stone, 2010).

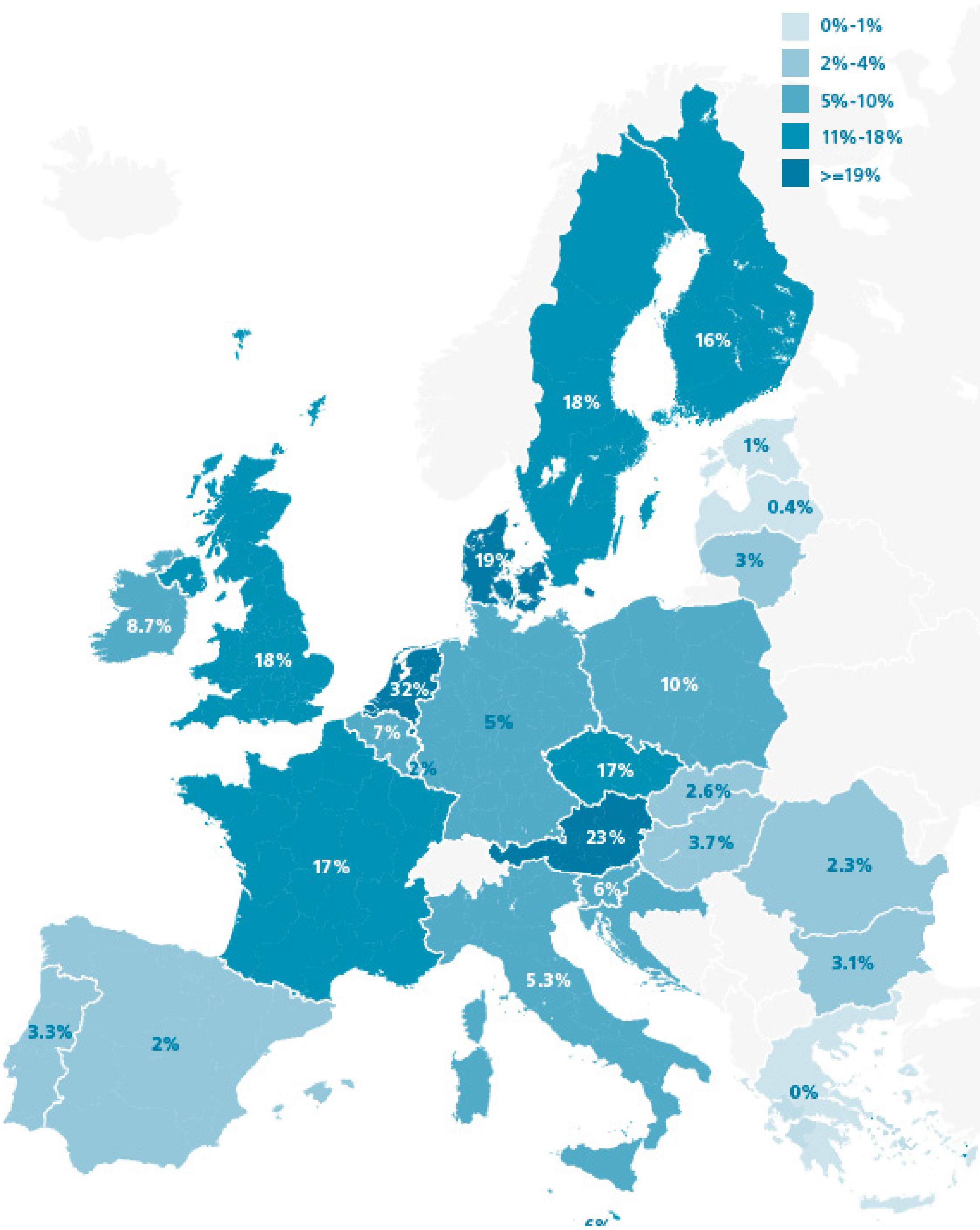


Fig. 17. Map: Social rental housing as percentage of total housing stock. Source: Social Housing in the European Union. https://www.researchgate.net/publication/308964157_Social_Housing_in_the_European_Union

The map in Figure. 17 shows the proportion of social rental stock to the total housing stock in a country, which is typically used to demonstrate the size of the sector. Despite these challenges, social housing remains a critical tool in addressing the affordable housing crisis. Governments and policymakers must work together to find innovative solutions that provide safe and affordable housing for all, regardless of income level.

In conclusion, social housing is an important topic that affects millions of people worldwide. It has the potential to alleviate the affordable housing crisis and improve the well-being of low-income households. However, it also faces many challenges and requires ongoing support from governments and policymakers.

2.1.2.2. AFFORDABLE HOUSING

Social housing and affordable housing share the common goal of providing affordable homes to those in need, but they differ in a number of ways. Social housing is a form of accommodation that is typically provided by the government or non-profit organizations. Its primary aim is to cater to vulnerable groups such as low-income families, elderly individuals, and those with disabilities, who are unable to afford housing in the private market. However, is often subsidized, which means that tenants pay rents below the market rate, while the government or organization covers the remaining costs. Generally, social housing units are owned and managed by the government or non-profit organizations, and tenants may be subject to income restrictions and other eligibility criteria.

On the other hand, affordable housing is generally geared towards individuals or families with moderate incomes who are still unable to afford market-rate housing. Unlike social housing, affordable housing can be developed by either private or public organizations, and it may include rental or homeownership opportunities. Affordable housing units are usually rented or sold at a price that is below the market rate, but they may not be as heavily subsidized as social housing. In addition, affordable housing may have fewer restrictions on tenant eligibility than social housing, and it may not be owned and managed by the government or non-profit organizations.

The meaning of "affordable housing" can differ between economies, but it generally involves a financial aspect (the portion of income spent on housing), a standard for determining what constitutes a minimum socially acceptable dwelling, as well as an understanding of which income groups are affected and at what income level households should qualify for housing aid. The definition should take into account various factors such as housing size, tenure options (rental vs. purchase), and affordability thresholds that vary by household size and income in the area. In many parts of the world, "affordability" is defined as housing costs that don't exceed 30 to 40 percent of household income, while a standard socially acceptable housing unit is defined by the local community's perception of what is required for decent living. The following diagram outlines the definition of affordable housing using three parameters that cities should customize according to their specific circumstances, taking into consideration current obstacles and future projections for the year 2050.

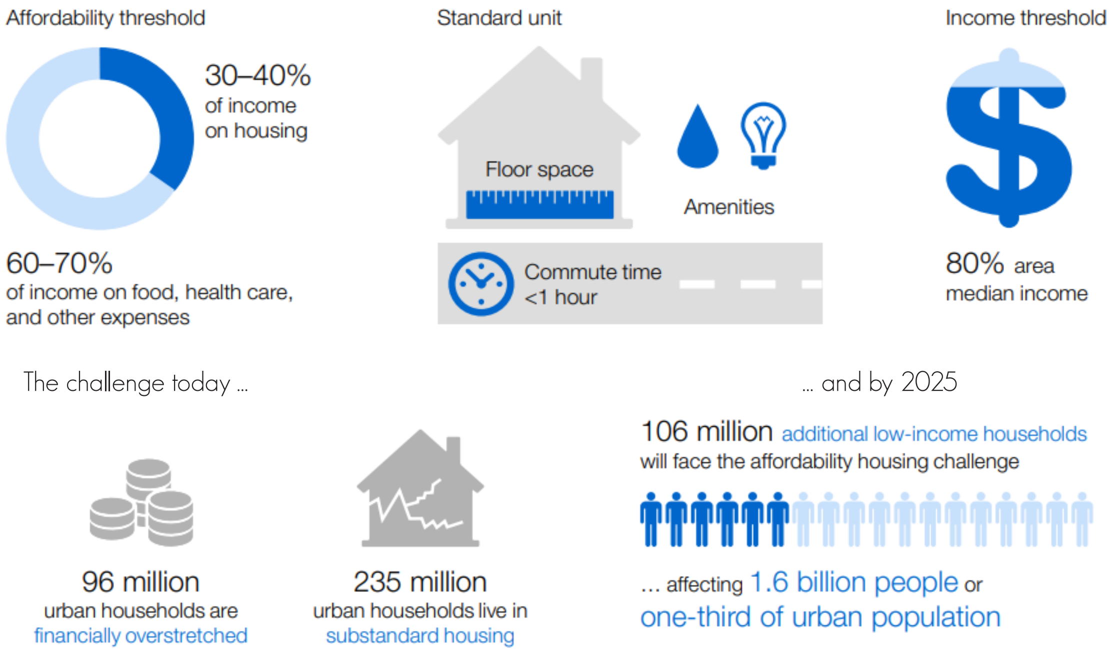


Fig. 18. Affordable housing parameters. Source: A blueprint for addressithe global affordable housing challenge. McKinsey Global Institute.

The amount of space necessary in a standard unit is influenced by consumer preferences, market conditions, and regulatory limitations. The definition should also include minimum requirements for basic amenities like running water and toilets, as well as access to essential social services such as schools and healthcare clinics. An acceptable housing unit should also ensure that employees aren't located more than an hour away from employment centers. Finally, as cities develop definitions for affordable, socially acceptable housing for policy-making purposes, they should determine which types of households will receive direct government assistance. In our analysis, we concentrate on households earning 80% or less of the local median income and the affordability gap they experience. Care must be taken when developing definitions for use in policy making since setting the floor-space standard too high could result in overpriced units for low-income households and push more households into the informal housing sector. The followinf diagram displays the primary four mechanisms that can tackle the worldwide issue of affordable housing.

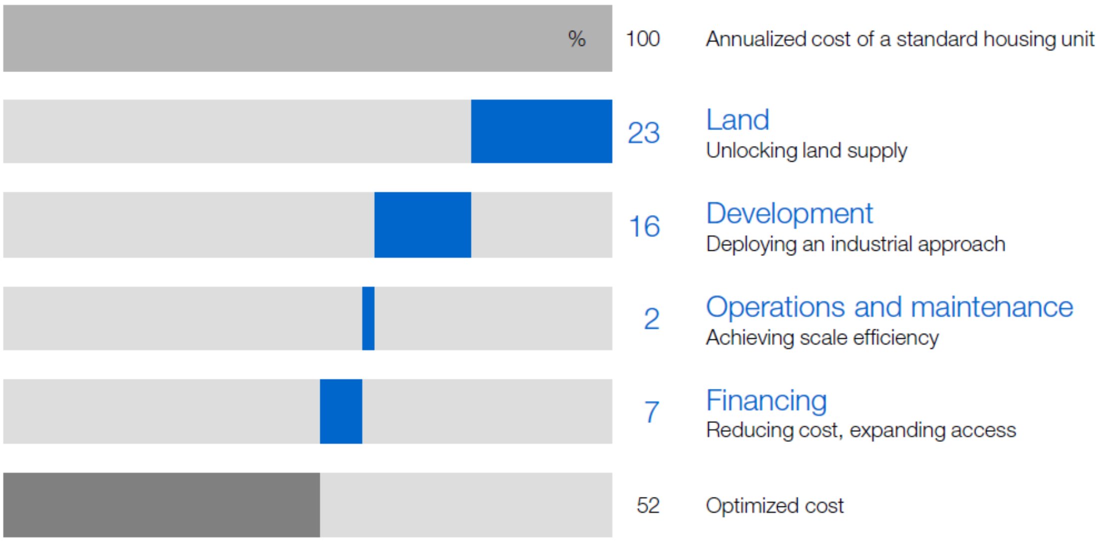


Fig. 19. Four mechanisms that can tackle the worldwide issue of affordable housing. Source: A blueprint for addressithe global affordable housing challenge. McKinsey Global Institute.

Access to affordable housing is crucial for individuals and families to have a stable living situation, which can positively impact their physical and mental health, education, and overall quality of life. In this chapter, we will discuss the importance of affordable housing, the challenges involved in creating affordable housing, and some possible solutions to address this issue. According to the United Nations, affordable housing is defined as housing that costs no more than 30 percent of a household's income. However, this benchmark is often difficult to achieve in many cities around the world, where housing prices are rising rapidly, and incomes are not keeping up. In some cases, people are forced to live in substandard housing, in overcrowded conditions, or to pay more than half of their income on housing costs. The lack of affordable housing is a complex problem that involves economic, political, and social factors. Some of the challenges that prevent the creation of affordable housing include land availability, zoning regulations, construction costs, and financing. Land is a finite resource, and in many cities, it is expensive and scarce, which makes it difficult to build affordable housing. Zoning regulations can also be a barrier to creating affordable housing, as they can limit the density of development and require developers to set aside a certain percentage of units for low-income residents, which can increase construction costs.

Construction costs are another factor that contributes to the lack of affordable housing. Building materials, labor, and regulations can add up quickly, making it challenging to create affordable housing that meets all the necessary standards. Financing is also a challenge, as lenders may be hesitant to finance affordable housing projects due to the perceived risk.

Despite these challenges, there are possible solutions to address the lack of affordable housing. One solution is to provide financial incentives to developers who build affordable housing. Governments can provide tax breaks, grants, and subsidies to encourage developers to create more affordable housing. Another solution is to loosen zoning regulations and allow for higher-density development, which can increase the supply of housing and lower construction costs. Community land trusts are another innovative approach to creating affordable housing. Community land trusts are nonprofit organizations that acquire land and hold it in trust for the benefit of the community. They can lease the land to developers who agree to create affordable housing, ensuring that the land remains affordable in perpetuity.

In conclusion, the lack of affordable housing is a critical issue that affects many people around the world. It is a complex problem that requires innovative solutions from government, developers, and communities. By providing financial incentives, loosening zoning regulations, and exploring alternative approaches like community land trusts, we can begin to address the lack of affordable housing and provide stable, healthy living situations for everyone.

ARGUMENTS AGAINST AFFORDABLE HOUSING

Affordable housing is often seen as a solution to the housing crisis, but there are arguments against its implementation. Critics argue that affordable housing policies can have unintended consequences, such as worsening the housing crisis, perpetuating poverty, and promoting urban sprawl. Moreover, some argue that affordable housing programs can be costly and inefficient, diverting resources away from other areas of need. In this context, it is important to consider the arguments against affordable housing and to explore alternative policy solutions that can effectively address the housing crisis without exacerbating other social and economic problems. While affordable housing is a crucial need in many parts of the world, there are some arguments against it. Here are some of them, along with references supporting them:

1. Reduced property values: Some homeowners believe that affordable housing can reduce the value of their properties. They argue that the presence of affordable housing can lower the desirability of the neighborhood, making it less attractive to potential buyers. A study by the National Bureau of Economic Research found that affordable housing developments had a negative effect on nearby home prices, with the impact being larger in higher-income neighborhoods.
2. Strained resources: Affordable housing can place a strain on local resources, such as schools, hospitals, and transportation infrastructure. More residents in an area can lead to overcrowded schools, longer wait times at healthcare facilities, and more traffic on the roads. A study by the Brookings Institution found that affordable housing can cause fiscal stress for local governments, as they have to spend more on public services to accommodate a larger population.
3. Stigma and discrimination: There is a social stigma attached to affordable housing, with some people believing that it is only for low-income families and individuals. This can lead to discrimination against those who live in affordable housing, including lower-quality services, job discrimination, and limited access to resources. A report by the Urban Institute found that affordable housing residents face discrimination in the rental market and are often subject to negative stereotypes.
4. Crime and safety concerns: Some people believe that affordable housing can increase crime rates and make neighborhoods less safe. This is often due to a perception that affordable housing residents are more likely to engage in criminal activity. However, research by the Urban Institute has found that there is no evidence to support this claim and that affordable housing does not increase crime rates.
5. Financial burden on taxpayers: Affordable housing developments often receive public subsidies and tax breaks, which some argue places a financial burden on taxpayers. Critics contend that public funds should not be

used to subsidize housing for low-income families and individuals. However, supporters of affordable housing argue that it is a public good that benefits society as a whole by promoting economic growth, reducing homelessness, and improving health outcomes.

According to the article ¨ Affordable housing is a myth that worsens the housing crisis – but there is a fix, the author argues that the idea of "affordable housing" is a myth that exacerbates the housing crisis because it fails to provide truly affordable homes for people in need. The article suggests that the solution is to shift the focus from building more affordable homes to implementing policies that increase the supply of social housing, which is designed to provide genuinely affordable homes to those who need them. The article proposes a range of policy measures that can be used to increase the supply of social housing, including increasing funding for social housing, reforming tax policies that incentivize property speculation, and introducing rent control measures. By shifting the focus from affordable housing to social housing, the article suggests that it is possible to provide truly affordable homes for those in need and to address the housing crisis more effectively.

COST-SAVING MEASURES FOR SUSTAINABLE ASSET VALUES FOR AFFORDABLE HOUSING.

Asset values can be maintained and operating expenses can be reduced through the implementation of improved maintenance and operational measures. These measures can result in cost savings of up to 20 to 30 percent of annual housing expenditures, depending on the country. By reducing these costs, housing can become more affordable, and proper standards and governance can help prevent dilapidation and preserve housing stock. There are two primary ways to achieve an overall reduction of 10 to 15 percent in operations and maintenance costs. First, energy efficiency can be improved through retrofitting homes with energy-saving materials and efficient heating and air-conditioning systems. Second, maintenance costs can be reduced by promoting scale economies and efficiency among repair and maintenance service providers.

To encourage scale improvements, demand for services should be pooled and certification and listing of maintenance and repair services should be established to give purchasers a better basis for selecting vendors. Homeowner groups should also be empowered, and standards should be established to ensure the quality of operations and maintenance activities. For example, the UK Decent Homes Standard specifies minimum maintenance requirements and provides funding to assist social landlords with repairs. Additionally, the government encouraged the transfer of ownership of social housing to private owners.

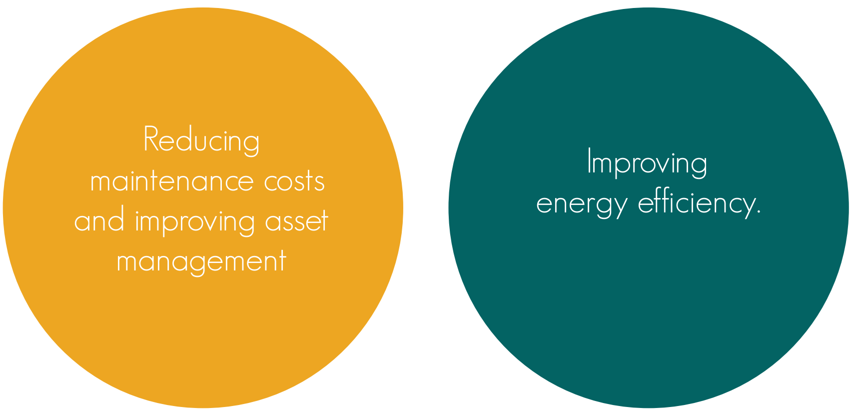


Fig. 20. Two major ways to cut overall operations and maintenance costs. (Authors)

2.1.2.3. HOUSING EXCLUSION

Housing exclusion is a pressing issue that affects many people in Europe, particularly young people who face significant challenges in accessing affordable and suitable housing. This chapter will explore the issue of housing exclusion among the youth population in Europe, with a focus on the housing market and relevant policies. The chapter will also examine the impacts of housing exclusion on young people, as well as potential solutions and policy measures to address this issue.

THE HOUSING MARKET AND YOUTH EXCLUSION

The housing market is a complex and challenging system for young people, particularly those from low-income backgrounds. The inability to access affordable housing has become an increasingly significant issue for young people, leading to youth exclusion from the housing market. Several factors contribute to this situation, including a lack of affordable rental options, low wages, and the inability to secure mortgages due to poor credit histories or insufficient savings. The inability to access affordable housing creates a situation where young people are excluded from many aspects of society, including access to education, employment, and social mobility.

The housing market in Europe is characterized by various factors that contribute to housing exclusion among the youth population. One major issue is the high demand for housing, coupled with limited supply, which leads to high rental and property prices. This makes it difficult for young people, who typically have lower incomes and less access to credit, to access secure and affordable housing. In addition, the increasing trend of short-term rentals and the rise of platforms such as Airbnb has reduced the availability of long-term rental properties, making it challenging for young people to find stable housing. The inability to secure mortgages due to poor credit histories or insufficient savings is another significant factor contributing to youth exclusion from the housing market. Many young people have not had the opportunity to establish credit histories, making it difficult to secure a mortgage. Additionally, many young people have not had the opportunity to save for a down payment, which further limits their ability to purchase a home.

Youth exclusion from the housing market is a rising concern globally, as young people, especially those from low-income backgrounds or starting their careers, confront numerous difficulties in obtaining affordable and satisfactory housing. One of the main reasons for youth exclusion from the housing market is the high cost of housing. In many areas, the cost of housing has risen rapidly, making it difficult for young people to afford even basic rental accommodations. This has led to a situation where many young people must rely on the generosity of family and friends or live in substandard housing conditions. Even when young people can afford housing, they often find themselves living in cramped, overcrowded conditions, which can have a detrimental impact on their physical and mental health.

Another significant factor contributing to youth exclusion from the housing market is low wages. Many young people work in low-paying jobs, making it challenging to save enough money for a down payment on a home or to afford rent in many areas. Additionally, many young people are burdened with student loan debt, which further limits their ability to save for a home or afford rental accommodation. Moreover, another, challenge facing young people in the housing market is discrimination. Landlords and property managers may refuse to rent to young people, charge higher rent based on age, or require larger deposits. Discrimination can also occur based on other factors, such as ethnicity, nationality, or gender. This discrimination can lead to exclusion from the private rental market, forcing young people to seek alternative accommodation such as substandard housing or homelessness.

The dearth of affordable housing has a widespread impact on Europe, especially in its capital cities. However, the shortage of new construction and the growth in demand for housing have caused prices to rise significantly. Young people, who are either in school, training, or beginning their careers, are the most severely affected by this situation and face challenges in finding suitable accommodation. When they do eventually leave their family homes, they typically have to resort to the private housing market, which can be prohibitively expensive and offer living conditions that are worse than what the general population experiences.

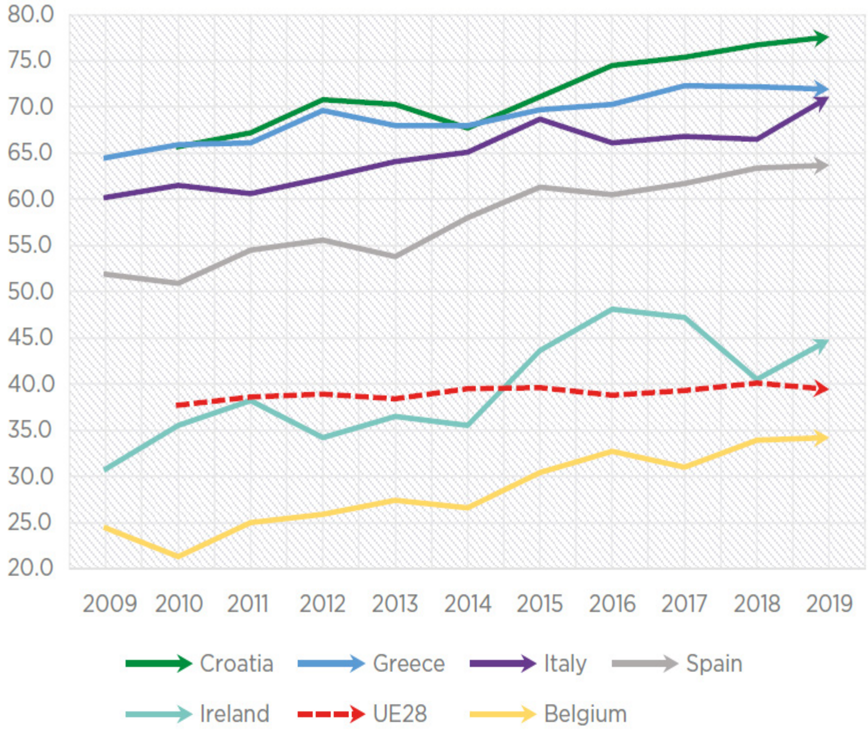


Fig. 21. Proportion of young adults aged 25-29 years living with their parents (%). Source: Sixth overview of housing exclusion in Europe 2021| FEANTSA - Fondation Abbé Pierr

In Europe in 2019, the majority of young adults aged 18-24 relied on their family home as their primary housing option, with 80% choosing this option. This marks an increase of 1.9 percentage points since 2010. However, the percentage varies among European countries, with Denmark having the lowest proportion at 36% due to the availability of social support for young people, while Italy has the highest proportion at 95% due to the underdevelopment of rental options. Additionally, there has been a rising trend in the number of 25-29 year olds living with their parents, with 39% of individuals in this age group across the EU choosing this option.

YOUTH LIVING CONDITIONS COMPARED TO ADULTS

The living conditions of young people in the housing market differ significantly from those of adults. Young people are more likely to live in overcrowded or substandard housing conditions than adults. They are also more likely to live in rental accommodation rather than owning their own homes.

- The lack of affordable rental options means that many young people must live in shared accommodation or with family members, which can be challenging and limit their independence. Additionally, young people are more likely to live in urban areas where rental accommodation is often more expensive than in suburban or rural areas.
- The impact of living in substandard or overcrowded housing conditions can be significant for young people. It can lead to physical and mental health issues, including respiratory problems, depression, and anxiety. Additionally, living in cramped conditions can limit young people's ability to study, work, and socialize.
- In contrast, adults are more likely to own their homes and live in more spacious accommodation. They have had more time to establish credit histories and save for a down payment on a home, making it easier for them to secure a mortgage. Additionally, adults are more likely to have stable employment and higher wages, which makes it easier for them to afford housing.

Overall, the housing market presents significant challenges for young people, leading to youth exclusion from the housing market. The lack of affordable rental options, low wages, and the inability to secure mortgages are significant barriers that must be addressed to ensure that young people have access to safe, secure, and affordable housing.

The high cost of housing in most European cities poses a significant challenge for young people trying to find accommodation. Since they are often drawn to major urban centers to study, train, or work, they typically search for housing in these cities, which have the most constrained housing markets. Due to frequent movement and different circumstances when transitioning to independence, young people usually start out living alone and therefore seek small housing units. However, this market segment is also contested by families experiencing changing circumstances, an aging population, and the rise of seasonal rentals and tourism. Rents are generally increasing, but they have risen particularly sharply for small housing units across the EU, with a 16% increase between 2009 and 2019. In Paris, for example, the cost of renting a studio apartment can exceed EUR 50/m2.

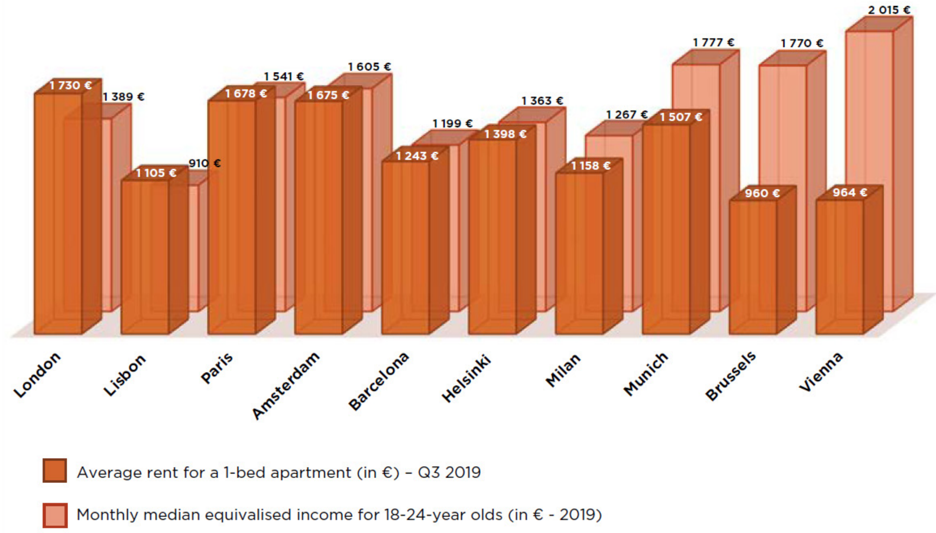


Fig. 22. Rental madness in capital cities – what renting a one-bed apartment in a large european city costs a young person as a % of income (in euros, 2019). Source: Sixth overview of housing exclusion in Europe 2021| FEANTSA - Fondation Abbé Pierr

Fig. 23. Young people more affected by housing exclusion than the rest of the population (EU28, 2019, IN %). Source: Sixth overview of housing exclusion in Europe 2021| FEANTSA - Fondation Abbé Pierr

Compared to adults, young individuals are at a higher risk of experiencing unsuitable living conditions such as severe housing deprivation or living in overcrowded residences that fall below acceptable comfort levels. In the EU28, 5.7% of young people between the ages of 15 and 29 were living in conditions of severe housing deprivation in 2019, whereas only 3.8% of the total population were affected. Additionally, 23.5% of 15-29 year olds were living in overcrowded conditions in 2019, while the percentage was lower at 15.6% for the overall population.

IMPACTS OF HOUSING EXCLUSION ON YOUNG PEOPLE

The impacts of housing exclusion on young people are far-reaching and can have significant consequences for their health, well-being, and future prospects. Homelessness, for example, can lead to physical and mental health problems, as well as social isolation and stigmatization. Moreover, young people who experience housing exclusion may be unable to access education or employment opportunities, leading to a cycle of poverty and social exclusion.

Housing exclusion can also have intergenerational impacts. Young people who are unable to access secure and affordable housing may be forced to live with their parents or other family members for longer periods, delaying their transition to independence and adulthood. This can place a burden on the family, who may have limited space and resources to accommodate them.

POLICY MEASURES TO ADDRESS HOUSING EXCLUSION

Various policy measures have been implemented to address the issue of housing exclusion among young people in Europe. One such measure is social housing, which provides affordable and secure housing for low-income individuals and households. Social housing can be targeted at specific groups, such as young people, to address their unique housing needs. For example, in the UK, the National Housing Federation has launched a campaign to increase the provision of social housing for young people.

In addition, there are policies aimed at increasing the availability of affordable housing for young people, such as rent control measures and the promotion of affordable housing construction. For instance, in Germany, the government has introduced rent control measures to limit rent increases in areas with high demand, which has helped to make housing more affordable for young people.

Furthermore, policies that address discrimination in the housing market are crucial in addressing housing exclusion among young people. These policies can include anti-discrimination legislation, awareness campaigns, and training for landlords and property managers. In Sweden, for example, there are laws prohibiting discrimination based on age in the private rental market, and landlords who violate these laws can be fined or face legal action.

Taking into account all of the aforementioned aspects, it can be concluded that the housing exclusion among young people in Europe is a significant issue that needs to be addressed through various policies and measures. The housing market, with its limited supply and high demand, presents significant challenges for young people seeking secure and affordable housing. Policies such as social housing, rent control measures, and anti-discrimination legislation are crucial in addressing the issue of housing exclusion and ensuring that young people have access to adequate and suitable housing.

2.2
THEORETICAL FRAMEWORK

2.2.1.
PREFABRICATED MODULAR ARCHITECTURE

Fig. 24. New York to Complete First Prefabricated "Micro-Apartments"
Source: https://www.archdaily.com/602157/new-york-to-complete-first-prefabricated-micro-apartments-this-summer

Modular architecture refers to a construction approach where buildings are constructed using pre-fabricated modules that are assembled on site. These modules are typically constructed in a factory and then transported to the construction site where they are assembled into a larger building.

Prefabricated modular architecture refers to the construction of buildings and structures using pre-manufactured modules or sections that are produced in a factory setting and assembled on-site. This type of construction is becoming increasingly popular due to its many advantages, including faster construction times, cost savings, increased sustainability, and greater flexibility in design. Prefabricated modular architecture involves designing and manufacturing a building in sections or modules that can be easily transported to the building site and assembled quickly and efficiently. These modules can be customized to suit specific design requirements, and can be assembled into a wide range of building types, from small residential homes to large commercial structures. With advances in technology and materials, prefabricated modular architecture is rapidly evolving, and is poised to become an important component of the construction industry in the years to come.

2.2.1.1.EVOLUTION

THE HISTORY OF PREFABRICATED MODULAR ARCHITECTURE

The history and development of modular architecture, a building design technique that involves constructing structures from pre-fabricated modules with off-site construction and then assembled on-site. It starts by tracing modular architecture back to the early 20th century when architects started experimenting with prefabrication techniques to provide affordable housing solutions for the growing population. Moreover, companies such as Sears, Roebuck, and Company began offering mail-order houses. These houses were delivered in pre-cut pieces with instructions for assembly, and they were particularly popular in rural areas where traditional construction was difficult. During World War II, modular buildings were used extensively for military housing and hospitals. The speed and efficiency of modular construction were crucial in meeting the demands of the war effort. After the war, the popularity of modular construction declined as traditional construction methods regained popularity.

An example of modular architecture is the Maison Dom-Ino, a design by Swiss architect Le Corbusier, which was based on reinforced concrete slabs that could be mass-produced and have an onn-site assembly to create various housing configurations. After World War II, modular construction gained popularity as a way to provide efficient, affordable, and customizable housing solutions. Architects like Buckminster Fuller and Walter Gropius explored the potential of pre-fabricated structures to create sustainable and adaptable buildings in the 1960s and 1970s Modular architecture became more popular in the 1980s and 1990s, particularly in urban areas where space was limited, and construction costs were high. During this time, new materials and construction techniques were developed, and modular housing companies emerged, specializing in manufacturing and assembling pre-fabricated modules. Today, there is a renewed interest in modular architecture as architects and designers explore its potential to create sustainable, affordable, and customizable buildings.

Summarizing the many benefits of modular architecture, such as its ability to provide fast, efficient, and environmentally-friendly building solutions. It suggests that modular architecture will continue to be vital in the future as architects and designers explore innovative ways to create efficient, sustainable, and customizable structures. Overall, the article provides a brief overview of the evolution of modular architecture and how it has transformed the field of architecture and construction over the past century.

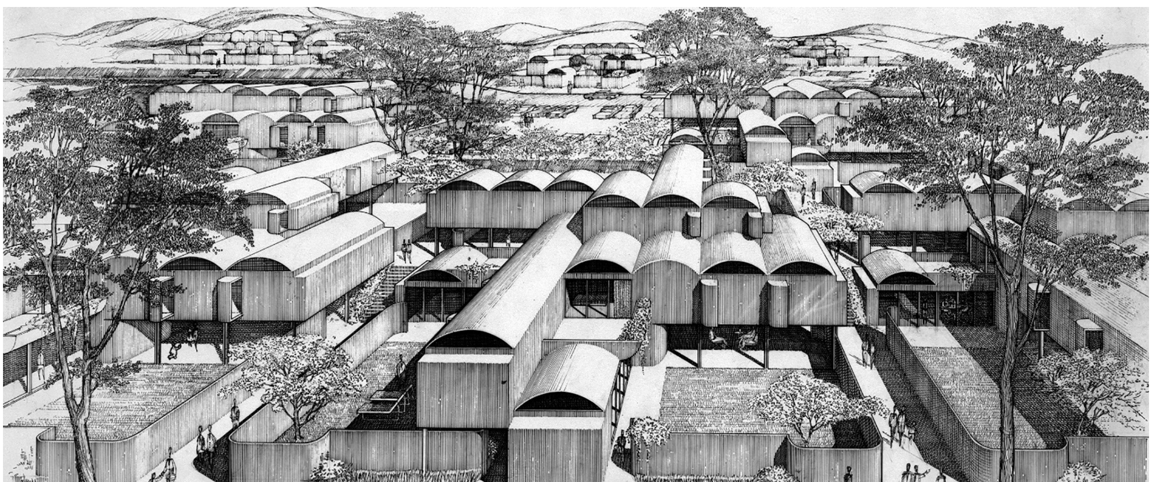


Fig. 25. Oriental Masonic Gardens via the Paul Rudolph Collection at UMass Dartmouth Source: https://www.gkvarchitects.com/news/a-brief-history-on-modular-architecture

2.2.1.2. TYPOLOGIES

Prefabricated modular architecture has become increasingly popular in recent years due to its numerous advantages, such as speed of construction, cost-effectiveness, and sustainability. This form of architecture involves constructing buildings from pre-manufactured modules or panels that are assembled on-site.

In general, modular building components that are prefabricated off-site can be either volumetric or non-volumetric. Volumetric modular construction involves creating three-dimensional units of enclosed space off-site, which are then connected on-site to form a complete building. This method is commonly used for multiunit residential projects, like hotels, dormitories, and apartments, where each unit may be made up of one or more modules. Examples of volumetric elements include patient rooms, bathroom pods, and elevator or stair sections. Non-volumetric modular construction involves creating building elements off-site, like structural frames, façade sections, wall panels, and floor cassettes, which are then connected on-site. Modular projects may use a combination of volumetric and non-volumetric components, as well as off-site and on-site construction. Although non-volumetric elements may be transported more compactly than volumetric units, they require additional on-site assembly and sealing work, which may offset any transport savings. However, the total time and labor cost for non-volumetric modular construction is generally lower than traditional on-site construction.

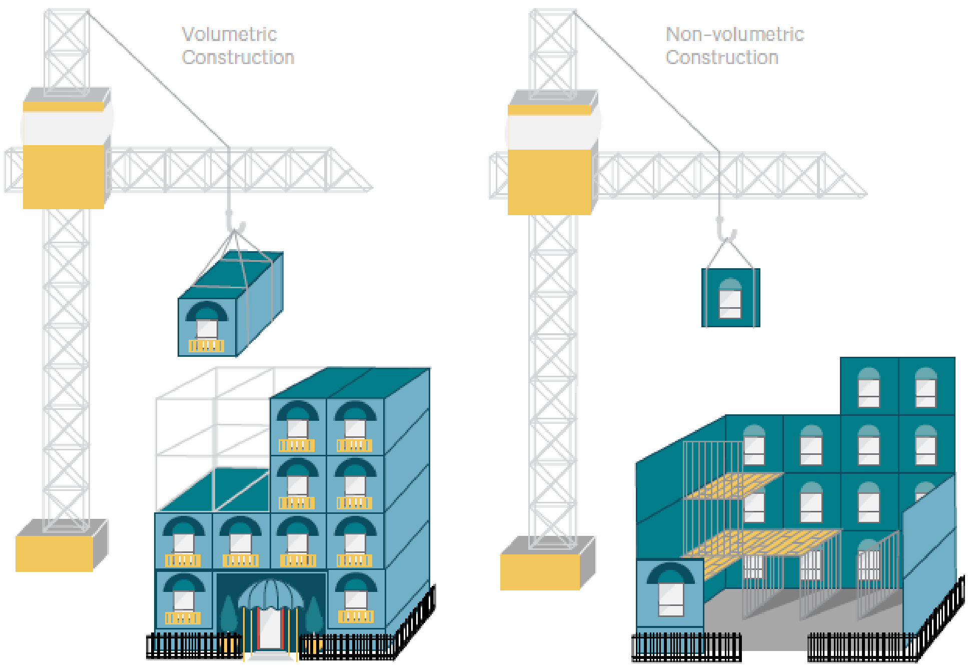


Fig. 26. Volumetric and non-Volumetric construction. Source: Design for modular construction: an introduction for architects| National Institute of Building Science.

This guide will mainly focus on volumetric modular construction, but the principles may also apply to other off-site fabrication technologies, including non-volumetric panelized construction. Permanent modular construction can be used at all scales, from single-family homes to high-rise buildings. Although most modular projects are four stories or less, an increasing number of projects have exceeded 10 stories. Modular construction can be used to build structures up to any height, unless restricted by local code. Small-scale modular buildings are often used for non-permanent installations, such as temporary offices, classrooms, and emergency relief housing.

However, there are several different typologies of prefabricated modular architecture, each with its own unique characteristics and applications.

1. Panelized construction is the most common form of prefabricated modular architecture. This typology involves assembling building components, such as walls, floors, and roofs, in a factory and then transporting them to the construction site for installation. The panels are typically made of wood, metal, or concrete and are pre-finished with insulation, electrical, and plumbing systems. Panelized construction is known for its speed and efficiency, as well as its cost-effectiveness. It is also highly customizable and can be adapted to various architectural styles.

Fig. 27. Panelized construction. Source: https://www.atamate.com/atamate-blog/modern-offsite-construction-techniques-an-overview

2. Volumetric construction involves manufacturing entire modules or sections of a building in a factory and then transporting them to the construction site for installation. This typology is often used for multi-story buildings, such as apartments and hotels, and can significantly reduce construction time and costs. Volumetric construction is highly efficient and minimizes waste since the modules are manufactured in a controlled environment. This approach also allows for greater precision and quality control since the modules are built to precise specifications in a factory.

Fig. 28. Volumetric construction. Source: https://villavo.com/blog/what-is-volumetric-construction/

3. Container architecture involves repurposing shipping containers as building modules. This typology has gained popularity in recent years due to its sustainability and affordability. Shipping containers are readily available and can be repurposed into a wide range of building types, from homes to commercial buildings. Container architecture is highly modular, allowing for easy expansion or relocation, and can be adapted to various site conditions. However, it also poses some challenges, such as limited interior space and the need for extensive insulation and ventilation systems.

Fig. 29. Container arch. Source: https://www.containerwerk.com/en/container-architecture/

4. Hybrid construction combines traditional construction methods with prefabricated modular elements. This typology is often used for larger and more complex building types, such as hospitals and schools, where a combination of speed, cost-effectiveness, and customizability is required. Hybrid construction can also incorporate sustainable building practices, such as the use of recycled materials and energy-efficient systems. However, it requires careful planning and coordination between the modular and traditional construction teams.

Fig. 30. Hybrid construction. Source: https://www.pbctoday.co.uk/news/mmc-news/modular-assemblies/104630/

Prefabricated modular architecture offers numerous benefits over traditional construction methods, such as speed, cost-effectiveness, and sustainability. The different typologies of prefabricated modular architecture allow for customization and adaptability to various building types and site conditions. As technology continues to advance and demand for sustainable building practices increases, it is likely that prefabricated modular architecture will become even more prevalent in the construction industry.

2.2.1.3. ADVANTAGES AND DISADVANTAGES

Modular construction has become increasingly popular in recent years due to its numerous advantages, including affordability, speed of construction, and customization options. However, it has some disadvantages that need to be considered before deciding whether to invest in this type of structure. Also, refers to the manufacturing of uniform parts of a building in a factory located away from the construction site, which are then put together on location. The terms offsite construction, prefabrication, and modular construction are interchangeable and encompass various methods and systems. The complexity of the components determines the range of systems available, from basic single elements that are joined together with standard connections and interfaces.

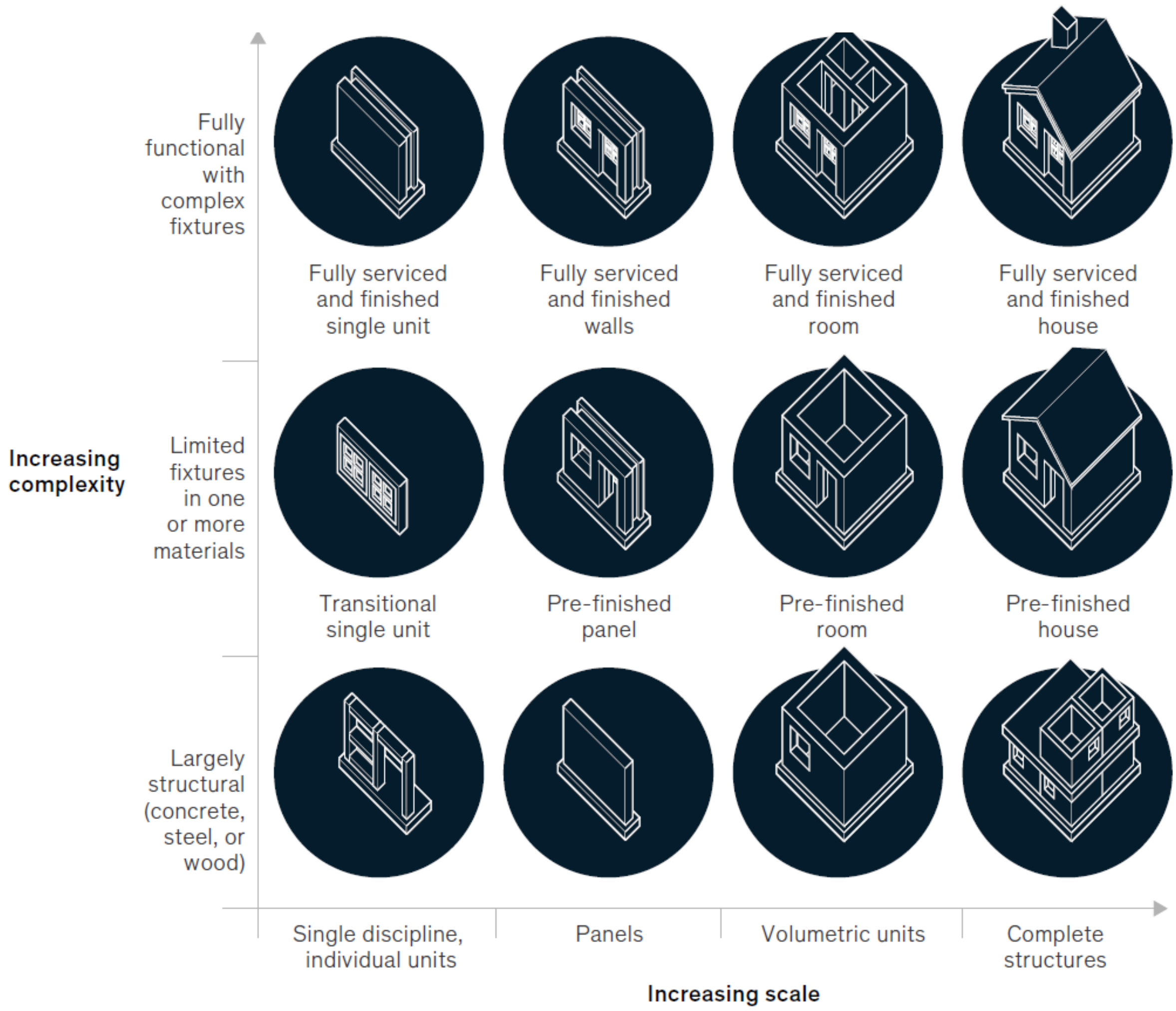


Fig. 31. Complexity and scale of modular construction—comparison of approaches. Source: Case studies; interviews; McKinsey Capital Projects & Infrastructure.

Moving towards more complex systems, there are two-dimensional panels, which can be either open or closed, and three-dimensional volumetric units that are fully equipped with fixtures. Wood, concrete, or steel can be used separately or in hybrid systems in various ways. Furthermore, two primary types of modular products: 2D components that require more assembly work on the construction site and 3D volumetric units that are fully furnished off-site. Each of these approaches has its advantages and is suitable for different segments of the real estate industry (as shown in following figure). These two approaches can also be combined to form a hybrid model.

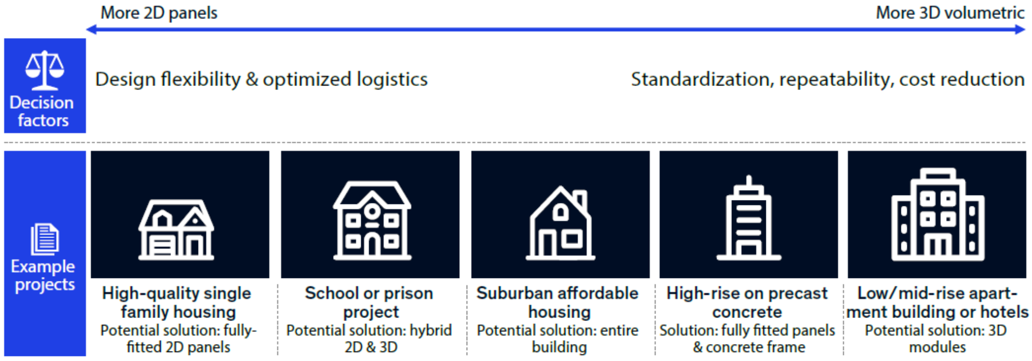


Fig. 32. A project's specific requirements will determine the choice of modular system. Source: Modular construction: From project to products McKinsey Capital Projects & Infrastructure.

Additionally, 3D volumetric solutions, are fully equipped units that can be assembled on site like Lego bricks. They are typically made of timber or steel due to their weight and logistical advantages, with most of the work being done offsite in a manufacturing facility. The advantages of using 3D volumetric solutions include potential maximum efficiencies and time savings. However, there are trade-offs to consider such as transportation costs and size limitations, with the maximum width for road transport being typically around 3.5 meters. As a result, 3D volumetric solutions are most suitable for projects such as hotels, hostels, or affordable housing. These solutions are also advantageous for rooms with intricate finishing, particularly wet rooms like bathrooms and kitchens. They are most suitable for projects with a high level of repeatability and a high ratio of wet to dry rooms. However, repeatability does not mean all products must look the same, as various standardized modules can be combined differently to create a customized end result.

The 2D panelized solutions, which are similar to the flat-pack assembly approach used in home furniture. These panels contain necessary conduits for services such as HVAC and plumbing that can be easily linked together with standard connectors. Onsite assembly work for 2D panels is simpler than traditional building, but more complex than putting together 3D modules, and requires more internal finishing. However, it is easier to transport panels than larger 3D modules, with several room components able to fit into a single standard container. This makes it possible to transport materials for a significantly greater floor area at one time, with lower shipping costs. 2D panelized solutions offer greater flexibility than 3D modules and are suitable for large open-plan offices or high-end residential projects such as single-family homes or apartments where differentiation is important, and the ratio of wet areas to dry areas is lower. Combining 2D and 3D approaches in construction can optimize the building process. Using a mix of 3D modules and 2D panels can bring high-productivity improvements to wet areas, while maintaining flexibility in other areas. However, the manufacturing process becomes more complex and requires coordination of the supply chain. Moreover, a 2D and 3D hybrid solution can be 20% cheaper than traditional approaches for affordable housing units of four floors.


Fig. 33. Graphical Abstract combination of 2D and 3D modular construction. Source: https://www.mdpi.com/2071-1050/8/6/558

ADVANTAGES OF MODULAR CONSTRUCTION

1. Affordability: Modular construction is often more affordable than traditional stick-built assembly. This is because they are constructed in a factory, which allows for economies of scale and reduces material waste. In addition, because the construction process is standardized, the cost of labor is also lower than that of traditional construction. Figure. 34, is an example of achieving a 20% cost reduction, but it also comes with a potential risk of up to 10% increase in costs if the savings in labor are offset by higher expenses in logistics or materials.
2. Speed of construction: it can be constructed much faster than traditional stick-built buildings. This is because the construction process is not subject to weather conditions or other environmental factors that can delay construction. Additionally, since they are constructed in a factory, there is no need for on-site coordination of construction activities, which further reduces construction time. In Figure. 35, is an Comparison of the duration of constructing an apartment project using traditional methods versus using on-site 3D volumetric construction, in months. Reducing the project timeline by 20% to 50%.
3. Customization options: these structures can be customized to a greater degree than traditional methodes. This is because they are constructed from pre-fabricated modules, which can be configured in a wide variety of ways to meet the specific needs of the client. In addition, because the modules are constructed in a factory, they can be designed to exact specifications and then shipped to the site for installation.
4. Energy efficiency: Modular fabrication is often more energy-efficient than traditional buildings. This is because they are constructed using energy-efficient materials and methods, and they are often designed to meet or exceed energy efficiency standards such as Energy Star or LEED certification. In addition, the standardized construction process used in modular construction ensures that there are fewer air leaks and other energy-wasting features in the final product.

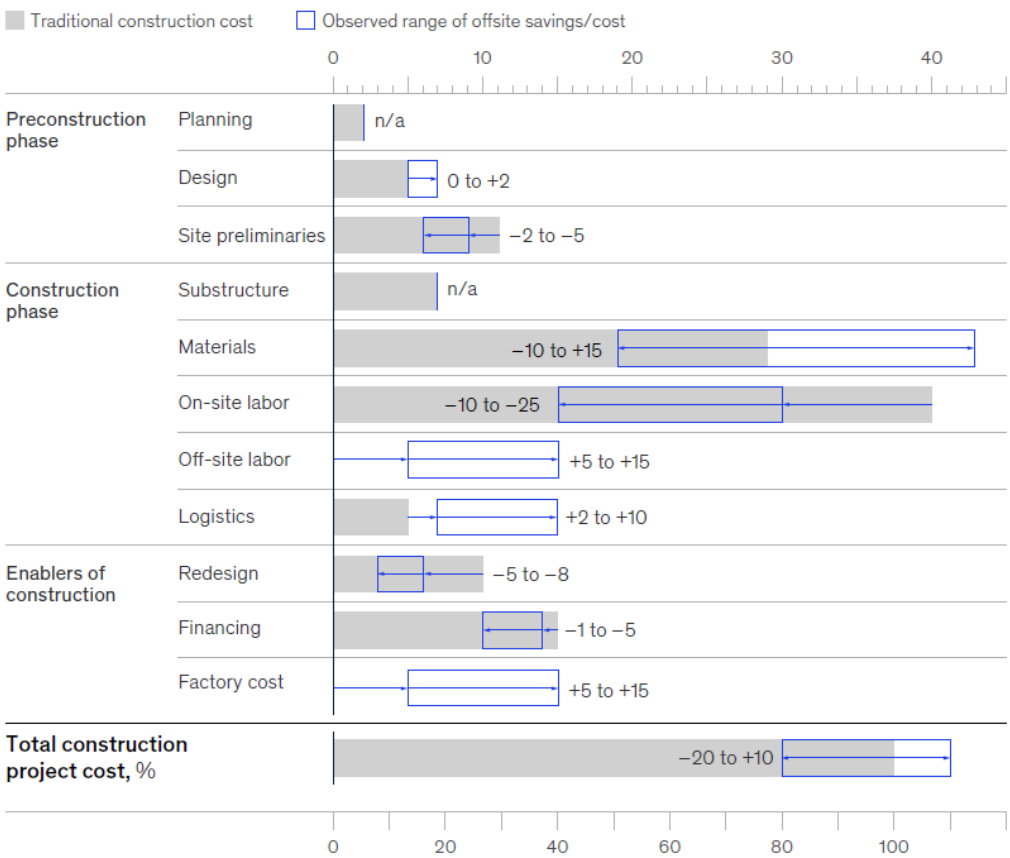


Fig. 34. Traditional construction cost,[1] % of total, and potential osite savings/cost, percentage point shift . Source: US Federal Highway Administration; McKinsey Capital Projects & Infrastructure.

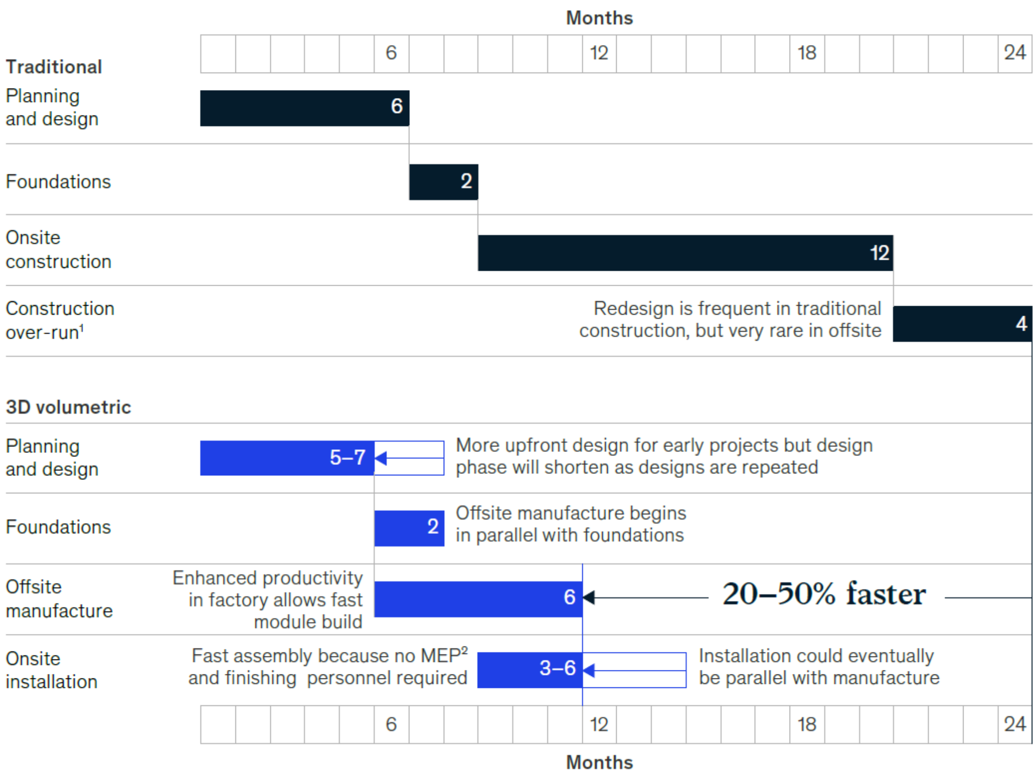


Fig. 35. Example apartment project construction duration, traditional vs osite 3D volumetric, months. Source: Case studies; interviews; McKinsey Capital Projects & Infrastructure

DISADVANTAGES OF MODULAR CONSTRUCTION

1. Limited design options: Prefabricated modular architecture may have limited design options due to the constraints of module sizes, transportation and assembly. This can lead to a lack of creativity in the final design, which may not be suitable for some applications.
2. Limited customization options: While modular housing offers a great deal of customization, there are some limitations to what can be done. This is because the modules are pre-fabricated off-site and then shipped to the site for installation. This means that there may be limitations on the size and shape of the modules that can be used, which can limit the overall design options.
3. Transportation costs: One of the disadvantages of modular housing is the transportation costs associated with shipping the modules to the site. Because the modules are large and heavy, they require specialized equipment and transportation, which can add to the overall cost of the home.
4. Land restrictions: Modular homes are subject to the same land-use restrictions as traditional stick-built homes. This means that there may be restrictions on where modular homes can be built, which can limit the overall availability of this type of housing.
5. Permitting process: Another potential disadvantage of modular housing is the permitting process. Because modular homes are constructed off-site and then shipped to the site for installation, there may be additional permitting requirements that need to be met before the home can be installed. This can add time and cost to the overall construction process.

With all these aforementioned, it can be concluded that, modular construction offers many advantages over traditional stick-built homes, including affordability, speed of construction, and customization options. However, there are also some disadvantages to consider, such as limited customization options, transportation costs, land restrictions, and the permitting process. Overall, the decision to invest in modular housing should be made based on a careful consideration of the pros and cons, as well as the specific needs and budget of the homeowner.

2.2.1.4. TRANSPORTATION AND ASSEMBLY

TRANSPORTATION

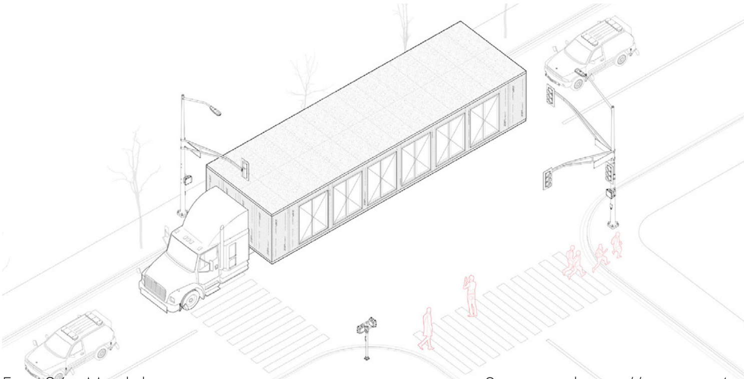


Fig. 36. Modular construction trasnportation. Source: https://www.re4a.com/the-modern-modular

Modular construction is a building method that involves the manufacture of prefabricated modules in a factory setting and their transportation to the construction site for assembly. The transportation of modular components requires careful planning and adherence to regulations to ensure safe and efficient delivery to the construction site. In this chapter, we will examine the methods of transportation for modular construction, including their advantages and disadvantages.

METHODS OF TRANSPORTATION FOR MODULAR CONSTRUCTION

1. Flatbed trucks are the most common method of transportation for modular components. The modules are loaded onto the flatbed truck at the factory and then transported to the construction site. The advantages of using flatbed trucks include their versatility, as they can transport modules of various sizes and weights, and their ability to access most construction sites. However, the disadvantages include the need for a crane or other lifting equipment to unload the modules, which can add to the cost and complexity of the project.
2. Trailers are another method of transportation for modular components. Like flatbed trucks, trailers can transport modules of various sizes and weights, and can access most construction sites. However, trailers are typically more expensive than flatbed trucks, and they require a larger truck to tow them, which can limit their flexibility.
3. Shipping containers are sometimes used to transport modular components, particularly for international projects. Shipping containers can be easily transported by ship, truck, or train, and can be stacked for efficient storage and transportation. However, the use of shipping containers for modular construction can be limited by the size of the container and the need for specialized equipment to unload the modules.
4. Cranes can be used to transport modular components from the factory to the construction site. The advantages of using a crane include their ability to lift and transport modules of various sizes and weights, and their ability to place modules directly onto the foundation at the construction site. However, the disadvantages include the need for a large and expensive crane, which can add to the cost and complexity of the project.
5. Rail is another method of transportation for modular components, particularly for large projects that require the transportation of many modules over long distances. The advantages of using rail include its cost-effectiveness and efficiency, as large numbers of modules can be transported at once. However, the use of rail can be limited by the availability of rail lines and the need for specialized equipment to unload the modules at the construction site.
6. Helicopters are a potential method of transportation for modular components, particularly for projects in remote or difficult-to-access locations. Helicopters have the advantage of being able to transport modules quickly and efficiently, without the need for a road or rail network. However, the use of helicopters for modular construction is limited by the cost and availability of helicopters, the size and weight of the modules, and the need for specialized equipment to unload the modules at the construction site. Additionally, the noise and wind generated by helicopters can cause disruption to nearby communities and wildlife, which may limit their use in some locations.

The transportation of modular components requires careful planning and consideration of the advantages and disadvantages of each method. Flatbed trucks and trailers are the most common methods of transportation, while shipping containers, cranes, and rail can also be used for certain projects. It is important to consider the size and weight of the modules, the location of the construction site, and the cost and complexity of the transportation method when selecting the best option for a modular construction project.

TRANSPORTATION STANDARDS

Europe has several standards and regulations in place for the transportation of modular buildings. These regulations are designed to ensure that modular buildings are transported safely and efficiently, while also protecting the environment and public safety. One of the most important regulations in Europe is the European Modular System (EMS). The EMS is a standardized system for the dimensions and weights of modular building components, which aims to make the transportation of modular buildings more efficient and cost-effective. The EMS allows for modules to be easily transported across borders, as they are designed to fit within the maximum dimensions and weights allowed on European roads.

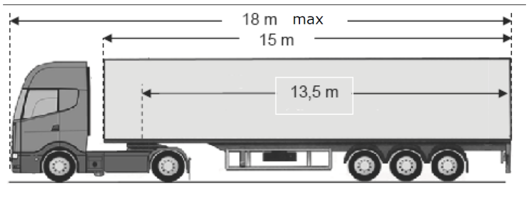


Fig. 37. Truck dimension. Source: EUROCOMBI EMS - European Modular system.

PERMISSIBLE MAXIMUM DIMENSIONS OF TRUCKS IN EUROPE

COUNTRY	HEIGHT	WIDTH	LENGTH		
			Lorry or Trailer	Road Train	Articulated Vehicle
Denmark	4 m	2.55 m (3)	12 m	18.75 m	16.50 m
France	not defined	2.55 m (3)	12 m	18.75 m	16.50 m
Germany	4 m	2.55 m (3)	12 m	18.75 m	16.50 m
Greece	4 m	2.55 m	12 m	18.75 m	16.50 m
Italy (2)	4 m	2.55 m (3)	12 m	18.75 m	16.50 m

Fig. 38. Permisible dimension of trucks in Europe. Source: International Trasport Forum

Regulatory Requirements: Transporting modular components in Europe requires compliance with various regulatory requirements to ensure safe and secure transportation. The European Union (EU) has established regulations for the transportation of hazardous materials, oversize loads, and overweight loads, which may apply to modular components depending on their size and weight. The EU has also established the European Modular System (EMS) for the transportation of modular components, which allows for the standardization of modular component dimensions across the EU. Compliance with these regulations is critical to ensure that modular components are transported safely and efficiently.

In addition to regulatory requirements, there are several industry best practices for transporting modular components in Europe that can improve safety, efficiency, and cost-effectiveness. One of the most important best practices is to properly secure and protect the modular components during transportation. This includes using appropriate strapping and bracing, as well as packaging and protecting the components from damage during transit. Modular components should also be properly labeled and identified to ensure accurate routing and delivery. Another best practice is to carefully plan the transportation route, taking into account road conditions, bridges, and other potential obstacles that may impact the transportation of oversize or overweight loads. This may require the use of specialized equipment, such as pilot cars or escort vehicles, to ensure safe and efficient transportation.

Transportation standards are critical to ensuring the safe and efficient transportation of modular components for construction projects in Europe. Compliance with regulatory requirements and adherence to industry best practices can improve safety, reduce costs, and minimize delays in project timelines. As modular construction continues to grow in popularity in Europe, it is important for manufacturers, transporters, and construction companies to stay informed of the latest transportation standards and best practices.

ASSEMBLY

Prefabricated modular architecture is a construction method that involves the use of pre-made components, or modules, that are manufactured off-site and then assembled on-site. The assembly process of prefabricated modular architecture is a critical aspect of the construction process that requires careful planning, coordination, and execution. In this chapter, we will explore the process of assembling prefabricated modular architecture, including the steps involved, the equipment used, and the challenges that may arise.

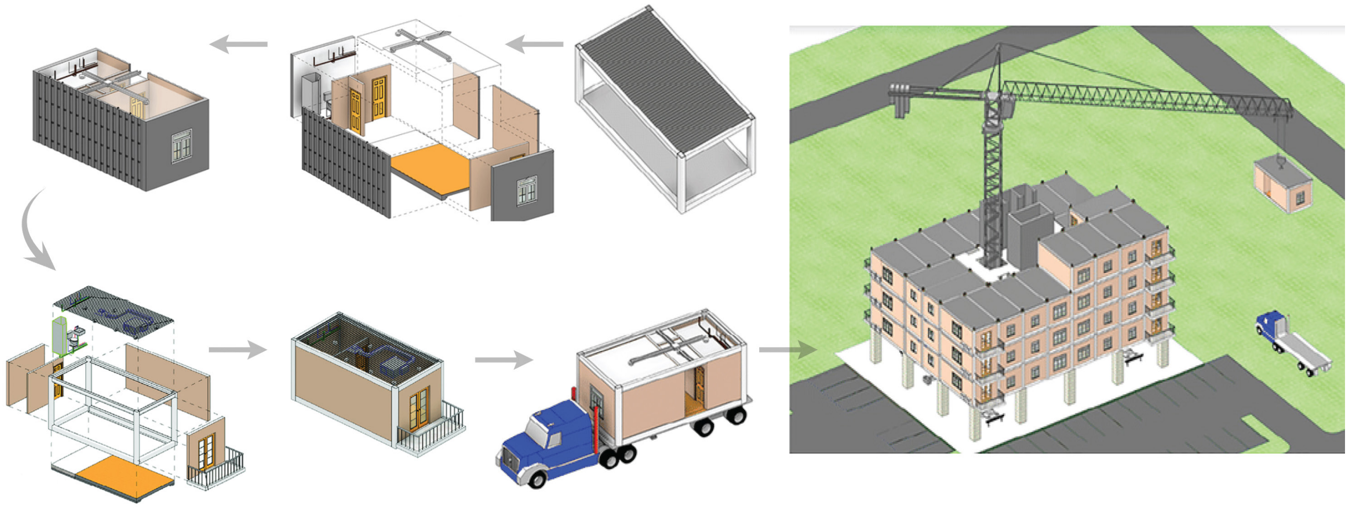
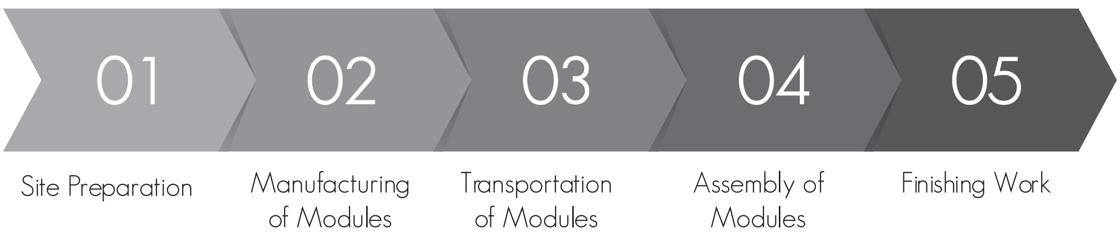


Fig. 39. Modular construction Assembling process. Source: Paper "Steel concrete composite systems for modular construction of high-risebuildings", J.Y.R. Liew.

STEPS INVOLVED IN ASSEMBLING PREFABRICATED MODULAR ARCHITECTURE

The assembly process of prefabricated modular architecture can be broken down into several key steps:

1. Site Preparation: The construction site must be prepared before the modules can be delivered. This may include clearing the site, leveling the ground, and installing utilities.
2. Manufacturing of Modules: The modules are manufactured off-site in a factory or manufacturing facility. The modules can be custom-designed to fit the specific requirements of the project.
3. Transportation of Modules: The modules are transported to the construction site using flatbed trucks or other specialized equipment. The transportation of modules requires careful coordination to ensure that the modules are delivered on time and in the correct sequence.
4. Assembly of Modules: The modules are assembled on-site using cranes or other heavy equipment. The modules are typically bolted or welded together to form the final structure.
5. Finishing Work: Once the modules are assembled, finishing work can begin. This may include the installation of electrical and plumbing systems, drywall, flooring, and other finishing materials.



EQUIPMENT USED IN ASSEMBLING PREFABRICATED MODULAR ARCHITECTURE

The assembly process of prefabricated modular architecture requires specialized equipment to transport and assemble the modules. Some of the most commonly used equipment includes:

01

CRANES

Cranes are used to lift and position the modules into place. They can be either mobile or stationary and can have a lifting capacity of up to 500 tons.

02

FLATBED TRUCKS

Flatbed trucks are used to transport the modules to the construction site. They are specially designed to carry heavy loads and can be equipped with hydraulic lifts to load and unload the modules.

03

WELDING EQUIPMENT

Welding equipment is used to weld the modules together. This requires skilled welders and specialized equipment to ensure that the welds are strong and durable.

CHALLENGES IN ASSEMBLING PREFABRICATED MODULAR ARCHITECTURE

While prefabricated modular architecture offers many benefits, there are also challenges that can arise during the assembly process. Some of the most common challenges include:

1. Site Constraints: The construction site may have constraints that make it difficult to transport and assemble the modules. This may include narrow roads, limited access, or overhead power lines.
2. Weather: Weather can also be a challenge during the assembly process. High winds, rain, or snow can delay the delivery and assembly of the modules.
3. Coordination: The assembly process requires careful coordination between the manufacturer, transportation companies, and the construction site. Any delays or miscommunications can cause delays in the construction timeline.

The assembly process of prefabricated modular architecture requires careful planning, coordination, and execution. The process involves several key steps, including site preparation, manufacturing of modules, transportation of modules, assembly of modules, and finishing work. Specialized equipment, such as cranes, flatbed trucks, and welding equipment, is used to transport and assemble the modules. While there are challenges that can arise during the assembly process, the benefits of prefabricated modular architecture, such as speed of construction, cost savings, and quality control, make it a popular choice for many construction projects.

2.3
THEORETICAL FRAMEWORK

2.3.1. DFMA
DESIGN FOR MANUFACTURE AND ASSEMBLY

Design for Manufacture and Assembly (DFMA) is an engineering methodology that aims to optimize the design of a product for efficient and cost-effective manufacturing and assembly. It involves designing products that are easy to manufacture, assemble, and maintain, with minimal use of materials, resources, and labor.

The term "Design for Manufacture and Assembly" (DfMA) has its roots in the manufacturing industry and focuses on two important design considerations - how a component is made and how it is assembled into a larger product. These considerations can improve the efficiency of production, but they are often overlooked in favor of design for use, particularly in construction. Originally, DfMA applied to factory-made, mass-produced components that were assembled into larger products for end-users. However, with advances in manufacturing, DfMA now also applies to the production of products that can be customized to varying degrees, a process known as mass customization. This has expanded the relevance of DfMA to include the design of more complex, larger, and less frequently sold products such as buildings, in addition to providing consumers with more choices.

The aim is to optimize the manufacturing and assembly process and another goal is reducing the overall cost of the product while maintaining its functionality, quality, and reliability. DFMA involves designing products that are easy to manufacture and assemble, reducing the number of parts and components, and simplifying the assembly process. The DFMA approach can be applied to a wide range of products, from simple consumer goods to complex industrial machinery.

It is based on the principle that the cost of a product is largely determined during the design phase. Therefore, by designing products with manufacturing and assembly in mind, companies can reduce the cost of production and increase profits. DFMA is not just about cost reduction; it also leads to improved product quality and reliability, as well as shorter lead times.

DFMA can be divided into two main categories: Design for Manufacture (DFM) and Design for Assembly (DFA). DFM focuses on designing products that are easy to manufacture, while DFA focuses on designing products that are easy to assemble. Both approaches aim to reduce the overall cost of production by simplifying the manufacturing and assembly process.

DFM

DFM involves designing products that can be produced efficiently and economically. This includes designing products with the minimum number of parts and components, as well as designing parts that can be easily manufactured using standard production techniques. The use of standard parts and components also reduces the cost of production by minimizing the need for custom-made parts.

DFA

DFA involves designing products that can be assembled easily and quickly. This includes designing products with fewer assembly steps and fewer fasteners. The use of snap-fit and self-aligning components can also simplify the assembly process and reduce the need for specialized assembly tools.

In the context of construction, DfMA refers to the process of streamlining the design phase, enhancing the material selection process, and optimizing the planning and logistics of construction projects. The approach involves identifying opportunities to design buildings using a limited range of commonly used and ideally standardized components, sub-assemblies, or assemblies that can be manufactured off-site, transported to the site efficiently, and assembled safely, quickly, and easily. These components or assemblies can be utilized for a single project or, with the use of mass customization, can be applied to many different projects.

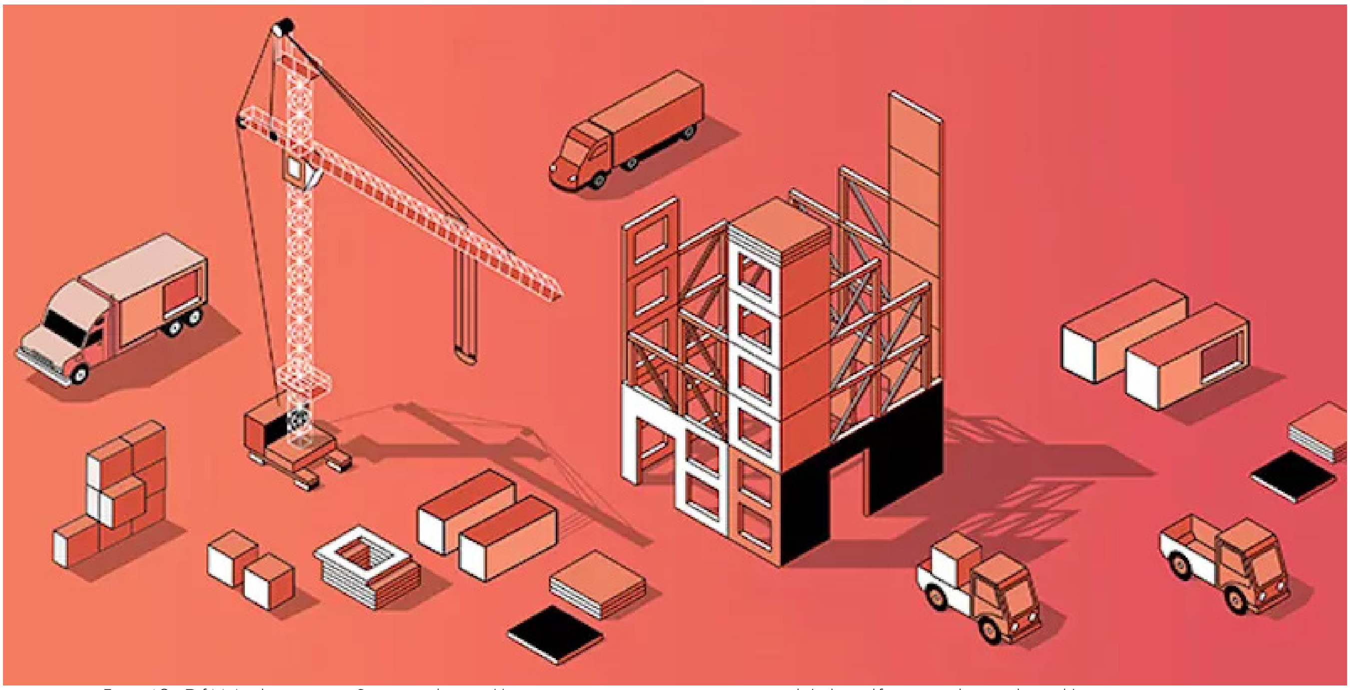


Fig. 40. DfMA diagram. Source: https://constructionmanagement.co.uk/riba-dfma-guide-updated/

It is important to define the importance of Mass customization, this one refers to the process that allows manufacturers to tailor their products to meet specific customer needs while still maintaining the low prices associated with mass production. This approach is enabled by the use of digital technology and innovative manufacturing methods that allow for the creation of interchangeable components that can be produced in different sizes and finishes. By reducing the time and cost required to change manufacturing processes, manufacturers can quickly adapt to produce different product variants. Additionally, the use of standardized parameters and production lines/supply chains for similar components allows for efficiency similar to that of mass production.

DFMA can be applied in a wide range of industries, from automotive and aerospace to consumer goods and electronics. For example, Apple Inc. has been widely recognized for its use of DFMA in the design of its products. Apple products are designed with a minimalist approach, using a small number of components and standard parts that are easy to manufacture and assemble. This approach has enabled Apple to reduce the cost of production while maintaining high levels of product quality and reliability.

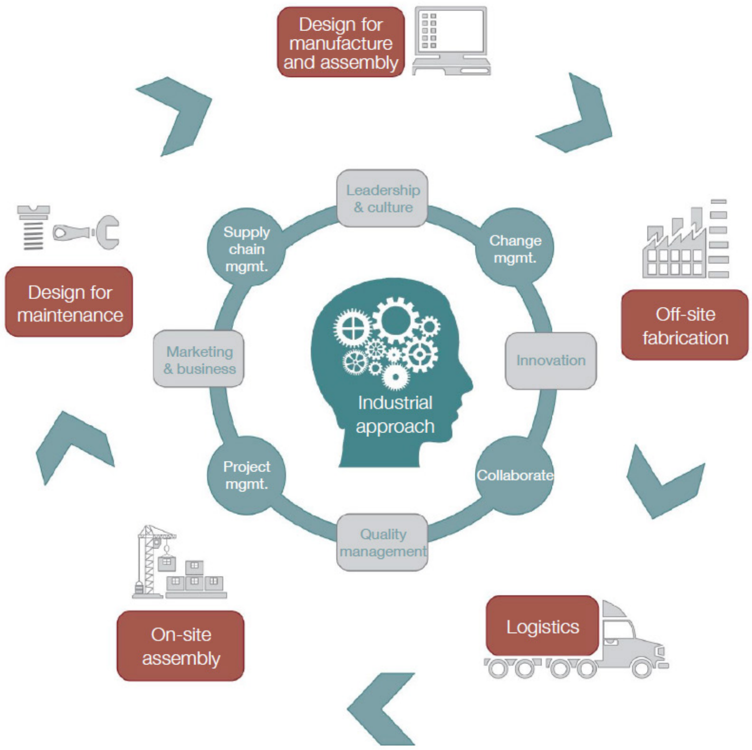


Fig. 41. The DfMA approach. Source: https://www.ribaj.com/intelligence/push-for-prefab

BENEFITS

There are several reasons why we should consider designing for offsite manufacturing. When designing for manufacturing, the components become more straightforward to produce, while designing for assembly makes it easier to put the products together. By using the DfMA process, the functionality of many parts can be combined into fewer components, resulting in the same or even better functionality.

Fig. 42. Factory DfMA production. Source: https://netzerobuildings.co.uk/premier-modular-announces-acquisition-of-netzero-buildings-2/

Factory benefits:

A report by Buildoffsite in 2016 suggests that on-site conditions are up to 80% less safe compared to factory conditions. While constructing in a shed alone may not provide a safer environment, adopting manufacturing practices can significantly enhance safety, especially through the use of industry standards and competitive pricing. On-site labor is over twice as expensive as factory-based labor, and factory productivity can reach 80%, compared to only 40% on-site. In a factory setting, waste can be almost entirely eliminated, and production can be more easily controlled and inspected. As a result, build quality is improved, outcomes become more certain, and costs are minimized.

Fig. 43. Site project. Source: https://www.pbctoday.co.uk/news/mmc-news/design-for-manufacture-and-assembly/74186/

On-site benefits:

Although it's not possible to complete most buildings entirely in a factory like a car, they are typically constructed partially on-site. However, since the on-site assembly has been carefully planned, optimized, and simplified, less on-site labor is required, leading to reduced preliminary costs and overheads. Compared to traditional construction methods, adopting a DfMA approach should result in faster completion times, requiring less material, labor, management, paperwork, and rework, as well as generating less waste, fewer defects, and safer work environments. These benefits not only reduce risks but also lead to significant cost savings. It's important to note that effective management of the interfaces between on-site and off-site elements is crucial to achieving these benefits.

Environmental sustainability benefits

Although it's not possible to complete most buildings entirely in a factory like a car, they are typically constructed partially on-site. However, since the on-site assembly has been carefully planned, optimized, and simplified, less on-site labor is required, leading to reduced preliminary costs and overheads. Compared to traditional construction methods, adopting a DfMA approach should result in faster completion times, requiring less material, labor, management, paperwork, and rework, as well as generating less waste, fewer defects, and safer work environments. These benefits not only reduce risks but also lead to significant cost savings. It's important to note that effective management of the interfaces between on-site and off-site elements is crucial to achieving these benefits.

- Manufacturing in a factory setting results in reduced waste as a result of improved planning, production control, and fewer errors, leading to more effective utilization of materials and reduced material waste.
- Offsite manufacturing leads to lower transportation costs, better air quality, and reduced noise pollution as only necessary materials are transported to the building site. This minimizes the embodied transport carbon costs involved in getting components, sub-assemblies, and pre-assemblies to the site and removing waste from it. As a result, the negative impacts on air quality and noise pollution are also minimized.
- The ease and rapidity of assembly result in reduced on-site energy and water consumption, leading to environmental benefits.
- Improved and earlier design resolution results in reduced material redundancy, such as avoiding unnecessarily large ceiling voids. If applied consistently throughout entire programs of work, this has the potential to considerably decrease material usage.
- The precision and quality of components, sub-assemblies, and preassemblies, as well as their ease of assembly on site, decrease the risk of poor workmanship and help to narrow the performance gap between design intent and asset in use. For instance, the utilization of offsite cut cross-laminated timber (CLT) can result in exceptional airtightness, which lowers operational energy loads and leads to substantial carbon savings throughout the asset's lifespan.
- Promotes circular economy: Certain components, sub-assemblies, and pre-assemblies can be conveniently reused, contributing to both the project's whole-life carbon cost prediction and endeavors to promote a circular economy.

2.4
CONCEPTUAL FRAMEWORK

2.4.1.
MODULAR-PREFABRICATED HOUSING

Modular prefabricated housing is a growing trend in the housing industry, offering numerous advantages over traditional construction methods. This type of housing is typically built off-site in a factory setting and then transported to the final location for assembly. Moreover, it offers several benefits over traditional construction, including cost savings, faster construction times, and increased energy efficiency.

One of the key advantages of is its flexibility in terms of design and construction. Modular units can be arranged in a variety of configurations, allowing for a wide range of housing typologies, including single-family homes, multi-family apartments, and microhomes. Also, is also highly customizable, allowing for a range of finishes and materials.

Modular prefabricated housing is gaining popularity in both the private and public sectors, with an increasing number of developers and governments turning to this method of construction to meet their housing needs. This trend is expected to continue in the coming years as the demand for affordable, sustainable housing continues to grow.

Fig. 44. The prefabricated house Source: https://www.globalwoodmarketsinfo.com/prefabricated-house-industry-germany-reaching-new-records/

2.4.2.HOUSING TYPOLOGIES

Housing typologies encompass the various housing options accessible to people across the world, which are determined by their design, construction, and arrangement. These typologies are influenced by a range of factors, including cultural, social, economic, and environmental considerations. In the following section, we will explore some of the prevalent housing typologies observed globally.

Single-Family Homes: Single-family homes are standalone houses that are designed to accommodate one family. They typically have a yard or garden area and are often preferred by families who want more space and privacy.

Apartments: Apartments are typically part of a larger building and offer multiple living units. They are usually rented or leased, and they often offer amenities like shared laundry facilities, a fitness center, or a pool.

Condominiums: or condos, are similar to apartments in that they are multi-unit buildings. However, condos are owned rather than rented. Owners typically have control over the interior of their unit, but share ownership and responsibility for the common areas of the building.

Townhouses: Townhouses are multi-level homes that are attached to other homes in a row. They often have a shared wall with one or more neighboring homes but still provide more privacy than apartments or condos.

Co-Housing: Co-housing is a housing arrangement where multiple families or individuals share common spaces, such as kitchens, living rooms, or outdoor areas. This arrangement encourages community living and often results in a closer-knit community.

Duplexes: are two-unit buildings that share a common wall. Each unit is typically designed as a separate living space, with its own entrance and amenities. Duplexes are common in areas where space is limited, but where single-family homes are still desired.

Tiny Homes: Tiny homes are typically small, portable homes that are designed to be energy-efficient and space-saving. They are often preferred by those who want to downsize their living space or those who want a more minimalist lifestyle.

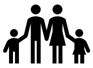
Mobile Homes: Mobile homes are prefabricated homes that are designed to be transported to a final location. They are often used as a permanent residence or as a second home, and they offer more flexibility than traditional homes in terms of location.

Student Housing: Student housing refers to housing that is specifically designed for students, usually located near a university or college campus. These housing options often offer shared spaces and a social atmosphere that is conducive to student life.

In conclusion, there are many different housing typologies available to people, each with its own advantages and disadvantages. The choice of housing type often depends on personal preference, lifestyle, and budget.

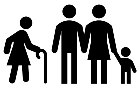
2.4.3.HOUSEHOLD COMPOSITION

Household composition refers to the number and types of individuals who live in a household. There are many different types of household compositions, including:

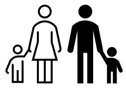


Nuclear Family: This is a household composed of a married couple and their children.

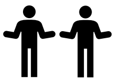
Single Parent Family: This is a household headed by a single parent, typically a mother or father, who may or may not have children living with them.



Extended Family: This is a household that includes multiple generations of a family living together, such as grandparents, parents, and children.

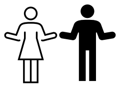


Blended Family: This is a household that includes children from previous relationships, as well as the new partner and their children.



Roommates: This is a household composed of individuals who are not related by blood or marriage but share living expenses and living space.

Empty Nesters: This is a household composed of a couple whose children have grown up and moved out, leaving only the parents in the home.



Cohabitating Partners: This is a household composed of unmarried partners who live together.

Single-person: This is a household consisting of only one person.

The composition of a household is heavily influenced by various factors such as the city's demographics, cultural norms, economic conditions, and lifestyle choices. Understanding these factors is crucial to comprehend the dynamics of households in a particular city. For instance, taking the example of the housing situation in Milan as we discussed in the previous section, the housing market in Milan is highly competitive and expensive, especially in the city center. Many families opt to live in apartments or flats, which are often smaller than those found in suburban areas. However, this gave insights into the typical household composition in the city. Milanese households are diverse and often adapting to the challenges of limited living space in the city center. Therefore, a thorough understanding of the local context is essential to gain a holistic view of households in any given city.

The household composition in Milan can vary widely, but some common types of households include: nuclear family, single-person household (which is becoming increasingly common in Milan due to demographic changes and social trends), extended family (that is less common in Milan but still exists), cohabitating partners, blended family, and single-parent family. It's important to note that household composition can vary widely in Milan and can be influenced by cultural, economic, and personal factors.As a result, many households in Milan have adapted to a minimalist lifestyle to make the most out of their living space. This means that they prioritize owning essential possessions and make use of the available space in an efficient manner. Overall, the minimalist lifestyle of Milanese households is a reflection of the city's urban environment, where efficient use of space is essential. It is also a cultural adaptation to the challenges posed by living in a city where space is at a premium, making the most of the limited living area available to them.


Fig. 45. MicroHome. Source:https://microhomes.eu/

2.4.4. THE CONCEPT OF MICRO-HOME

The term Micro homes or micro housing typically refer to small-scale, compact housing units designed to efficiently use limited space while providing functional living spaces. These homes are often built on a smaller scale than traditional homes, with a focus on maximizing the use of every square meter of space.

The concept of micro-homes can be traced back to the early 20th century when architects and designers such as Le Corbusier and Buckminster Fuller proposed compact living spaces as a solution to the housing crisis in urban areas. However, it was not until the 21st century that the idea gained significant traction. The emergence of micro-homes can be attributed to several factors, including the rising cost of housing, the growing trend towards minimalism, and the need for sustainable housing solutions. With the increasing urbanization of populations worldwide, many people are seeking smaller, more affordable living spaces that are closer to their workplaces and other amenities.

Advancements in technology have also played a significant role in the development of micro-homes. For instance, innovations in building materials, such as prefabricated modules, have made it easier and more cost-effective to construct small dwellings. Moreover, the sustainability movement has also influenced the popularity of micro-homes. Many designers and builders are now incorporating environmentally-friendly features such as solar panels, rainwater harvesting systems, and energy-efficient appliances to reduce the ecological footprint of these homes.

In recent years, the concept of micro-homes has gained significant attention, with numerous architectural firms, developers, and builders specializing in this niche market. Moreover, many local governments have also recognized the potential of micro-homes to address the housing crisis and have begun to relax zoning laws to accommodate smaller dwellings.

Overall, the emergence of the concept of micro-homes represents a response to the growing need for affordable and sustainable housing solutions in urban areas. As cities continue to grow and populations become increasingly urbanized, it is likely that the demand for micro-homes will continue to increase in the coming years.

The idea of living in smaller spaces with a minimalist mindset has been embraced by more than just the micro-home concept; another concept that shares this philosophy is known as Tiny houses. Although both share common parameters regarding the living area, lifestyle, and principles, microhousing units are small apartments or housing units in multi-unit buildings that are designed for affordable urban living. Meanwhile, tiny houses are standalone structures that are designed to be self-contained living spaces and can be built on wheels.

In order to gain a deeper comprehension of the principles of Micro Housing, it is crucial to grasp the concept of minimalism as a way of life.

MINIMALISM LIFESTYLE

It is a philosophy that values experiences over material possessions and encourages individuals to focus on what truly matters. Minimalism has gained popularity in recent years as people seek to declutter their lives and find more meaning and purpose in their daily routines. Also, this can involve decluttering one's home, simplifying one's wardrobe, and reducing digital distractions. By simplifying our lives, we can reduce stress and anxiety, free up time and energy, and focus on the things that truly matter. In other words, minimalism is a lifestyle that focuses on living with less, both in terms of physical possessions and mental clutter. It is a philosophy that emphasizes the importance of simplifying your life, prioritizing what truly matters, and eliminating unnecessary distractions. Below are several principles that characterize a minimalistic lifestyle:

1. Own less: The core idea of minimalism is to own fewer possessions. It means only keeping the things that add value to your life and letting go of the rest.

2. Prioritize experiences over things: Instead of accumulating more material possessions, minimalists prioritize experiences and meaningful relationships. They focus on building memories and cultivating fulfilling experiences.

3. Simplify your schedule: Minimalism is not just about decluttering your home; it's also about decluttering your schedule. Minimalists prioritize their time and energy on the things that matter most and eliminate unnecessary commitments.

4. Practice mindfulness: Minimalism encourages mindfulness and present-moment awareness. It means being fully engaged in the moment, paying attention to your thoughts and feelings, and being intentional in your actions.

5. Live within your means: Minimalists live within their means and avoid excessive consumption. They avoid over-spending on things they don't need and prioritize saving and investing for the future.

Studies have shown that people who prioritize experiences over material possessions tend to be happier and more satisfied with their lives (Howell & Hill, 2009). This is because experiences provide a sense of meaning and purpose that material possessions cannot. By decluttering our physical space, simplifying our commitments and routines, and being intentional about our consumption habits, we can create a life that is focused on what truly matters. As we continue to navigate a world that is increasingly complex and overwhelming, minimalism offers a simple and powerful antidote to the chaos.

Minimalism as a lifestyle philosophy has not only influenced personal choices but also architectural designs. The minimalistic approach to architecture prioritizes functionality, simplicity, and reduction of visual and material clutter. Minimalist architects aim to create designs that are unobtrusive, energy-efficient, and sustainable, while still being visually appealing.

MINIMALISM MINDSET IN MICRO HOUSING

The minimalist mindset is a great approach when it comes to micro housing. Micro housing, by definition, involves living in a small space with limited square footage. As such, it's essential to keep things simple and streamlined. To embrace a minimalist mindset in micro housing, here are a few principles based on the idea of prioritizing function over aesthetics,:

1. Focus on functionality: When designing your micro home, prioritize function over aesthetics. Think about how you'll use each space and what you need to do to make it as functional as possible.
2. Embrace multipurpose furniture: In a micro home, every piece of furniture should serve more than one purpose. For example, a sofa that doubles as a bed or a coffee table with built-in storage can help maximize space.
3. Keep clutter to a minimum: In a small space, clutter can quickly build up and make things feel cramped. Make a habit of regularly decluttering your belongings, and only keep what you need and love.
4. Opt for neutral colors: Choosing a neutral color palette for your micro home can make the space feel larger and more open. Stick to whites, grays, and other muted tones to create a calm, minimalist atmosphere.
5. Simplify your possessions: Living in a small space can be a great opportunity to embrace a simpler, more minimalist lifestyle. Take stock of your possessions and consider what you truly need and what you can let go of.

Fig. 46. Minimalism mindset. Source: https://www.theguardian.com/lifeandstyle/2020/jan/03/empty-promises-marie-kondo-craze-for-minimalism

SIZE

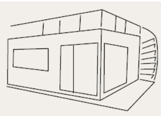
According to the International Code Council (ICC), the minimum size for a habitable room in a residential dwelling is 6.5 square meters (70 square feet), while the minimum size for a bedroom is 11.2 square meters (120 square feet). These guidelines have been put in place to ensure that homes are safe and healthy for their occupants. However, micro homes are often smaller than these minimum requirements, with some as small as 7.4 square meters (80 square feet) in total.The size of micro homes can vary and can be up to 90 square meters (approximately 970 square feet).

In fact, some micro homes can be quite spacious and luxurious, with high-end finishes and amenities. These larger micro homes may include features like multiple bedrooms, full-size appliances, and even rooftop decks.

Fig. 47. Ten micro homes with floor plans, different compositions, single unit and building. Source: https://www.dezeen.com/2019/03/18/micro-home-floor-plans-micro-apartment/

Overall, the size of a micro home can vary based on the specific needs and preferences of the occupants, as well as the available space and local building codes. While some micro homes may be as small as 7.4 square meters, others may be up to 90 square meters or larger. Regardless of the size, micro homes offer a more sustainable and minimalist lifestyle, which can be a viable housing solution for those seeking a simpler and more affordable way of living.

The concept of microhousing is becoming increasingly popular in Europe, as it aligns with the principles of minimalism and collaborative living. In the following images we can see the profile of microhosing in euripe and the typical sizes.



- **Names**: Micro house, mini house, tiny house, single house, nomad house.
- **Market:** approx. 80 supplies in Europe
- **Size/layout:** 58% with floor space of 25-60 m², 13% ≤ 24 m², 29% ≥ 61 m²
- **Construction:** 55% wood, 18% stone, 11% plastic, 9% straw, foundations not present or supplemental; on wheels; on water (floating home); majority are fully fitted with sleeping area, cooking corner, bathroom, living room and terrace
- **Fittings:** from spartan & functional to luxurious
- **Price range:** €25,000 – €350,000 (luxury units)
- **Uses/suitability:** Weekend home, second home, site for parties, business/display space, workspace
- **Prevalence in Europe:** Austria, Denmark, Estonia, Finland, Germany, Italy, Latvia, Lithuania, Poland, Sweden, Switzerland, Slovenia, UK

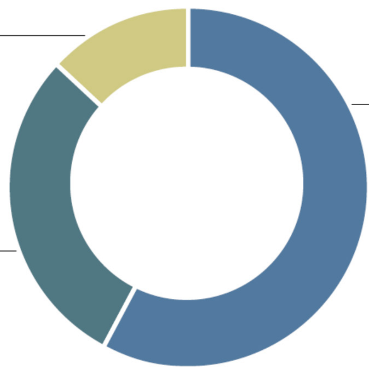


Fig. 48. The European Micro house: a profile and chart of size of Micro houses in Europe. Source: Catella Research 2016

ADVANTAGES AND DISADVANTAGES OF MICROHOME

Micro-homes have advantages, but they also have some disadvantages. We will examine both in more detail, drawing on relevant literature and research to provide a comprehensive overview of this housing trend.

A D V A N T A G E S

1. Affordability: Microhomes are much cheaper to build and maintain than traditional homes, making them a viable option for people who are on a tight budget.
2. Sustainability: Micro-homes require fewer resources to build and consume less energy, which makes them a more environmentally friendly option than larger homes.
3. Mobility: Many micro-homes are built on trailers or are designed to be portable, allowing owners to easily move them to new locations.
4. Simplicity: The small size of micro-homes often means less clutter and fewer possessions, which can lead to a simpler, more minimalist lifestyle.
5. Customization: Micro-homes can be customized to fit individual needs and preferences, allowing owners to create a space that is uniquely their own.

D I S A D V A N T A G E S

1. Limited Space: The limited space of micro-homes can make it challenging to accommodate a family or guests, as well as store possessions.
2. Zoning Restrictions: Many cities have zoning regulations that limit where micro-homes can be located or how they can be used, which can limit their availability as a housing option.
3. Building Codes: Some building codes may not permit the construction of micro-homes, or require certain design features that make them less affordable or less sustainable.
4. Lack of Privacy: The small size of micro-homes can make it difficult to find privacy or personal space, especially if more than one person is living in the space.
5. Resale Value: Micro-homes may have limited resale value, as they may not appeal to a wide range of buyers or may be difficult to resell due to zoning restrictions or other factors.

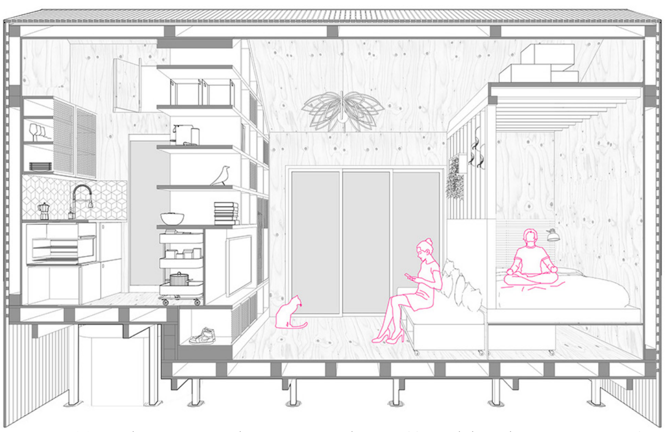


Fig. 49. Microhome exaple. Source: https://worldarchitecture.org/article-links/eevmc/microhome-2019-design-competition-winners-announced.html

Despite the challenges, micro-homes continue to be a viable solution to address the housing affordability crisis and promote sustainable living. As more people seek simpler and more efficient lifestyles, micro-homes are likely to remain a popular alternative to traditional homes. However, it is important to carefully consider both the advantages and disadvantages of micro-homes before making a decision to live in one. Overall, micro-homes represent a unique opportunity for individuals to redefine their relationship with living spaces and embrace a more minimalist and sustainable way of life.

2.4.5. ARCHITECT'S PERSPECTIVE AND RESEARCH ARGUMENTS

From an architectural perspective, micro housing presents unique challenges and opportunities. One of the main challenges is designing a living space that is both functional and comfortable within a small footprint. This requires careful consideration of every aspect of the design, from the layout of the space to the selection of materials and finishes. Another challenge is creating a sense of privacy and personal space within a small unit. This can be achieved through the use of clever design features such as sliding walls, built-in storage, and multi-functional furniture.

On the other hand, micro housing also presents several opportunities for architects. For example, the small size of the units allows for more experimentation with materials, finishes, and construction techniques. Architects can also explore new ways to incorporate green spaces and community areas within the building, which can enhance the quality of life for residents.

One argument against micro housing is that it may not be suitable for everyone. While micro housing can be a viable option for single individuals or couples who value affordability and compact living, it may not be suitable for families or individuals who require more space for their daily activities or storage.

Another argument is that micro housing may not provide enough privacy and comfort for residents. Living in a small unit can be challenging for some people, particularly if they do not have adequate space for their belongings or if the unit lacks natural light and ventilation.

Another argument is that micro housing may not provide enough privacy and comfort for residents. Living in a small unit can be challenging for some people, particularly if they do not have adequate space for their belongings or if the unit lacks natural light and ventilation.

Thin and narrow townhouses are being used to optimize density in urban areas. The concept involves building townhouses on long. These units can be stacked side-by-side and/or on top of each other to create a taller building that fits in with the surrounding neighborhood. This approach to development is gaining popularity due to the increased demand for urban living and the need for more affordable housing options.

Lastly, some architects may argue that the development of micro housing may not address the root causes of the housing crisis, such as income inequality, urban planning, and zoning regulations. They may suggest that policymakers should address these issues to create more sustainable and equitable housing solutions.

"We need to think of a new way of living in the city. We need to learn to live in small spaces, and to make those spaces liveable."

Renzo Piano

One of the latest global initiatives being implemented is the development of new formats of housing. Among them, micro homes have gained popularity and even inspired competitions.

BUILDNER ARCHITECTURE COMPETITIONS

Bee Breeders, an architectural competition organizer, has launched a new platform called Buildner. As part of this launch, they are hosting a MICROHOME competition to design a sustainable and affordable tiny house prototype.

The competition invites architects, students, and designers from around the world to submit their innovative and sustainable designs for a microhome that can be constructed using eco-friendly materials and techniques. The aim is to create a model for a low-cost, energy-efficient dwelling that can address issues of affordable housing, environmental sustainability, and resource efficiency.
The competition is open for registration until April 28, 2023, and the submission deadline is May 4, 2023. The winners of the competition will be announced on May 31, 2023, and the top entries will be featured on the Buildner platform.

Fig. 50. MICROHOME | Small Living, Huge Impact!s, different compositions. Source: https://competitions.archi/competition/microhome-edition-no4-small-living-huge-impact/

3

METHODOLOGY

This chapter is a critical section of any research project, as it outlines the approach that will be used to investigate the research questions and achieve the research objectives. In this chapter, we will present the research structure and phases that were employed in this study, including case studies, diagnostic phase, exploratory phase, and proposal phase. We will also describe the analytical methods and tools that were used to analyze the data and draw conclusions from the study.

The research structure and phases of this study were designed to provide a systematic and comprehensive approach to investigating the research questions. The research structure included three main phases: diagnostic phase, exploratory phase, and proposal phase. Each phase of the research structure had a specific purpose, and the results of one phase informed the development of the next.

Furthermore, this chapter will elucidate the utilization of analytical methods and tools in the development of the project.

3.1

CASE STUDY ANALYSIS

3.1.1. HISTORICAL APPROACH

In this section, we will explore several projects: two historical ones that marked the beginning of modular prefabricated housing, as well as four contemporary projects that align with the current trend towards modular units designed for micro-housing.

3.1.1.1 HABITAT 67

PROJECT INFO:
Name: Habitat 67
Architect: Moshe Safdie.
Original Completion: 1967
Location: Montreal, Quebec, Canada,
Area: 3,091.23 sqm
Floor numbers: 13
Materials of the units: Prefabricated concrete
Size of the unit: 20-90 m2

The complex is a pioneering example of modular design, with its striking, angular form comprising 354 prefabricated concrete units that were assembled on site to create a range of unique configurations. The complex was designed to offer a dynamic and visually engaging living environment that would maximize natural light, air flow, and views of the surrounding city and river. The units are arranged in a range of configurations, from single-story apartments to multi-story townhouses, with each unit featuring its own unique layout and design. The modular design allows for maximum flexibility and customization, with residents able to combine units to create larger living spaces or customize their units to suit their needs. In addition to the private outdoor spaces, the complex offers shared amenities such as gardens, pathways, and recreational areas, creating a sense of community and encouraging social interaction among residents. The complex is widely regarded as a landmark of modernist architecture and an innovative model for high-density urban living.

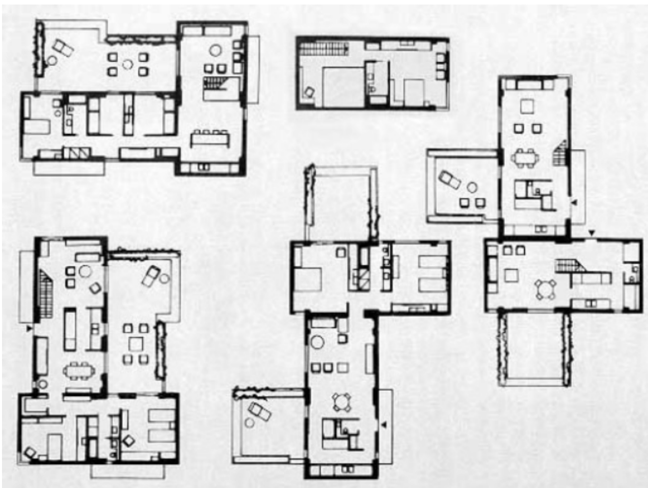


Fig. 51. Exterior view Habitat 67, Fig. 52. Floor plan, Habitat 67. Source: https://www.wsj.com/articles/moshe-safdies-habitat-67-an-architectural-icon-arrives-at-a-crossroad-11662563151

3.1.1.2 CAPSULE TOWER

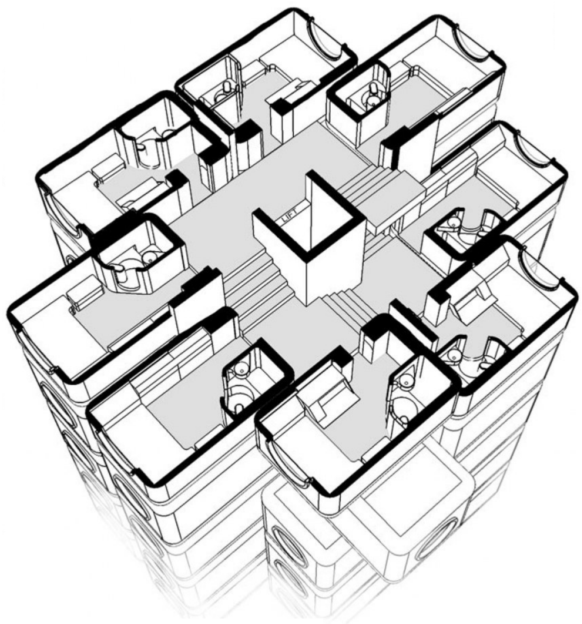
PROJECT INFO:
Name: Nakagin Capsule Tower
Architect: Kisho Kurokawa
Original Completion: 1972
Location: Ginza, Tokyo, Japan
Area: 3,091.23 sqm
Floor numbers: 13
Materials of the units: Steel boxes finished with galvanized steel panels, reinforced with anti-oxide treatment.
Size of the unit: 4 x 2.5 m

The Nakagin Capsule Tower is a unique architectural masterpiece that was built in Tokyo, Japan, in 1972 by Kisho Kurokawa. The building is made up of two interconnected concrete towers, which stand at 13 and 11 stories tall respectively. Each of the floors is divided into two parts: a central core and modular capsules, which can be easily replaced or interchanged, depending on the needs of the residents. The building is considered an important example of the Metabolist movement, which aimed to create adaptable and flexible urban structures.

The building's unique design is characterized by its modular, prefabricated units or "capsules," which were designed to be easily replaceable and adaptable. Each capsule is 2.3 meters by 3.8 meters and features a bedroom, bathroom, and kitchenette. The capsules were designed to be assembled off-site and then inserted into the building's core. The core provides shared spaces, such as elevators and stairs, as well as infrastructure for water, electricity, and ventilation. Also, notable for its innovative approach to sustainability. The building was designed to be energy-efficient, with the capsules featuring double-glazed windows and insulated walls. The use of prefabricated units also helped to reduce waste and construction time, while the building's small footprint allowed it to fit into Tokyo's dense urban landscape.

Despite its innovative design and sustainability features, the Nakagin Capsule Tower has faced challenges over the years. In 2007, a proposal was made to demolish the building due to safety concerns and a lack of maintenance. However, the building's unique design and cultural significance have led to calls for preservation and restoration, with some even calling for the building to be designated as a UNESCO World Heritage Site.

Fig. 53. Exterior view Capsule tower. Source: https://www.metalocus.es/en/news/nakagin-capsule-tower-tokyo-1969-72-kisho-kurokawa



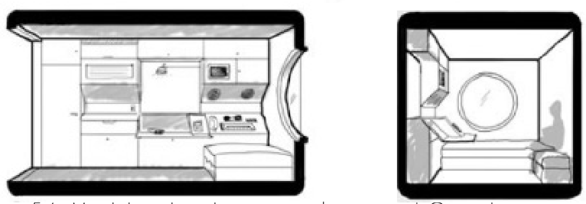


Fig. 54. Modules distribution, and sectionsl Capsule tower. Source: https://www.metalocus.es/en/news/nakagin-capsule-tower-tokyo-1969-72-kisho-kurokawa

3.1.2. CURRENT PERSPECTIVE

3.1.2.1. CARMEL PLACE

PROJECT INFO:
Name: Carmel Place
Architect: nARCHITECTS
Original Completion: 2016
Location: New York, USA
Area: 3,251.61 sqm.
Floor numbers: 9
Materials of the units: Steel frame modules.
Size of the unit: 37 sqm.

Carmel Place is located in the Kips Bay neighborhood of Manhattan, and was completed in 2016. The building comprises 55 micro-unit apartments, each of which features a built-in kitchen, bathroom, and living space. The units are designed with high ceilings, large windows, and flexible furniture options to make the most of the limited space.

One of the key features of the building is the use of modular construction. The apartments were manufactured offsite and transported to the building site, where they were assembled in just 19 days. This approach allowed for a quicker construction process and a reduced impact on the surrounding neighborhood.

The building also incorporates several sustainable features, including a green roof and energy-efficient appliances. In addition, the project team worked closely with the New York City Department of Buildings to secure a special waiver to allow for the smaller unit sizes.

Carmel Place has received several awards for its innovative design and approach to affordable housing, including the 2017 Architizer A+ Award for Multi-Unit Housing (Mid-Rise) and the 2016 NYCxDesign Award for Best Affordable Housing Development. The project has been hailed as a model for addressing the housing needs of urban residents in dense, high-cost areas.

Fig. 55. Exterior view, Carmel Place

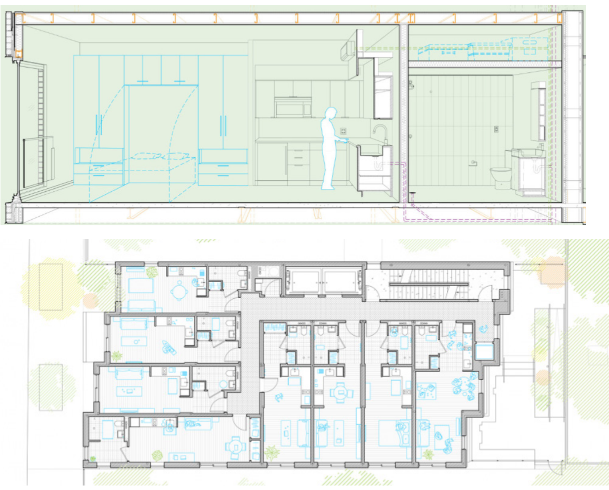


Fig. 56. Module section and buildind residential floor plan.

Fig. 57. Interior view. Source: https://narchitects.com/work/carmel-place/

3.1.2.2. TIETGEN DORMITORY

PROJECT INFO:
Name: Tietgen Dormitory
Architect: Lundgaard & Tranberg Architects
Original Completion: 2005
Location: Copenhagen, Denmark
Area: 26,515 sqm.
Floor numbers: 7
Materials of the units: Steel frame modules. With wood finishings
Size of the unit: 13-21 sqm Room- 47 sqm Appartments

The Tietgen Dormitory is a striking residential building located in the Ørestad district of Copenhagen, Denmark. Designed by Lundgaard & Tranberg Architects and completed in 2006, the project was commissioned by the Tietgen Foundation to provide affordable and comfortable housing for students attending nearby universities. The building is known for its unique circular shape and innovative use of materials, including perforated copper cladding that gives it a distinctive and eye-catching appearance.

The dormitory consists of a seven-story circular building with a central courtyard and communal spaces located on each floor. The building provides housing for 360 students in a variety of different room types, ranging from single rooms to larger shared units. The communal spaces include kitchens, dining rooms, and laundry facilities, as well as study rooms and lounges, which are designed to encourage social interaction and create a sense of community among residents.The design of the building reflects the architects' vision of creating a modern and sustainable living space that provides a sense of openness and connection to the surrounding environment. The circular shape of the building allows for maximum daylight and ventilation, while the use of natural materials and green roofs helps to reduce the building's carbon footprint.

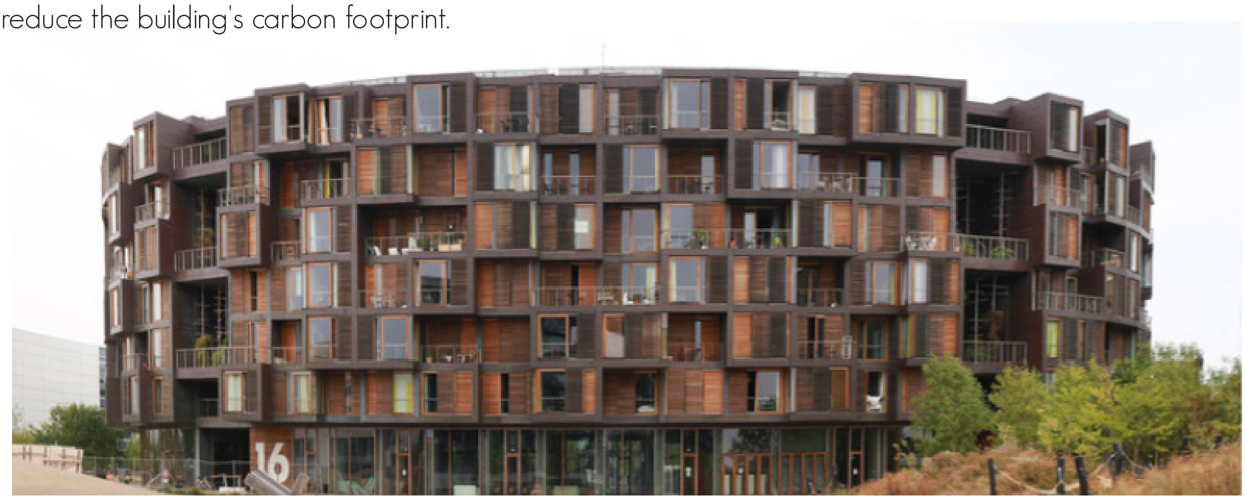


Fig. 58. Exterior view, Tietgen Dormitory. Source: https://www.archdaily.com/474237/tietgen-dormitory-lundgaard-and-tranberg-architects?ad_medium=gallery

Fig. 59. Building Section, Tietgen Dormitory. Source: https://www.ltarkitekter.dk/tietgen-en-0

3.1.2.3. TEN DEGREES

Fig. 60. 10 degrees building. Source. https://www.hta.co.uk/project/101-george-street

PROJECT INFO:
Name: Ten Degrees, 100a George Street
Architect: HTA Design LLP
Original Completion: 2020
Location: Croydon, south London.
Floor numbers: 44
Materials of the units: Steel frame modules.
Size of the unit: 38.5-100.5 sqm. Main module 50sqm

Ten Degrees is a residential development located in Croydon, London, designed by HTA Design. The project involved the creation of 288 homes, including one, two, and three-bedroom apartments, and a range of shared amenities such as a roof terrace, communal gardens, and a resident's lounge. The design approach aimed to create a welcoming and inclusive community, with a mix of affordable and market-rate housing. The development's sustainable features include green roofs, photovoltaic panels, and air source heat pumps. The project's design also sought to integrate with the surrounding area, with the building's facades featuring a distinctive geometric pattern inspired by the local context.

3.1.2.4. TREE TOWER

Fig. 61. Tree tower Toronto Source:https://www.archdaily.com/877049/penda-designs-modular-timber-tower-inspired-by-habitat-67-for-toronto

PROJECT INFO:
Name: Tree Tower Toronto
Architect: Penda
Original Completion: ---
Location: Toronto, Canada
Area: 4500 sqm.
Floor numbers: 18
Materials of the units: modular structure made from cross-laminated timber

The tower is inspired by the Habitat 67 housing complex in Montreal and features a modular design that would allow for flexibility in construction and adaptation to different sites. The tower would be built primarily from cross-laminated timber and would incorporate greenery into its design, with trees and gardens integrated into the building's facade and balconies. The project is intended to promote sustainable living in urban environments while creating a unique and visually striking architectural form.

3.1.3 CASE STUDI

CAPSULE TOWER

- The concept of metabolism in arch.
- Studio apartments for students/workers.
- Central Bearing Core (prefabricated).
- Each unit has natural light from one side.
- The capsules are click into the core.

CASE S

ANA

- Change the mindset o
- Offer diverse options for c
- Use lightweight structures
- Provide complementa activities to enhance
- Utilize flexible furnit spa
- Ensure two wo assemble th

- The concept of affordable housing in similar market situations.
- Micro-units for studios and young couples.
- Core made up of modules.
- Structural concept: one unit over another.
- Adding amenities spaces to encourage residents to live outside of their units.
- Five basic micro-unit types.

- Different options of house modules in the same floor plan.
- Lightweight structure.
- Use of prefabricated main core.
- The proposal for complementary spaces for extra activities to enhance the social aspect of the users.
- The changing of the mindset of dwellings while increasing the density of an urban sector.
- Different options of floor area.

Fig. 62. Nakagin Capsule Tower. Source: https://www.itoosoft.com/fr/gallery/nakagin-capsule-tower
Fig. 63. Carmel Place. Source: https://ny.curbed.com/2015/11/30/9895848/see-the-tiny-floorplans-for-carmel-places-micro-units
Fig. 64. Ten Degrees. Source: https://www.dezeen.com/2021/05/26/hta-worlds-tallest-modular-housing-scheme-residential-architecture/

ES CONCLUSION

HABITAT 67

- First Modular building.
- integration of two housing typologies—the suburban garden home and the economical high-rise apartment building.
- Concrete material units.
- Different configurations of the "boxes".
- Balconies in the top of other units.
- Integration with the context.

STUDIES

LYSIS

around modular housing

different types of households

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he modules.

TIETGEN DORM.

- Concept of student housing unit.
- Location of the modules in a way to generate cantilever.
- The use of balconies.
- Proposal of different module sizes - single, double, and apartment.
- The importance of enhancing daylight.

TREE TOWER

- Pre-fabricated and pre-cut CLT panels are assembled to modules off-site.
- On site, foundation, ground floor and a base core are done.
- All modules include fixtures and finishes delivered to the site.
- During the process of stacking the modules, the timber clad facade panels are installed and sealed.
- Use of balconies in cantilever.

Fig. 65. Habitat 67. Source: https://www.safdiearchitects.com/projects/habitat-67
Fig. 66. Tietgen dormitor. Source: https://www.flickr.com/photos/darrellg/6186638005
Fig. 67. Tree tower Toronto. Source: https://www.dezeen.com/2017/08/02/toronto-tree-tower-penda-cross-laminated-timber-construction/

3.2
BENCHMARK ANALYSIS

Modular construction is a construction method that involves the fabrication of building components off-site in a controlled environment and then assembling them on-site. It is a growing trend in the construction industry, driven by its potential to reduce construction time, cost, and waste while maintaining quality and safety. In this context, benchmarking analysis plays a critical role in comparing the performance of different modular construction companies and identifying best practices. In this article, we will discuss five leading modular construction companies - BOKLOK, LINDBACKS BYGG AB, KODASEMA, JK&P, and STORA ENSO - and examine their strengths and weaknesses through a benchmarking analysis, with a focus on the role of STORA ENSO in the design and calculation analysis process.

3.2.1. BOKLOK

Fig. 68. BOKLOK logo
Source: https://www.boklok.se/

It is a company that produces and builds sustainable, prefabricated homes and apartments. The company was founded in Sweden in 1996 as a joint venture between Skanska, one of the world's leading construction companies, and IKEA, the well-known furniture and home goods retailer.
Boklok's homes and apartments are designed to be affordable and functional, with a focus on sustainability and energy efficiency. Morover, it uses a variety of materials in their construction process, including sustainable wood and other eco-friendly materials. The homes are designed to meet high environmental standards, with features such as energy-efficient heating and ventilation systems, water-saving fixtures, and insulation that meets or exceeds local building codes.
Boklok has built thousands of homes and apartments across Europe, with a focus on Scandinavia and the United Kingdom. The company has received numerous awards for its innovative approach to sustainable housing and its commitment to affordability and quality.

3.2.2. LINDBÄCKS BYGG AB

Fig. 69. Lindbäcks Bygg AB logo. Source: https://lindbacks.se/

Lindbäcks Bygg AB is a Swedish construction company that specializes in modular construction. The company was founded in 1928 and has since grown to become a leading player in the construction industry. The main focus is on the production of high-quality modular buildings. They use a unique process that involves prefabricating modules in a controlled factory environment before transporting them to the construction site for assembly.
The company uses a variety of materials in their modular construction process, including timber, concrete, and steel. They also use advanced building technologies, such as 3D modeling and virtual reality, to ensure that each building meets the highest standards of quality and safety.

Lindbäcks Bygg AB has completed numerous projects across Sweden, including schools, hotels, and apartment buildings. Their buildings are known for their modern design, energy efficiency, and sustainability.

3.2.3. KODASEMA

Fig. 70. KODA by KODASEMA logo Source: https://kodasema.com/et/

Kodasema is an Estonian design and construction company that specializes in creating innovative, compact, and sustainable homes. The company was founded in 2014 by architect Ülar Mark and product designer Taavi Jakobson with the goal of creating affordable, high-quality living spaces that can be easily transported and assembled.

The company's homes are designed to be energy-efficient, sustainable, and easy to maintain, and they are built using high-quality materials that are carefully selected for their durability, sustainability, and aesthetic appeal. The process that Kodasema follows is highly collaborative and involves close communication between the company's designers, engineers, and clients. The company works closely with its clients to understand their specific needs and requirements, and then creates custom-designed homes that are tailored to their individual needs.

Kodasema uses a wide range of materials in its construction projects, including wood, steel, glass, and concrete. The company is known for its innovative use of materials, such as its use of large glass panels to create bright and airy living spaces, and its incorporation of high-quality insulation to ensure that its homes are energy-efficient and comfortable to live in.

3.2.4. JK&P

JK&P is a German company that specializes in prefabricated construction. It has been in the prefabricated construction business for over 40 years and has established itself as a leader in the industry. The company offers a wide range of prefabricated building solutions, including residential homes, commercial buildings, and industrial facilities.

Fig. 71. JK&P logo Source: https://www.jkundp.at/

JK&P's prefabricated buildings can be tailored to meet the specific needs and preferences of their clients. The company's experienced architects and engineers work closely with clients to design buildings that are functional, aesthetically pleasing, and meet all relevant building codes and regulations.

JK&P's prefabricated buildings are also known for their high quality. The company uses only the best materials and employs rigorous quality control standards to ensure that every building meets or exceeds industry standards.

On of the company's projects is K33 is a self-contained living unit, the unit is a prefabricated modular structure that is designed to be flexible and adaptable to a wide range of settings and uses. The unit is designed to be energy-efficient and sustainable, with features such as triple-glazed windows, LED lighting, and a heat-recovery ventilation system.

The K33 unit is also designed to be transportable and easy to install. It can be transported to a site and assembled within a few days, allowing for fast and efficient construction. It appears to be an innovative and practical solution for a wide range of applications, such as temporary housing, vacation homes, or additional living space.

3.2.5. STORA ENSO

Stora Enso is a Finnish company that operates in the renewable materials industry, with a focus on wood-based products. They are a leading provider of sustainable solutions in the construction sector, offering a range of innovative products and services that promote sustainability and reduce carbon emissions. One of the areas in which Stora Enso has made significant strides is in the development of prefabricated modules for construction. Stora Enso's prefabricated modules are made from cross-laminated timber (CLT), which is an engineered wood product that is strong, durable, and sustainable.

The modules are designed to be flexible and adaptable, with a range of options for customization. They can be used for a variety of applications, including residential buildings, schools, and offices. The modules are pre-fitted with windows, doors, and other components, before being transported to the construction site. In addition to their work with prefabricated modules, Stora Enso is also a leader in the use of timber construction. It is seen as a sustainable alternative to traditional construction methods. Stora Enso's timber construction products include CLT panels, laminated veneer lumber (LVL), and glulam beams, which can be used in a range of applications, from residential homes to large-scale commercial buildings. Stora Enso's work with prefabricated modules and timber construction demonstrates their commitment to sustainability and innovation in the construction industry. Their focus on reducing carbon emissions and promoting sustainable building practices is an example for others in the industry to follow..

STORA ENSO'S CALCULATIS SOFTWARE

It is a powerful tool that is used to calculate the strength and stiffness of structural elements made from wood-based products. The software is designed to support the design and engineering of sustainable buildings that use cross-laminated timber (CLT), laminated veneer lumber (LVL), and glulam products.

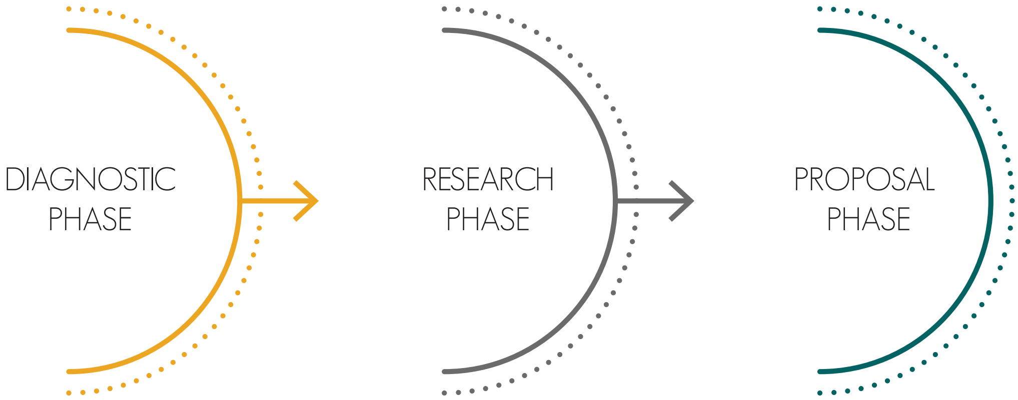
The software is easy to use, with a user-friendly interface that allows users to input their design parameters and receive accurate calculations on the structural performance of their wood-based elements. Calculatis can be used to calculate the strength, stiffness, and stability of beams, columns, walls, and other structural elements made from wood-based products.

Calculatis takes into account a wide range of factors when performing its calculations, including the mechanical properties of the wood-based products, the loading conditions, and the geometry of the structural elements. The software can also be used to analyze complex structures, such as multi-story buildings, and to optimize designs for maximum performance and efficiency.

It is a valuable tool for anyone involved in the design and engineering of sustainable buildings made from wood-based products. The software is part of Stora Enso's suite of digital tools that support sustainable building practices, and is an example of the company's commitment to innovation and sustainability in the construction industry.

3.3
RESEARCH STRUCTURE AND PHASES

This section describes the nature, structure, and phasing of the research project, while explaining the processes and the design made to obtain the final results. The following explains the three main phases in the metodological process.



3.3.1. DIAGNOSTIC PHASE

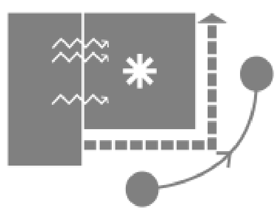
The diagnostic phase of the research will examine the current physical, social, and legal conditions of the project's environment, analyzing the factors that contribute to its challenges and opportunities. It will also review past research and plans for development in the area to gain a broader understanding of the initial conditions and the potential impact of the research on the surrounding region. The objective is to comprehend the starting point and the wider consequences of the research. After conducting an extensive bibliographical research, the diagnosis will be made to determine the present condition of the project site, as well as to examine the previous studies and proposals that have been officially sponsored for the area.

3.3.2. RESEARCH PHASE

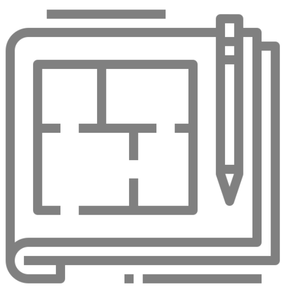
In Chapter 2, a second research phase was introduced. This phase involves examining and exploring various frameworks related to the housing situation, including the Contextual, theoretical, and Conceptual frameworks. Additionally, the concept of prefabricated architecture and micro-homes are also investigated. The main goal of this phase is to identify the key concepts, principles, and ideas that can be utilized in the upcoming project development. By highlighting these important aspects, we ensured that wehave a solid foundation to build upon as we move forward with the project.

3.3.3. PROPOSAL PHASE

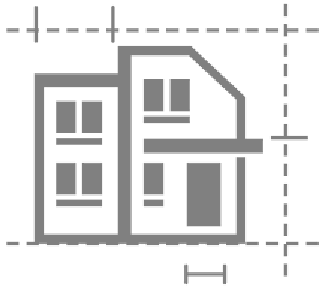
This phase proposal focuses on creating a design that is based on the findings from the earlier stages. This proposal is created in three different steps:



The inital phase will the site analysis. Begining with the climatic analysis of the chosen location followed by the site analysis. The analysis will cover the location's current state and its connection with the surranding area in addtion to aanalyzingits pros and cons through a deep analysis of the area and the availability of services such as public transportation stops.



Then next willl be the designing of the 3D volumetric modules. With defining the purpose and requirements of the building. This includes understanding the intended use of the building (in this case the use of the building will be for residental), the number of people who will use it, and the specific features required.



After that the design of the building that is formed from the designed 3D volumetric modules will be proposed. It will be accompanied by the definition of the proposed structure. This includes the number of floors, rooms, and daylight analysis, energy analysis, and any other features required.

3.4
QUALITATIVE ANALYSIS

This section of the report focuses on the methodology used to describe the functions and material selections of the proposed prefabricated modular housing. After analyzing the principles of prefabricated modular housing and microhousing, as well as the housing typologies and household situations in Milan, we developed a proposal for various analysis based on functional aspects and alternative options.

To develop this proposal, we conducted a study of the household needs in relation to the Milan housing situation and the real needs of the population excluded from the market. We also considered additional functions to offer to the project, taking into account the users and their activities. Additionally, we emphasized the importance of multifunctional spaces in microhousing and the use of flexible furniture.

Furthermore, we proposed a study of a flexibility matrix for the housing modules, enabling them to be placed in different configurations according to context, constraints, use, and other limitations and situations. After analyzing the functions, we conducted optioneering regarding the building's configuration, which resulted in the final proposal aligned with the project's main goals.

Regarding material selection criteria, we divided the analysis into the module and the building. For the module, we created a comparison table between the three most common materials for modular buildings: precast concrete, steel, and CLT units made from wood. We also conducted a structural analysis of the building and studied the different structural strategies for assembling the modules, resulting in a structural proposal for the building. Finally, we analyzed the façade as an external element, which connects with the analytical part of the project.

3.4.1. FUNCTIONS STUDY

For this stage, we follow different steps to generate the proposal, studying all the different components related to developing a project that can generate different alternatives. As a result, we generate a proposal that can showcase different solutions in the functional aspect.

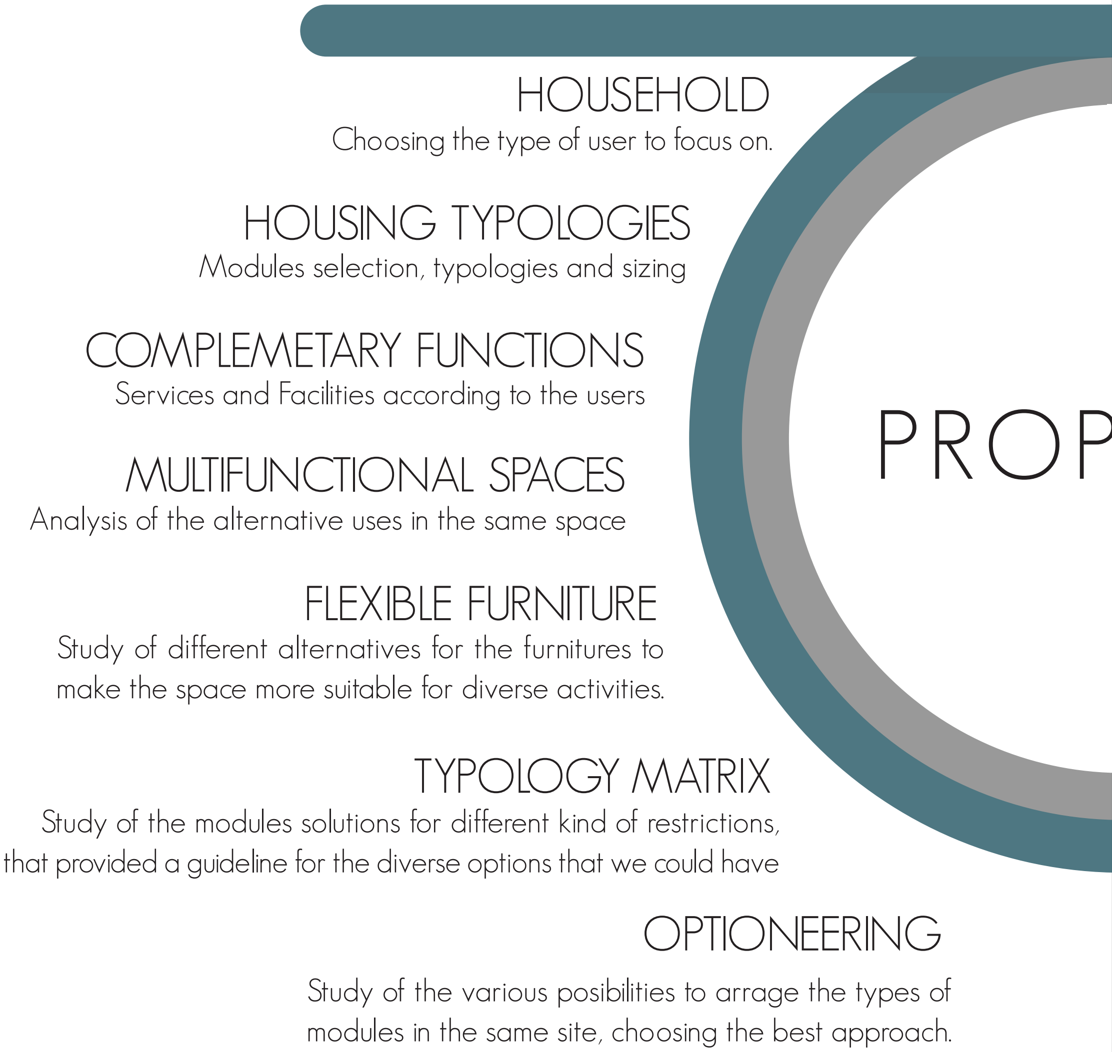


Fig. 72. Function study and Material selection

Identify the most suitable material for the facades, considering both the finishing and shading devices. The aim to determine the optimal material that will not only enhance the aesthetics of the building but also improve energy efficiency and user comfort.

FACADE DEVELOPMENT

Determine the optimal structural approach for installing the modules within the building, while considering the various alternatives available. By carefully selecting the most suitable material for the primary structure.

BUILDING MAIN STRUCTURE

OSAL

Analysis of the three main materials, Precast concrete, steel, and timber commonly used in the modular housing industry, comparing their respective advantages and disadvantages across different categories.

MODULES STRUCTURE

To complement the funtional aspect , we also connect the study for the material connected with the following stages and studies.

In this section, we will discuss the technical aspects that need to be connected with the analytical section of the project. This stage will provide us with guidelines for material selection criteria and help us identify the best solution according to the project requirements.

3.4.2. MATERIAL SELECTION

3.5

ANALYTICAL METHODS AND TOOLS

METHODOLOGY

01

PRE-DESIGN

Autodesk Revit
Stadistical studies.
Microsoft Excel

DIMENSIONING

MODULES
- Functions standards
- Structure

BUILDING
- Distribution
- Structure

02

DAYLIGHT ANALYSIS

Autodesk Insight

Climate Studio

NATURAL LIGHT

TRANSPARENT
- Size
- Glazing type

SDA & ASE
- Glare

DAYLIGHT FACTOR
- Amount of daylight

SHADING
- Size & orientation

03

Climate studio
UBAKUS

During the development of the chosen building unit's components, in addition to adhering to the necessary legal and technical requirements, a Performance Based Design methodology was employed. This involved utilizing specific analysis and indicators to forecast and compare the behavior of the components under anticipated situations, and evaluating their respective impact on the overall performance of the building. These informed decisions played a critical role in shaping the direction and ultimate outcome of the project proposal.

A variety of tools and techniques were utilized to carry out building performance analysis, which are described in further detail below.

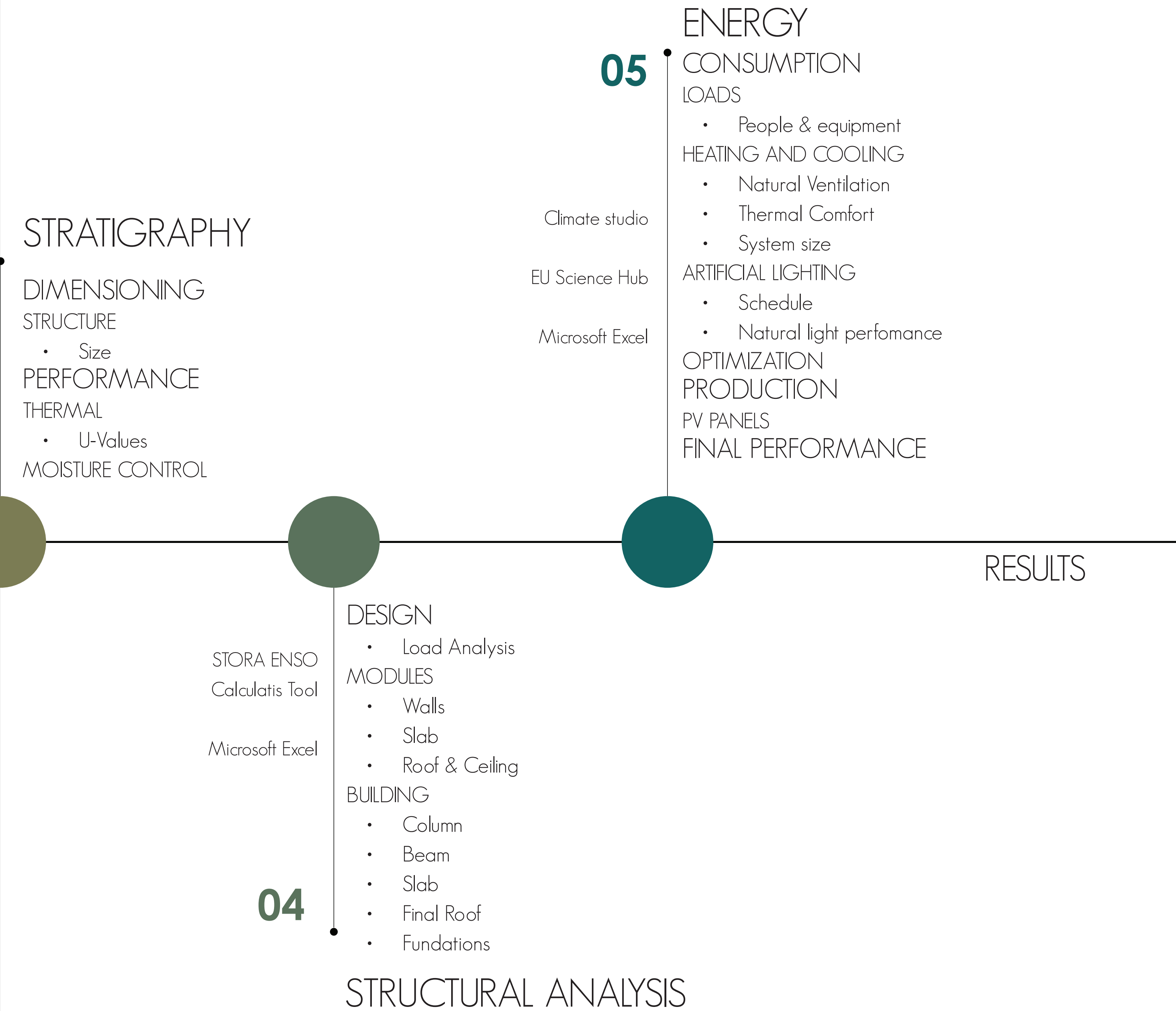


Fig. 73. Analytical methods and tools

4

ARCHITECTURAL DESIGN

The architectural design chapter is an essential component of any building project, as it encompasses a variety of factors that must be considered in order to create a successful design that meets the needs of its users. This chapter aims to provide an introduction to some of the key considerations involved in architectural design, including targeted users, typologies, functions, interior design strategies, modules, site analysis, adaptability and flexibility in the design and use, climate analysis, and optioneering by function.

One of the most important considerations in architectural design is the targeted users of the building. This can include a wide range of people, and understanding the needs and preferences of these users is critical to creating a design that meets their requirements and provides them with a comfortable and enjoyable experience. Another important factor to consider is the typology and function of the building. This can include commercial, residential, educational, healthcare, or cultural buildings, among others. Each of these typologies has unique requirements and considerations that must be taken into account in the design process.

Interior design strategies also play a significant role in architectural design. This can include the use of lighting, color, and materials to create a comfortable and functional interior environment, resulting in the design of each type of module.

After this, we analyze the different alternatives related to use and design that the modules can adapt and be installed, giving the result of a typology matrix that describes the different kinds of possible solutions that we can have.

Furthermore, we continue site analysis, as it is another critical component of architectural design. This involves analyzing the site where the building will be constructed, including factors such as topography, orientation, and access. This information is used to create a design that maximizes the site's potential while minimizing any potential challenges. Climate analysis is another important consideration in architectural design. This involves analyzing the local climate and designing a building that is able to maintain comfortable interior temperatures and minimize energy consumption.

Finally, optioneering by function involves considering a range of design options and selecting the one that best meets the specific needs and requirements of the building's users and functions.

4.1

DATA PRESENTATION AND ANALYSIS

4.1.1. KEY THEORETICAL INSIGHTS

The key theoretical insights obtained through an in-depth analysis of relevant literature on the topic serves as the foundation for understanding and providing a comprehensive overview of the key concepts, models, and theories. By synthesizing and interpreting the existing theoretical perspectives, a deeper understanding and identifying the key theoretical understanding that will guide the design process. The following diagram outlines the main findings of the literature review analysis and highlights the important aspects for the design.

A- CONTEXTUAL FRAMEWORK
Understanding the housing situation, studiying of the houisng market Identifying the possible households.

B- THEORETICAL FRAMEWORK
Analysing the principles of modular prefabrication as a constructive system.

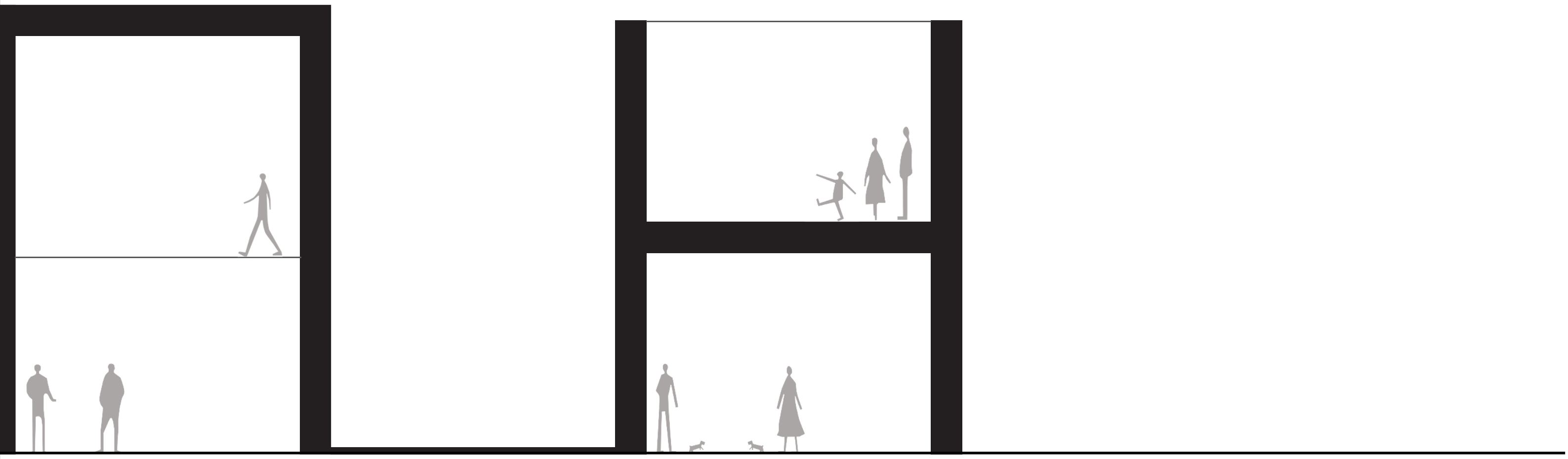
C- CONCEPTUAL FRAMEWORK.
Interpret the housing typologies, composition and the concept of Microhome.

D- CASE STUDIES
Comparing the different projects perspective reagarding the modular housing alternatives.

Fig. 74. Literature Review conclusions.

ADAPTABLE MODULA

Fig. 75. Proposal framework logo.



AR MICRO-HOUSING

4.1.2. TARGETED USERS' DEFINITION

The Modular units we are proposing are versatile and practical. Essentially, they can be combined to create larger living spaces, making them an ideal solution for urban environments where space is at a premium. One of the key advantages is that they can be customized to suit the needs of individual residents, whether they are living alone, as a couple, as a family, or as part of a shared apartment. In this way, modular units offer a level of flexibility that traditional housing designs simply cannot match. It will be shown why and how the modular units were designed to cater to different living arrangements and how they can provide a viable housing option for a wide range of people.

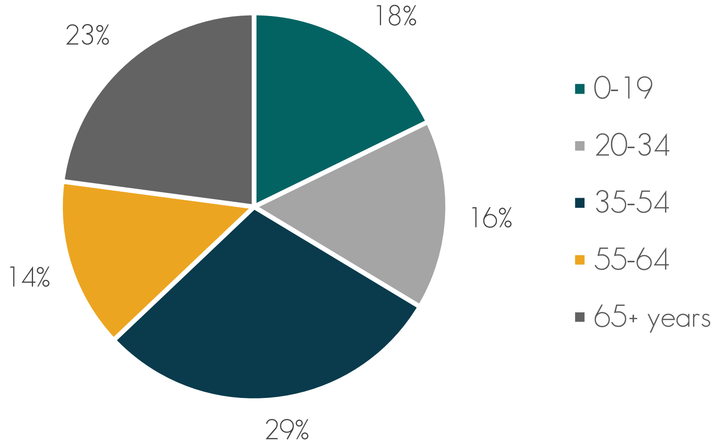


Fig. 76. Pie chart population of Milan by age group. Data Source: http://dati.istat.it/Index.aspx?QueryId=42869&lang=en

The pie chart represents the population of Milan, divided into different age groups. The data shows that the largest age group in Milan is between 35 and 54 years old, which makes up 29% of the population. The second-largest age group is 65 years old and over, with a percentage of 23%. The third-largest age group is between 55 and 64 years old, which accounts for 14% of the population.

The fourth largest age group is the 0 to 19-year-olds, which represents 18% of the population. Finally, the fifth largest age group is between 20 and 34 years old, making up 16% of the population.

Overall, the data shows that the population of Milan is relatively evenly distributed across the age groups, with no one group dominating the chart. The largest group, those between 35 and 54 years old, make-up less than a third of the population. The percentages of the other age groups are all within ten percentage points of each other, indicating a diverse age range in Milan.

After the analysis of the statistics of the population and the anaylsis about the youth excluded from the housing market explained in the Chapter 2, we can conclude that, the modular units design will targert users from the age groups of 20-34, 35-54. (At the same time it is needed to take into consideration that the current fertility rate for Italy in 2023 is 1.296 births per woman). As a conclusion these age gorups include Single person household, Cohabitating Partners, Roommates, Single parent family, Nuclear Family. Arranging them in the following groups:

STUDENTS YOUNG WORKERS YOUNG COUPLES SMALL FAMILIES.

4.1.3. DEFINING HOUSING TYPOLOGY

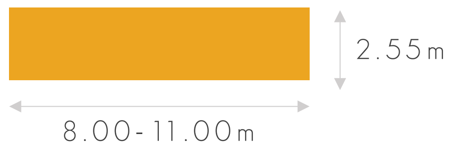
According to the analysis carried out by PwC using data from the Italian IRS, it was revealed that in 2016, the NNT (Number of Normalized Transactions) for real estate in Milan was highest for the sale of apartments that fell within the small to medium range, taking into account the typical area for each category. Specifically, studio apartments with an area of up to 45 sqm, small apartments between 45 and 60 sqm, small-to-medium apartments between 60 and 90 sqm, medium-sized apartments between 90 and 120 sqm, and large apartments measuring 120 sqm and above.

The case study projects have the same conceptual idea of modular microhousing, Carmel Place in New York (approx. 37sqm by unit) and the 10 Degrees in London (38.5- 100.5 sqm. main module 50sqm), which offer different options of housing typologies. In the following table, we compare the typical housing sizes in New York (a megacity like Milan) and the standardized Microhousing size in Europe given in the conceptual framework. It is evident that there are different types, ranging from studio tiny, small and medium units, to large houses.

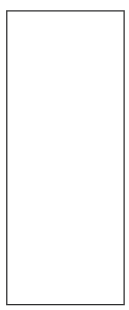
TYPE	# PEOPLE	# ROOM	MILAN STATISTICS (m2)	NY (m2)	EUROPE (m2)
STUDIO TINY	1-2	0-1	0	0	25
STUDIO	1-2	0-1	45	37.16	
SMALL	2	1	45-60	53.42	25-60
SMALL MEDIUM	3	2	60-90	72	
LARGE	4-	3	120-	88.26	60-

Table. 01. Comparison sizes dependinf of housing typology

At the same time, it was necessary to take into consideration the standards of transportation in Italy to give us a guideline of the module size that can be transported, thus establishing the size of the module. The illustration below summarizes the constructive module sizes that were used to configure the housing units.

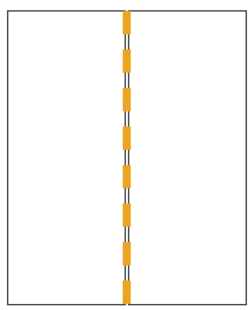


After considering the aforementioned aspects, the configuration of the modules was done in three housing types: studio, small-medium apartments, and large apartments that can be adapted to the different users' needs. These groups can be summarized in the following way:



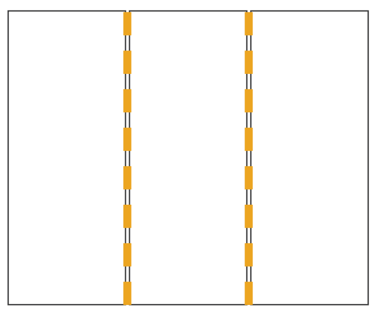
STUDIO FLAT
0-1 Rooms

20-25 sqm
1-2 people



SMALL-MEDIUM APT.
1-2 Rooms

40-55 sqm
1-3 people



LARGE APTARMENT
3-4 Rooms

55-80 sqm
3-5 people

4.2
DESIGN STRATEGIES BREAK DOWN

4.2.1. MODULE CONSTRUCTION

To begin developing design strategies, it is essential to have a clear understanding of the primary materials used in the modular construction modules. Through extensive research and analysis presented in Chapter 2, we have identified that the most prevalent materials in prefabricated modular constructions are Concrete, Timber, and Steel frame modules. Regarding concrete, our research has focused on Precast concrete, while for timber, we have examined the main companies and how they manufacture their units, with particular emphasis on the use of Cross Laminated Timber (CLT). Each of these three materials has its own unique advantages and disadvantages that must be taken into consideration during the construction and design process.

To facilitate a comprehensive comparison of these materials based on factors such as sustainability, initial cost, labor, common use, flexibility, structural advantages, environmental impact, and acoustics, we have created a table that describes each aspect for each material. This comparison will serve as a valuable tool for designing and constructing modular buildings.

	Precast concrete	Timber CLT	Steel
Initial Costs	Initial investment is expectedly higher based on the heavy machinery and skilled labor required.	High versatility, and the speed of realization allow to reduce the construction costs. It minimizes the wastage and offers better recyclability post life cycle.	Compared to traditional construction methods, steel frame modules may have a higher initial cost, but they can provide a cost-effective solution
Cost-Effective	Its fire- and damage-resistant properties make concrete more cost-efficient overall.	The extreme versatility, the lightness in the handling phase compared to traditional materials and the speed of realization allow to reduce the construction costs	Offsite construction can only be more cost efficient than on-site construction if the quantities of prefab components and modules is large. Over the long term due to their durability, ease of assembly, and potential for reuse, resulting in reduced maintenance costs and a lower total cost of ownership.
Efficiency	The use of precast concrete prefabricated modules can significantly increase efficiency in construction projects by reducing on-site labor and construction time.	The use of CLT in construction can also increase efficiency by reducing construction time and waste while providing a sustainable and cost-effective alternative to traditional building materials.	The rise of 3D modeling technology guarantees steel frames will be built precisely to a building's specifications, which reduces the risk of error. This technology also ensures fast product construction and completion.
Reduced Labor	The use of precast concrete prefabricated modules can lead to reduced labor requirements on construction sites since most of the manufacturing and assembly is done off-site in a controlled environment.	CLT can reduce labor requirements on construction sites since the panels are prefabricated off-site to precise specifications, reducing the need for on-site cutting and shaping of building materials.	Off-site steel construction minimizes the need for on-site labor as compared to cast-in-place concrete. Lowered labor reduces on-site risk and noise disruption to the surrounding community.
Sustainability	The use of precast concrete prefabricated modules can contribute to sustainability in construction by reducing waste, improving energy efficiency, and utilizing recycled materials in the manufacturing process.	CLT Panels are ecologically sustainable as the manufacturing process optimally uses the raw material significantly reducing the waste generated. . It minimizes the wastage and offers better recyclability post life cycle.	The use of steel frame modules in construction can also contribute to sustainability by reducing waste and allowing for efficient material usage, while providing a durable and adaptable building solution that can be disassembled,recycled, and reused in different configurations.
Durability	Precast concrete prefabricated modules can offer exceptional durability, as they are engineered to withstand extreme weather conditions, seismic activity, and fire, resulting in a building that can last for many years with minimal maintenance.	CLT is a highly durable building material that can offer similar or better structural performance than traditional construction materials such as concrete and steel, With proper design and maintenance, CLT buildings can have a long lifespan and be resilient to various environmental factors.	Provide exceptional durability due to the strength and resilience of steel, which can resist damage from severe weather conditions, fire, and pests. In addition, steel is a highly robust and low-maintenance material that can last for many years without degradation, making it a popular choice for construction projects that require long-term durability.
Versatility	Offer great versatility in construction since they can be designed and manufactured to meet specific project requirements and can be easily assembled on-site, allowing for faster project completion and adaptation to changing needs.	Depending on the level of prefabrication required in the project, CLT can be used to manufacture a wall, roof, stair, floor panels or even complete modules that can be delivered to the construction site. Compact, easy to transport and highly efficient handling makes delivery to large distances possible.	Felixible to changes during the contruction process, Maximaze the floor area of the bulding, New connections can be easily introduced in the structure. And, Supports adaptive re-use or change in functions/ layout over time.
Insulation	Offer and excellent insulation properties due to the use of high-density concrete and insulation layers.	CLT buildings offer a naturally high thermal insulation as they are made with excellent natural insulating wood, that means t offers strong thermal performance.	While steel structures are not inherently well-insulated, their insulation performance can be greatly improved through the addition of insulation layers, which can be incorporated into the building design to provide effective thermal insulation and reduce energy consumption.
Environmental Impact	it can have a lower environmental impact compared to traditional construction methods due to reduced waste, However, it is important to consider the environmental impact of the manufacturing process Additionally, the sourcing of materials used in precast concrete modules, such as cement, can have environmental implications due to carbon emissions associated with its production.	It has a lower environmental impact compared to traditional construction methods and other building materials, such as concrete or steel, due to its renewable and sustainable nature. The manufacturing process for CLT also requires less energy and produces fewer greenhouse gas emissions compared to the production of concrete or steel.	It can vary depending on the sourcing of materials and the manufacturing process. While steel is a highly recyclable material, the production of steel can result in significant greenhouse gas emissions and energy consumption. However, the use of recycled steel in the manufacturing of steel frame modules can significantly reduce the environmental impact of the building material.

	Precast concrete	Timber CLT	Steel
Safety	Provides increased safety for construction workers and building occupants due to their off-site manufacturing process, which reduces the potential for accidents and injuries on the construction site. Additionally, the use of precast concrete modules can provide enhanced fire resistance and structural stability, resulting in a safer building solution.	Wood as a building material is naturally anti-seismic and fire resistant, which allows it to maintain structural integrity even during fires. the manufacturing process of CLT can be conducted off-site, which can improve worker safety by reducing potential hazards associated with on-site construction	It is consider safe due to their durability, strength, and resistance to fire and other hazards. Additionally, steel frame modules may require additional fire protection measures to maintain safety, particularly in high-rise buildings or other structures where fire risk is increased.
Time-Taking	The off-site manufacturing process of precast concrete prefabricated modules can take time for planning, design, and production, but it can ultimately lead to faster on-site assembly and construction, reducing the overall time taken for a building project.	The manufacturing process for CLT can be relatively quick compared to traditional construction methods, as the material is prefabricated off-site and can be rapidly assembled on-site. However, the overall time taken for a CLT building project will depend on various factors such as design complexity, building size, and project scheduling.	The time taken for a steel frame building project can vary depending on the size, design complexity, and other factors such as transportation and assembly on-site. The availability of materials and fabrication facilities can also impact the project timeline, Morover, the assembling work is a lot faster as compared to other materials on/off site.
Acoustics	Precast concrete prefabricated modules typically have good acoustic properties due to the dense nature of the material, which can help to reduce sound transmission and provide a quieter indoor environment.	Cross-laminated timber (CLT) also has good acoustic properties due to its mass and stiffness, which can help to reduce sound transmission and improve indoor acoustics. Additionally, the use of wood as a building material can contribute to a pleasant and natural acoustic environment.	Steel frame modules may require additional measures to achieve good acoustic performance, such as adding insulation and sound-absorbing materials to reduce sound transmission. However, steel frame structures can also provide some benefits for acoustic performance due to their stiffness and vibration resistance.
Height limit	Typically ranges from two to ten stories.	Typically around ten stories, although this can vary based on various factors.	Typically ranging from several stories to dozens of stories
Common modular use	Precast concrete is a common material in prefabricated modular housing, as it is durable, fire-resistant, and energy-efficient. It is also highly customizable and can be molded into a variety of shapes and sizes.	CLT is gaining popularity in modular housing construction, especially in regions with abundant wood resources.	The most common material used in prefabricated modular housing varies by region and market, but in general, it is either steel.
Transportability	It can be transported by road and crane, but their weight and size may require special permits and equipment.	CLT panels and elements are comparitively light in weight which increases efficiency in transport and handling. The modular components can be designed and manufactured according to sizes of vehicles available for transport.	A large number of transportation vehicles are required to deliver the prefab components or modules. - They are typically lightweight and designed for easy transportation by truck, train, or even plane, allowing for rapid deployment to remote or hard-to-reach sites.
Maintenance	Precast concrete prefabricated modules require minimal maintenance due to their durability and resistance to weathering and erosion.	It is a low-maintenance material due to its dimensional stability, resistance to moisture, and ability to self-heal small cracks or dents. But needs maintenance and repair costs during the life cycle.	Mantainace againsts fire and corrosion. Easy to Repair. Usage of weathering and corrosion resistant steel is required if the structure is to have extensive exposure to natural elements like saline air and water.
Structural performance	High structural performance, with the ability to withstand extreme weather events and provide excellent resistance to fire and other hazards.	Good structural performance due to its high strength and stiffness. It can also withstand seismic activity and has been shown to perform well in fire resistance tests.	Steel frame modules are known for their high structural performance, with the ability to withstand high wind and seismic loads due to their inherent strength and rigidity.
Energy efficiency	Precast concrete prefabricated modules have high thermal mass, which helps to regulate indoor temperature, and when combined with proper insulation, can result in energy-efficient buildings.	CLT is known to have good energy efficiency due to its insulating properties and airtightness, resulting in reduced energy consumption for heating and cooling.	They can be less energy-efficient than other materials due to their high thermal conductivity, which can cause heat loss or gain, but proper insulation can help improve their energy performance.
Flexibility	Precast concrete prefabricated modules offer a high degree of flexibility in terms of design, layout, and integration of building systems.	CLT panels can be manufactured for various purposes such as building roofs, walls or ceilings. It offers flexibility with variable thickness, easy management, material combinations and variable structural and thermal properties, Moreover, offer a high degree of flexibility in design and can be easily customized to fit different project requirements.	Steel frame modules offer high flexibility due to their ability to accommodate changes during the construction process and the ease of introducing new connections, supporting adaptive re-use or change in functions/layout over time.

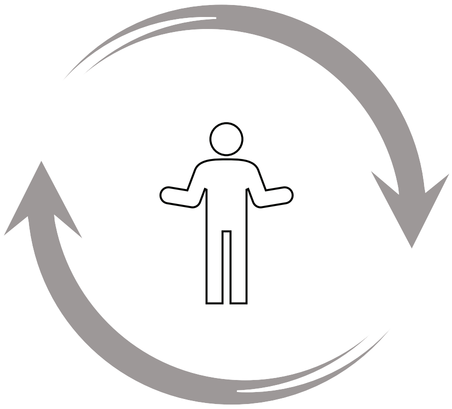
Table. 02. Comparison Primary matterials in prefabricated modular construction.

After the comparison conducted on the 3 main materials used in prefabricated modular construction showed that cross-laminated timber has high advantages.

One of the advantages is its strength and durability. With a high strength-to-weight ratio, it is a strong and durable material, which makes it an ideal choice for use in prefabricated modular housing. Prefabricated modular housing is built off-site in a factory setting and then transported to the site for installation. Its use in prefabricated modular housing can speed up the construction process, as the components can be manufactured and assembled quickly and efficiently. Also, it can be used to create a wide range of building shapes and sizes, making it a versatile material for use in prefabricated modular housing. It can be used to create curved and angled walls, which can add interest and character to a building.

This makes it a popular choice for architects and designers who want to create unique and aesthetically pleasing buildings. While CLT may initially be more expensive than some traditional building materials, its speed of construction and design flexibility can make it a cost-effective option for prefabricated modular housing in the long run. Furthermore, since is a prefabricated material, which means it can be easily transported to and assembled on remote or hard-to-reach sites. This can make it an ideal option for building in areas with limited access or infrastructure, such as rural or remote locations. In addition to its strength, durability, and design flexibility.

4.1.2. COMPLEMENTARY SERVICES AND FACILITIES



Providing complementary services and facilities in buildings can greatly enhance the overall experience of its occupants. These amenities can range from co-working spaces, gyms, study areas, community rooms, game rooms, and many others. Each of these facilities has its unique benefits, and together they can create a sense of community and convenience that enhances the daily lives of those who use them.

- Co-working spaces are becoming increasingly popular as more people work remotely or have flexible work arrangements. These spaces provide a collaborative and productive atmosphere for professionals to work together in a shared space. They often come equipped with high-speed internet, comfortable seating, meeting rooms, and other necessary amenities to help professionals stay productive.
- Gyms are another popular amenity in buildings that offer complementary services. Having a gym in the same building as the home or office can help to maintain an active lifestyle. Gyms in buildings may also offer a variety of classes, personal training, and other health and wellness programs to help keep occupants healthy and active.
- Study areas are another valuable amenity that can be provided in buildings, particularly for students or those who work from home. These spaces can be designed to be quiet and conducive to focused work, with desks, chairs, and power outlets available for use. They may also include resources such as printers, copiers.
- Community rooms are versatile spaces that can be used for a variety of purposes, including meetings, events, and social gatherings. These spaces are often used for social events such as game nights or potluck dinners, helping to build a sense of community among building occupants.
- Finally, game rooms can be a fun and relaxing way to unwind after a long day of work. They may include pool tables, foosball, ping pong, or other games that provide a break from the stress of everyday life. Game rooms can also be a social space, allowing occupants to connect with others in fun and informal setting.

In summary, providing complementary services and facilities in building can greatly enhance the quality of life for its occupants. From co-working spaces to gyms, study areas, community rooms, and game rooms, each of these amenities offers unique benefits that contribute to a sense of community, convenience, and wellbeing. By providing a range of amenities, building owners and managers can create a space that is both functional and enjoyable for those who use it.

4.1.3. INTERIOR DESIGN STRATEGIES

There are potential downsides to living in a small space. For some people, the lack of space can be challenging, and it may be difficult to entertain guests or host large gatherings. Additionally, living in a micro-housing unit can require a certain level of organization and creativity when it comes to storage and furnishings.

Overall, the point of view regarding micro-housing's small space is largely dependent on individual preferences and priorities. While some may see it as a limitation, others see it as an opportunity to simplify their lives and live more sustainably, or to gain access to urban amenities and opportunities that might otherwise be out of reach.

Some of the strategies used for optimizing the interior space of the modules are:

1. The use multifunctional furniture: In a micro house, every inch counts. Using multifunctional furniture such as a sofa bed, modular shelving, folding tables and chairs, or a storage ottoman can help maximize space and serve multiple purposes.
2. Utilization vertical space: Wall-mounted shelves, cabinets, and hanging organizers can help make use of vertical space and free up floor space.
3. Creating a sense of openness: Using light colors, mirrors, and open shelving can help create the illusion of more space and make the interior feel more open and airier.
4. Optimizing storage: Maximizing storage is key in a micro house. Built-in storage, or built-in shelving, can help make the most of every nook and cranny.
5. Choosing furniture and decor wisely: In a micro house, it's important to carefully consider every piece of furniture and decor. Choosing items that are appropriately scaled and serve a specific purpose can help prevent clutter and maximize space.
6. Incorporating natural light: Maximizing natural light can help create a sense of spaciousness in a micro house. Using large windows, or light-colored curtains to let in as much natural light as possible.

By incorporating these strategies, it's possible to create a comfortable and functional micro house with a surprisingly spacious feel.

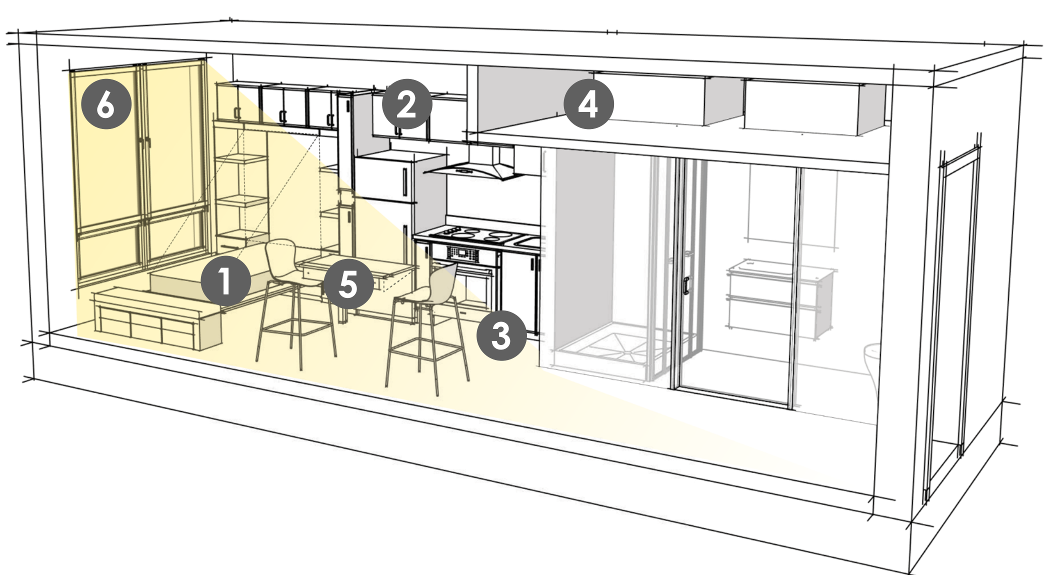


Fig. 77. Interior design strategies for the propused module.

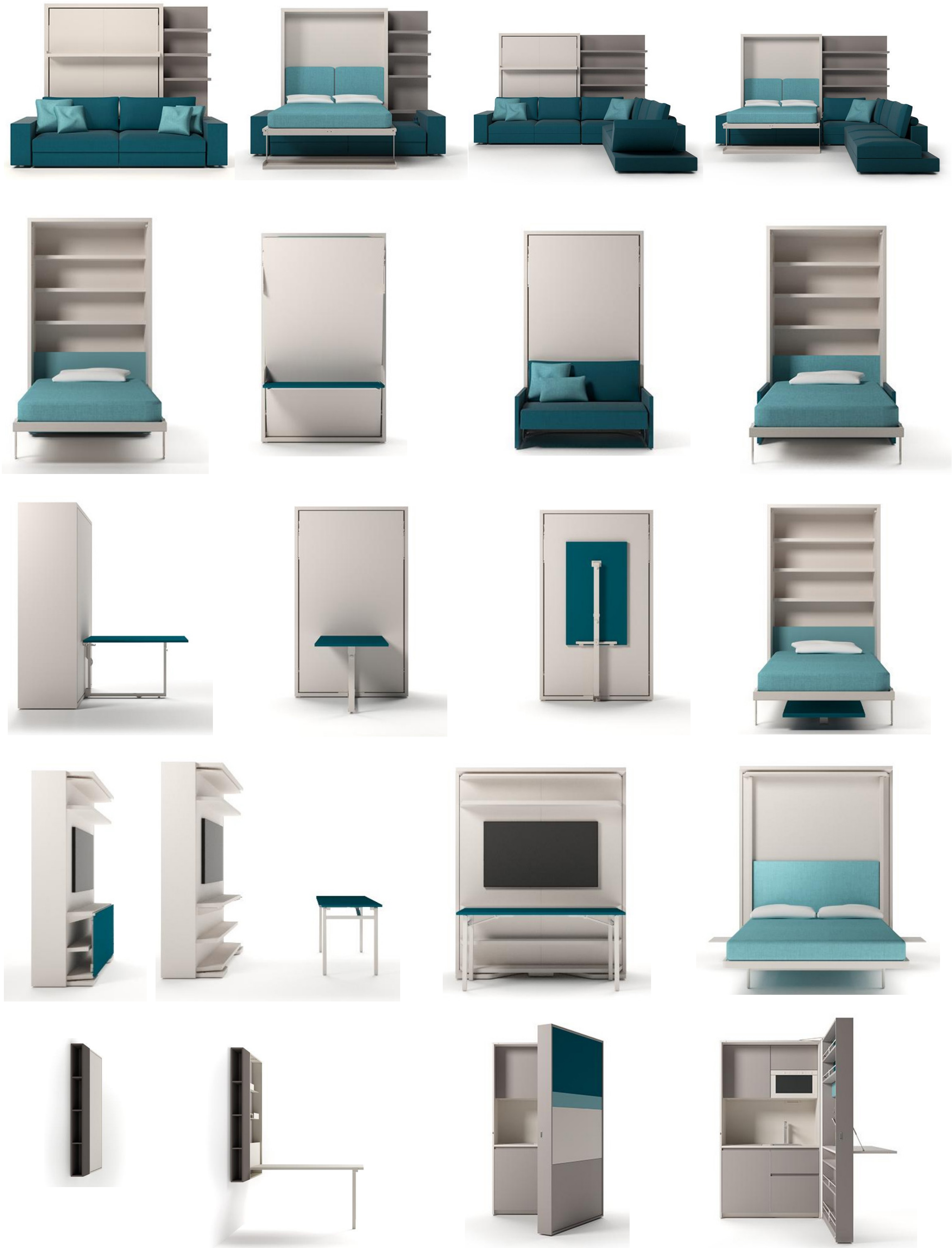


Fig. 78. Different dynamic and flexible furniture, for living room, studio kitchen. Source: https://www.clei.it/en/transforming-furniture

4.3

DETAILED DESIGN OF THE MODULES

Following an analysis of data on various households and housing types, we determined the required area based on the needs of different users. Being the main target audience were young people who were excluded from the market, and we developed three main solutions based on the module size to be designed. We then studied various strategies to maximize space utilization and enhance the experience within the space. Based on this study, we developed six main strategies (A, B, C, D, E, and F) arranged according to different options for small and medium-sized units. We began with an individual unit and multiplied it to create the rest of the hosuing units. All the modules design is adaptable to accommodate different transportation standards depending on the country.

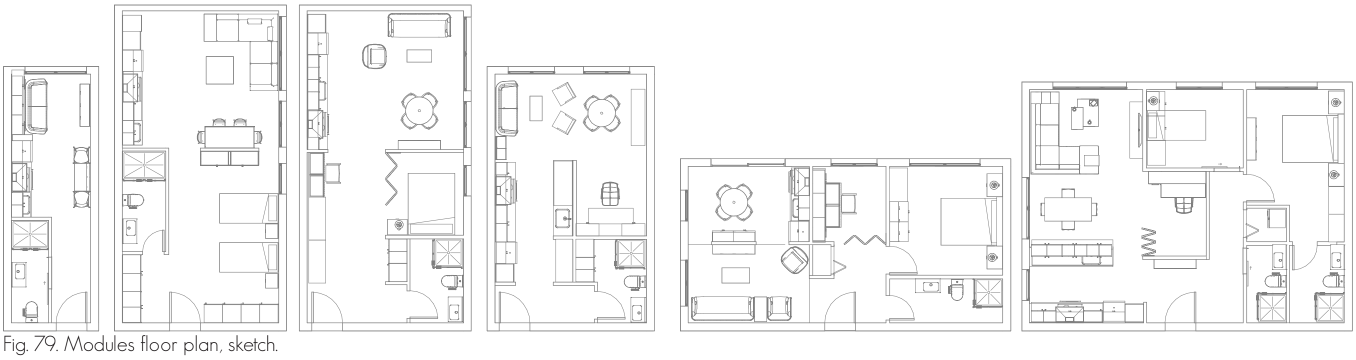


Fig. 79. Modules floor plan, sketch.

4.3.1. MODULE A

The first module was developed with the idea of offering a small studio for individual use, with the microhome concept behind it. This module was the starting point for the development of the following housing modules. First of all, the idea was to have an open space that could be used for different purposes, and to maximize the daylight in the area, a large-sized window was designed. On the other hand, the same space can be used for various functions such as a living room, working area, or sleeping area. These options were made possible for this module through the use of flexible furniture. The vertical space was also exploited to maximize the storage area, in addition to providing storage space on top of the bathroom. The module is designed to have all the equipment and fixtures installed inside. For instance, in countries that have width limitations, this module can be transported in two volumes. The area of this module corresponds to a studio flat with a size of 8.60mx 3.07m (external dimensions), with an internal area of 21sqm.

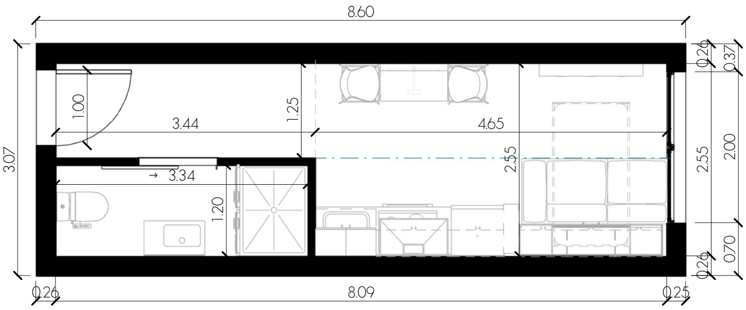


Fig. 80. Floor plan- Module A

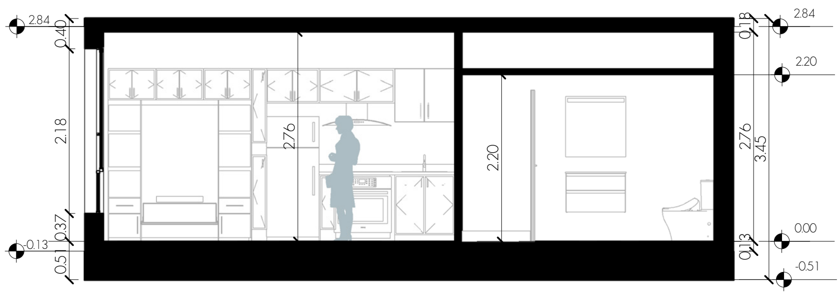


Fig. 81. Detailed section- Module A

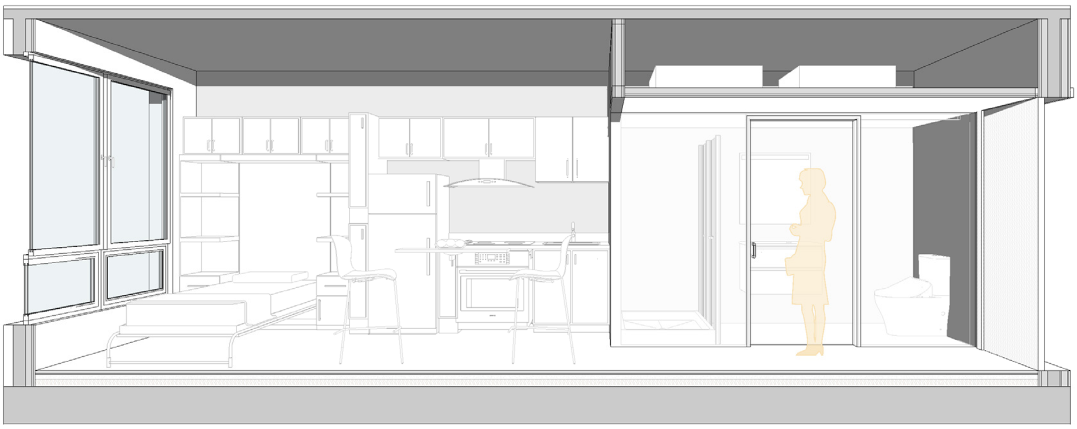


Fig. 82. 3D section- Module A

4.3.2. MODULE B

The module's design is tailored to meet the needs of students or young couples who prefer a separate living and sleeping area, with the added flexibility of creating an extra sleeping space in the living room using curtains. Depending on the occupants, this can be arranged as a double room for two students or two separate rooms for individual privacy. For couples, the space can function as a guest room. These features encourages the shared use of common areas like the dining area, bathroom, kitchen, and storage, while maintaining privacy in the sleeping areas. Also, it offers the same storage space in the bathroom. The size is 10.60 x 5.60, with an internal area of 52sqm.

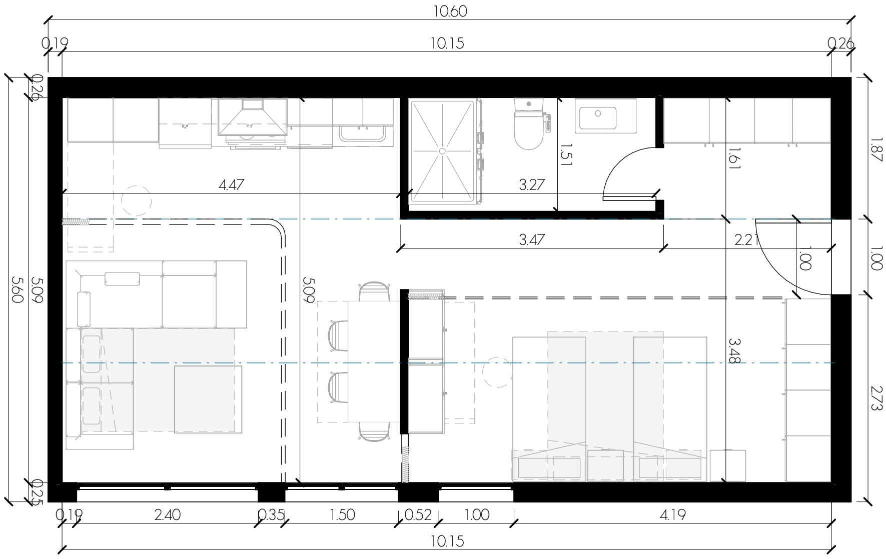


Fig. 83. Floor plan- Module B

Fig. 84. Detailed section- Module B

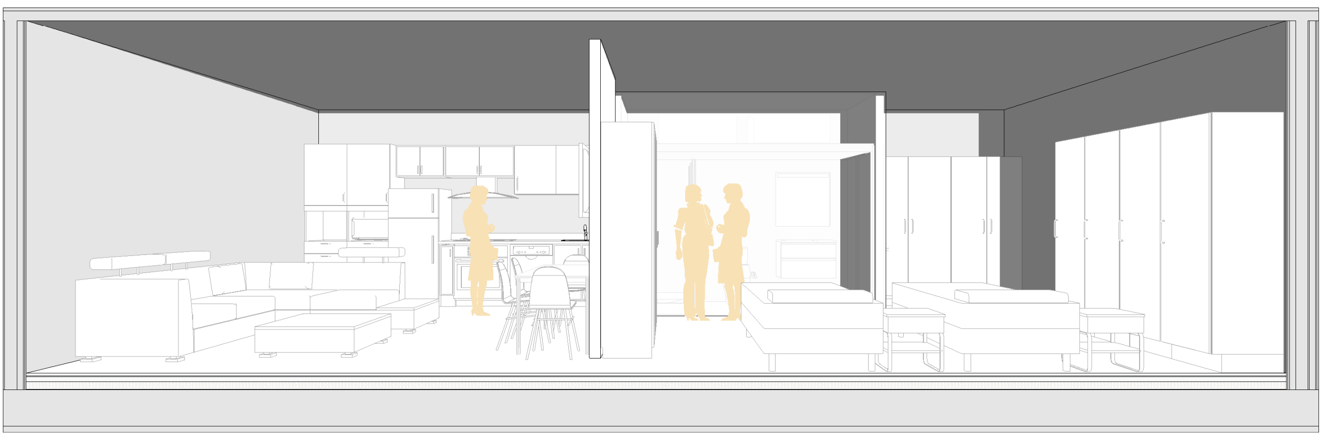


Fig. 85. 3D section- Module B

4.3.3. MODULE C

This module shares the same dimensions and internal area as Module B, and follows the same design principles, but with a different distribution of spaces. It is designed to accommodate a young couple or serve as a cohabitating apartment. The living room area can be closed off to create a separate space as needed, while still allowing access to common areas. Additionally, the separated room can function as a studio with the use of flexible furniture. Notably, this apartment has the particular feature of being able to convert into a large bedroom and a single bedroom.

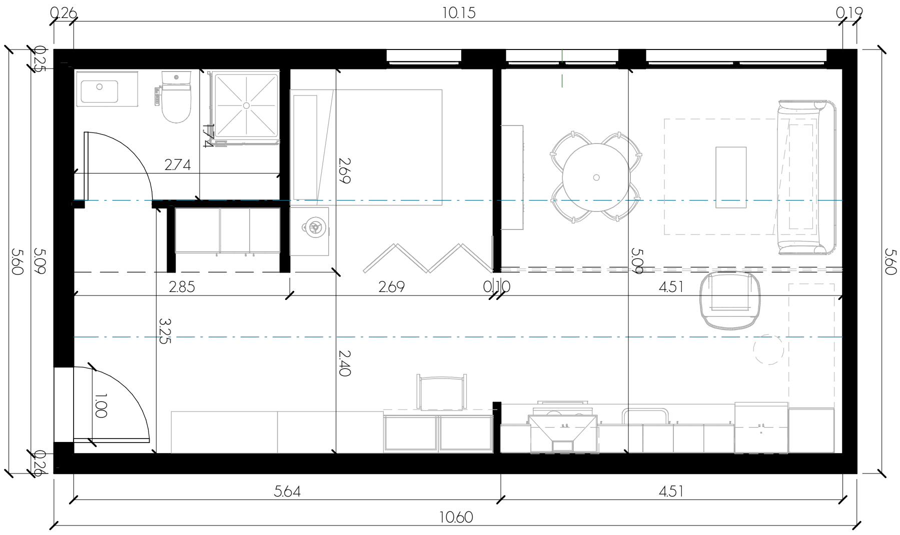


Fig. 86. Floor plan- Module C

Fig. 87. Detailed section- Module C

Fig. 88. 3D section- Module C

4.3.4. MODULE D

This module is designed to function as a studio flat for a couple, and it is twice the size of Module A. It is specifically tailored to meet the needs of this type of household, and it includes a living room, a separate studio that doubles as a bedroom, and a kitchen area that is separated from the living space. One unique feature of this module is that it can be resized to accommodate different preferences, with the option to open or close off the kitchen area.

MODULE D1

It proposed configuration, which includes windows in the front to provide natural light to the kitchen and studio. . Its dimensions are 8.60x5.45, with a total internal area of 40 sqm.

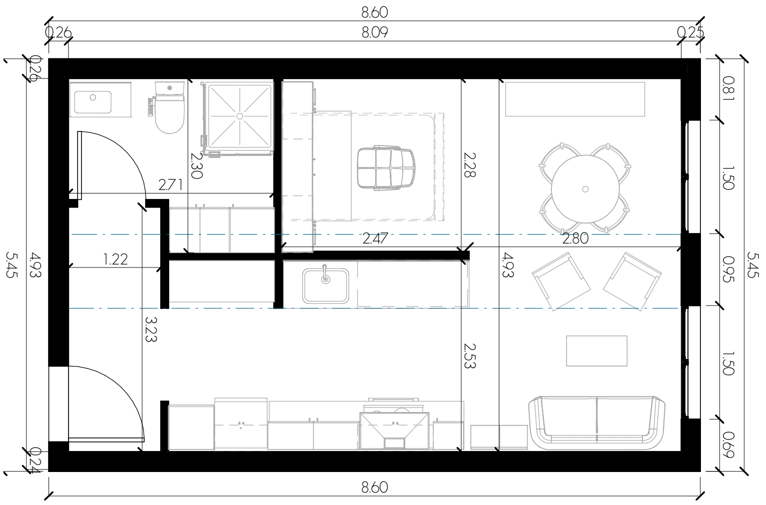


Fig. 89. Floor plan- Module D1

Fig. 90. Detailed section- Module D1

Fig. 91. 3D section- Module D1

MODULE D2

It offers the opportunity for a smaller floor area, with a total internal area of 37 sqm. It is designed to maximize natural light, and it includes a different kitchen configuration. The window openings can be adjusted based on site constraints and user preferences.

This module exemplifies the adaptability and flexibility of the module design, which will be further discussed in the next section. It showcases the versatility that this design can offer, providing options for users to customize their living space according to their specific needs and preferences.

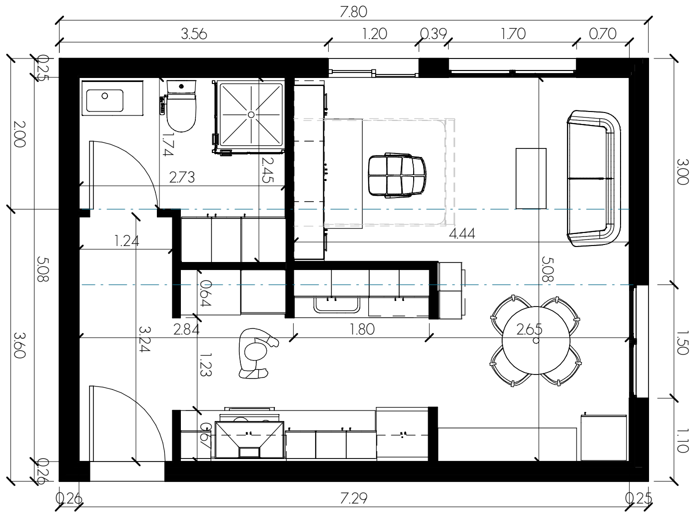


Fig. 92. Floor plan- Module D2

Fig. 93. Detailed section- Module D2

Fig. 94. 3D section- Module D2

4.3.5. MODULE E

This module aligns with the principles and dimensions of modules B and C, promoting co-habitation for 2-3 students. It can also serve as a family unit, with separate bedrooms for the young couple and child. The layout was designed to separate private areas, such as the bedrooms, from common areas. Additionally, this module provides a specific storage space that can also be utilized as a laundry closet.

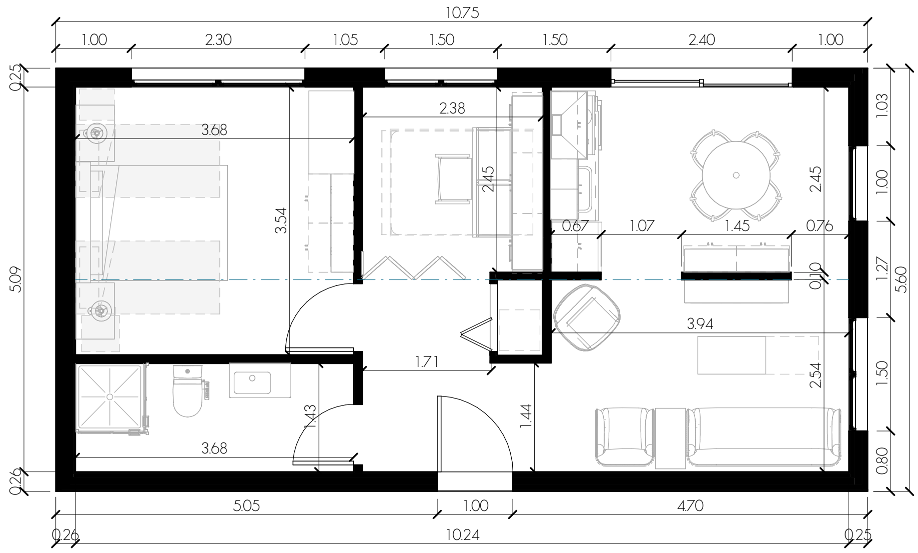


Fig. 95. Floor plan- Module E

Fig. 96. Detailed section- Module E

Fig. 97. 3D section- Module E

4.3.6. MODULE F

This module was designed to function as a family unit, featuring two separate single bedrooms and a studio that can be used as an additional bedroom, separate from the social area. Additionally, it is suitable as a cohabitating house, accommodating students and young workers with a double room and two single rooms, with the studio converted into a living room. There is also a storage area that can be utilized for laundry purposes. The module measures 10.75 x 8.10m, providing an internal area of 78sqm.

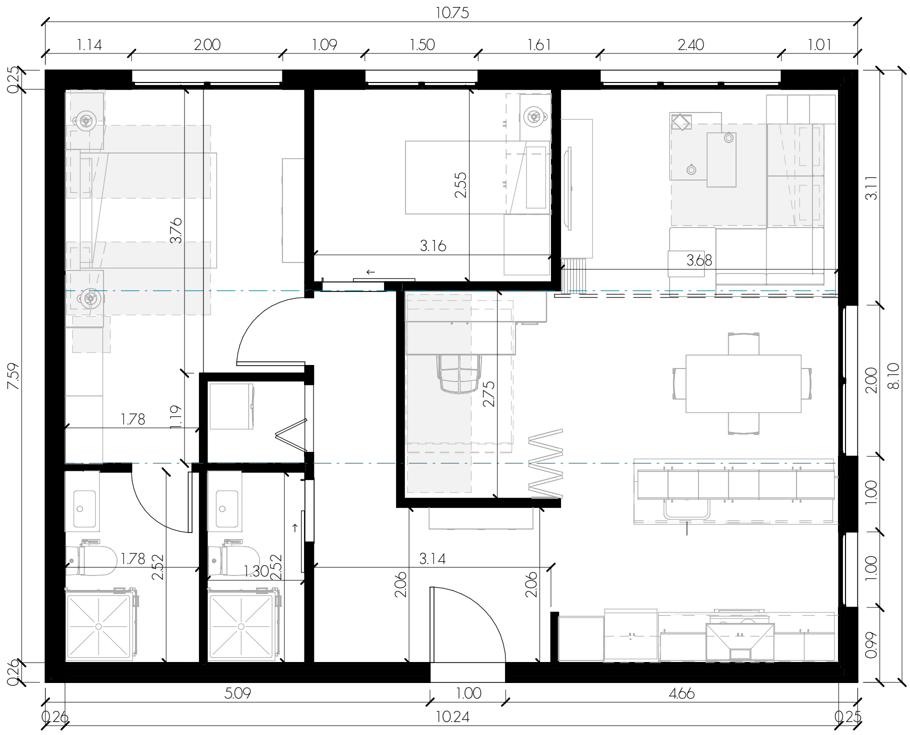


Fig. 98. Floor plan- Module F

Fig. 99. Detailed section- Module F

Fig. 100. 3D section- Module F

4.4
ADAPTABILITY & FLEXIBILITY

After the detailed design of each module, various strategies can be employed to make them adaptable to different situations. This section is divided into two parts. The first part focuses on the adaptability and flexibility of the module's design itself. This includes considering various strategies such as internal space divisions to create extra rooms or adding new openings to accommodate different needs and constraints. The second part involves analyzing how these units can be adaptable to different uses. This includes exploring different options for situating each module, such as as a single unit on a plot or as multiple units forming an entire building.

4.4.1. IN DESIGN

INTERIOR FLEXIBILITY

In the detailed design, it was explained that certain modules possess the capability to accommodate multifunctional spaces by utilizing various types of furniture. Through the use of foldable walls (highlighted in yellow) and thick curtains (indicated in blue) depicted in the following illustrations, we can create two separate spaces. Additionally, by incorporating flexible furniture, we can optimize the utilization of the space and increase its versatility.

Fig. 101. Module C, interior flexibility proposal

Fig. 102. Module C, interior flexibility proposal, curtain division.

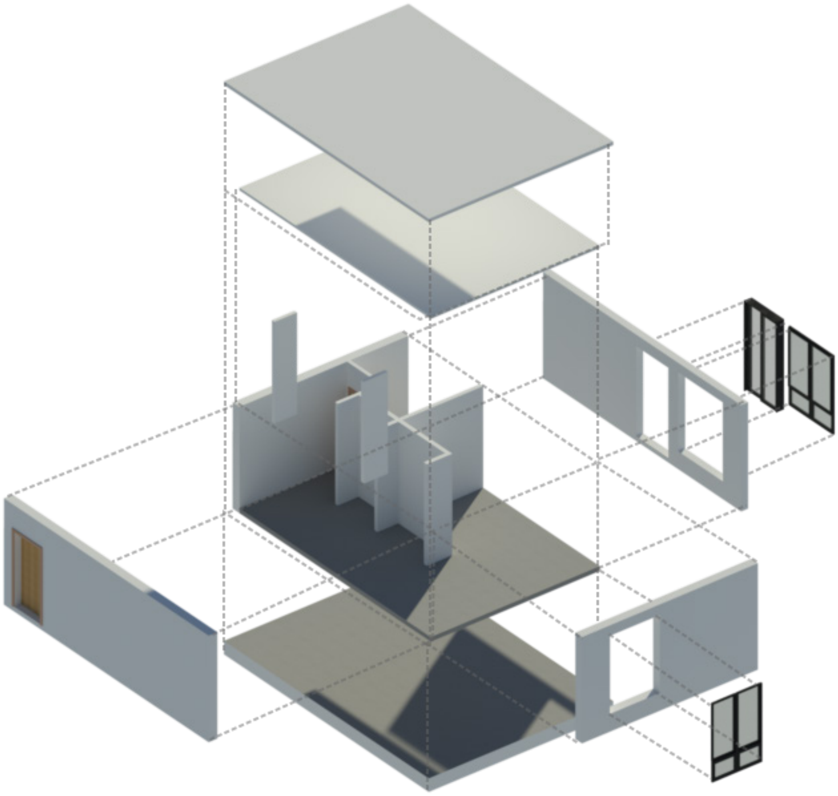


Fig. 103. 3D model shows an exploded view of module D1, with window openings on two sides.

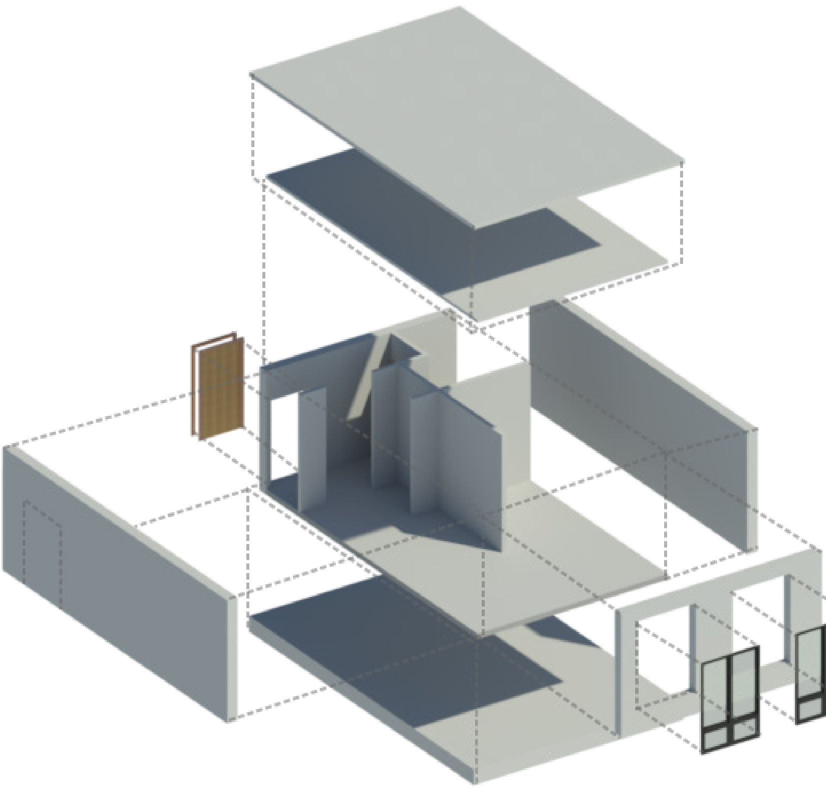


Fig. 104. 3D model shows an exploded view of module D2, with window openings on one sides.

OPENINGS

Depending on the location and context of the module, its design can be adapted accordingly. For example, in situations with obstacles such as trees, buildings, or neighbors, the module's openings can be adjusted to meet specific needs. Two examples of this are D1 and D2, which have the same functional distribution but differ in their window placement. This adaptability allows the module to take advantage of natural light, which is essential for well-lit spaces such as living rooms.

When it comes to entrance doors, the same principles apply. The design should be tailored to accommodate any limitations or restrictions present in the context, such as building access. Additionally, the size of the windows should be determined by the amount of daylight required for the space, which can vary depending on the orientation and placement of the module. If the module has a terrace or balcony, windows may be replaced with doors to provide access to the outside.

Finally, the internal walls can be modified to suit the client's preferences and suggestions, allowing for customization in several aspects. This flexibility enables the module to be adapted to various contexts and meet the specific needs of each client.

Customization is a critical aspect of modular design, as it enables the module to meet the unique needs and preferences of each client. However, the level of customization will depend on the client's budget, timeline, and specific needs

4.4.2. IN USE

The adaptability of modular units is closely related to the type of housing where they can be utilized. These prefabricated units can be used for different purposes, making them a rapid and lightweight solution in emergency housing situations such as socio-political conflicts, wars, and natural disasters like hurricanes or earthquakes. Additionally, these modules can be adapted for student housing, affordable, and social housing options. The finishing materials and interior fixtures can be customized according to the client's budget.

Moreover, the adaptability of these modules extend to their location. As depicted in the following images, they can be used in various settings, ranging from urban areas to remote locations. This flexibility makes modular units an ideal solution for housing projects in diverse environments.

Fig. 105. Different use configurations for the modules.

4.5 TYPOLOGY MATRIX

After gaining an understanding of each module type and its adaptability, the procedure continued with the demonstration of the general rules for aggregating modules in a building. These rules took into account constraints such as functions and height limitations. Using a matrix, we established the different ways that modules can be organized to suit various situations. The following table outlines the different rules related to the possible shape configurations of modules in relation to a standardized shape. It also takes into account horizontal and vertical circulation. Constraints can arise from the context and site locations, which may be restricted by physical aspects such as trees, buildings, and regulations. This means that the building can be configured in different shapes suitable for different limitations. For example, if we have a plot with two constraints where we cannot have openings, the orientation and openings of the module will be affected.

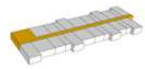
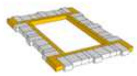
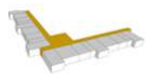
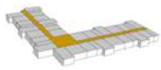
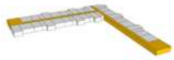
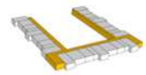
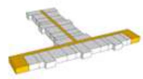
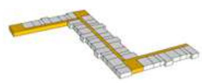
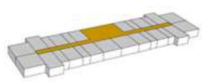
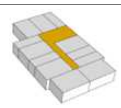
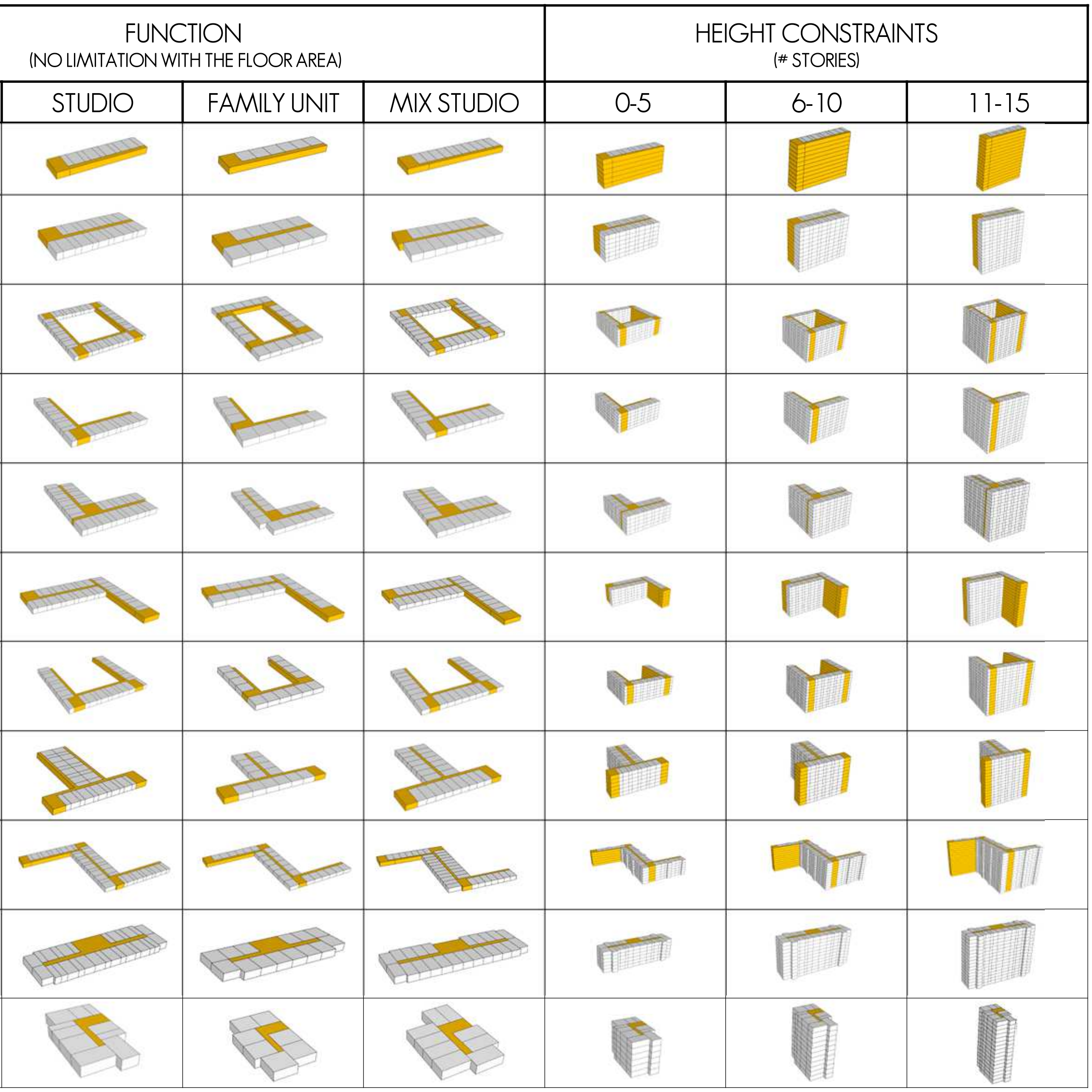
SHAPE	CONTEXT (CONSTRAINTS)				
	0	1	2	3	ALL
LINEAR	✓	✓	✓	✓	
DOUBLE LINEAR	✓	✓	✓	×	
SQUARE	✓	×	×	×	
L SHAPE	✓	✓	✓	×	
DOUBLE L SHAPE	✓	✓	✓	×	
L AND 1/2	✓	✓	✓	×	
U SHAPE	✓	✓	✓	✓	
T SHAPE	✓	×	×	×	
Z SHAPE	✓	×	×	×	
RECTANGULAR	✓	✓	✓	✓	
COMPACT	✓	✓	✓	✓	

Table. 03

The function column explains the configuration of modules for different functions, such as studio, family units, and studio with consideration for all floor plans. It is important to note that this matrix does not consider limitations in floor area. Lastly, height constraints depend on the primary material of the units, as indicated in the comparison table at the beginning of this chapter. The building shape guarantees how the building can be organized and provides a possible solution for vertical circulation, which may require more than one module.

Overall, the matrix and guidelines provided for modular prefabricated micro-housing offer a structured and systematic approach to the design and construction of these types of buildings. It allows for flexibility in adapting to different constraints and functions while still maintaining a cohesive and efficient building design. Additionally, using modular prefabrication techniques can offer cost savings and reduced construction time compared to traditional building methods. However, it is important to note that careful planning and coordination are necessary to ensure the successful execution of these projects.



3. Typology matrix

4.6 SITE SELECTION AND STUDY

In the first and second chapters, it was established that Milan poses unique challenges for housing projects. One of the key challenges was selecting an appropriate site within the city. Milan has a diverse range of morphologies, with the densely populated northeast central area being particularly challenging. This area is characterized by regular morphology and high-density residential buildings. To effectively demonstrate the adaptability aspects of the designed modules aggregation in forming a building, it was preferable to select a restricted site. By doing so, we could showcase how the modules could be adapted to suit the specific needs of the site, while also highlighting the versatility of the design. There are several reasons why using a small project site for a residential building can be justified:

1. Urban Density: Small project sites are often located in urban areas where there is a high demand for housing. Building on a small site allows for denser development and the ability to provide much-needed housing in an area where space is at a premium.
2. Limited Space: If the available space for the construction site is limited, modular buildings are a great solution. They are prefabricated off-site, then assembled on-site, so they require less space for construction than traditional buildings.
3. Sustainable Development: Smaller buildings require less energy to heat and cool, and can be designed to incorporate energy-efficient features and renewable energy sources.
4. Design Flexibility: Small buildings can be designed to be highly customized to the needs and preferences of the owner, and can incorporate innovative design features.
5. Community Integration: Small residential buildings can be integrated into the surrounding community more easily than larger buildings.

The first map demostrates the voids and solids, it is evident that the area of Loreto falls under the "high accessibility" category as defined in Article 8 of the Piano delle Regole/PdR (Plan of Rules of the PGT). For such areas, it is mandatory to achieve a Floor Area Ratio (FAR) of 1 sqm/sqm. In areas with a "compact urban grain," the maximum allowed Floor Area Ratio (FAR) can be greater than 1 sqm/sqm, subject to certain exceptions allowed by the Urban Plan based on morphology.

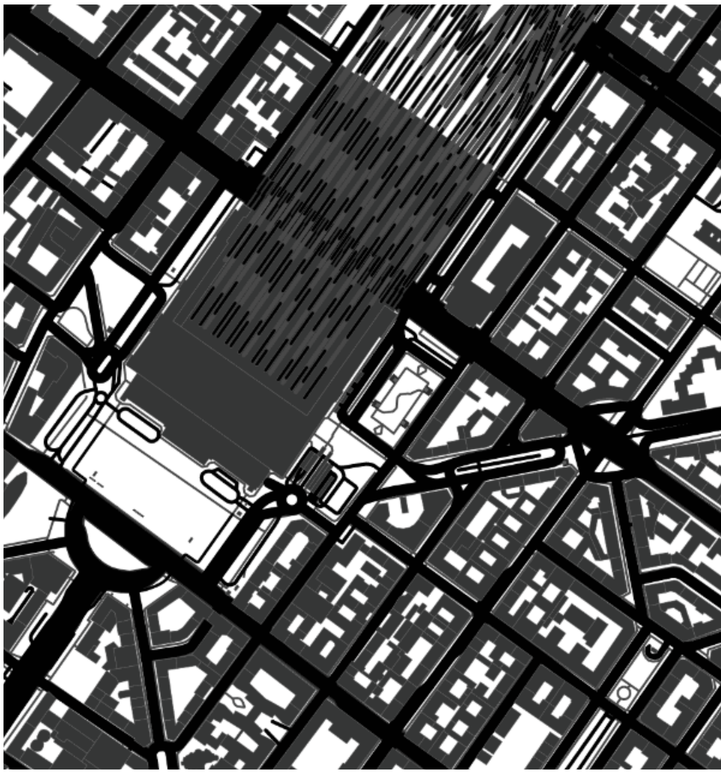


Fig. 106. Voids and solids map, Sc

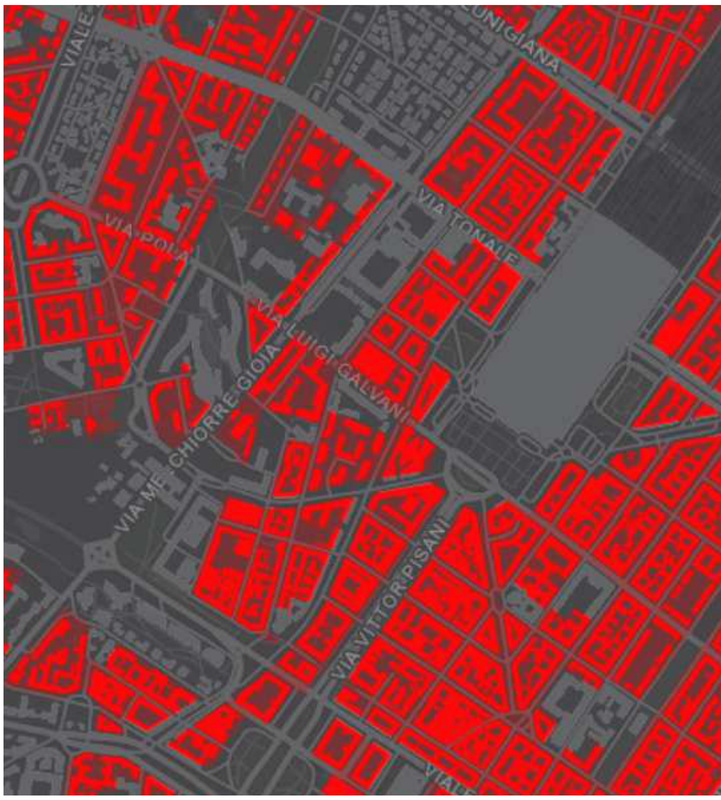


Fig. 107. Milan Ho

ource: mapz.com, data source: ©OpenStreetMap

In the street Andrea Doria, there is a plot area, that currently it is working as a parking plot. This area was stablished as the study site for the project.

using Density. Source: arcgis.com

This map shows Housing Density in MIlan.

4.6.1. URBAN FRAMEWORK

After the analysis of solids and voids, it was needed to study the main uses in the area and the different facilities that the sector offers to the residents.

LAND USES AND FACILITIES.

Fig. 108. Land uses and facilities. Source: ©OpenStreetMap

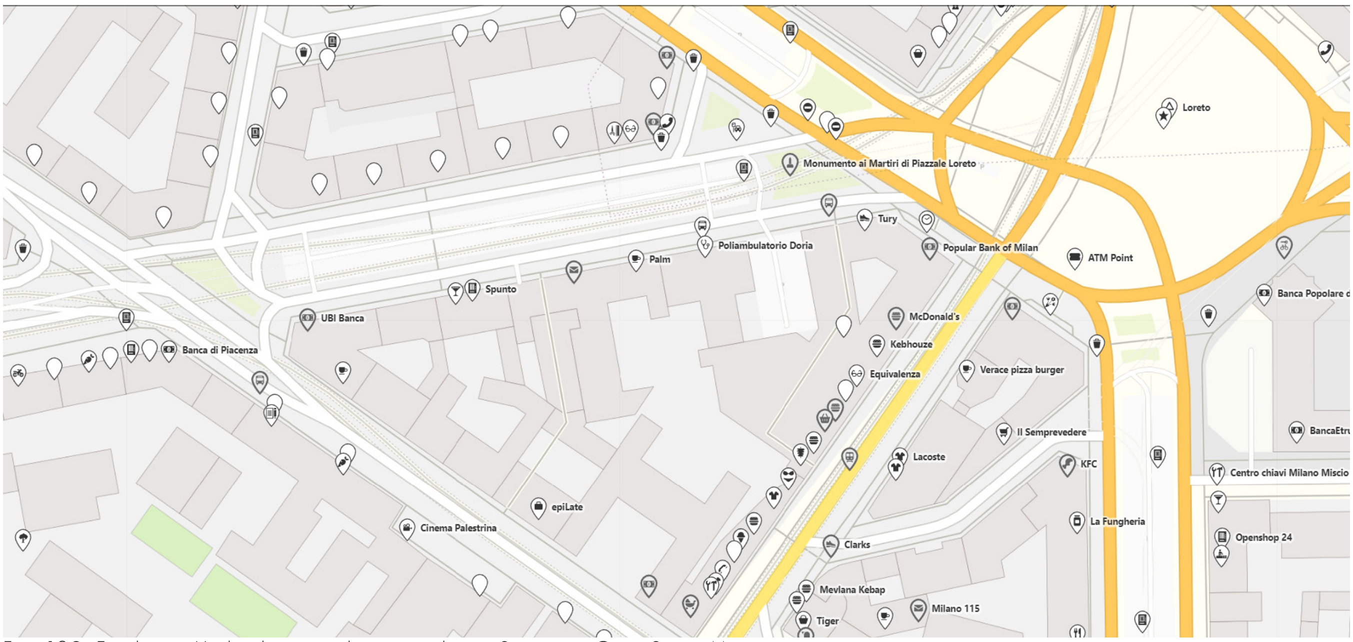


Fig. 109. Facilities, Viale doria and sorroundings. Source: ©OpenStreetMap

Fig. 110. Map of the open green areas in the sector

WALKABILITY: this is an essential factor to consider for the sector how walkable is the area and how many services are available for the residence in a ratio from 5min and 10min.

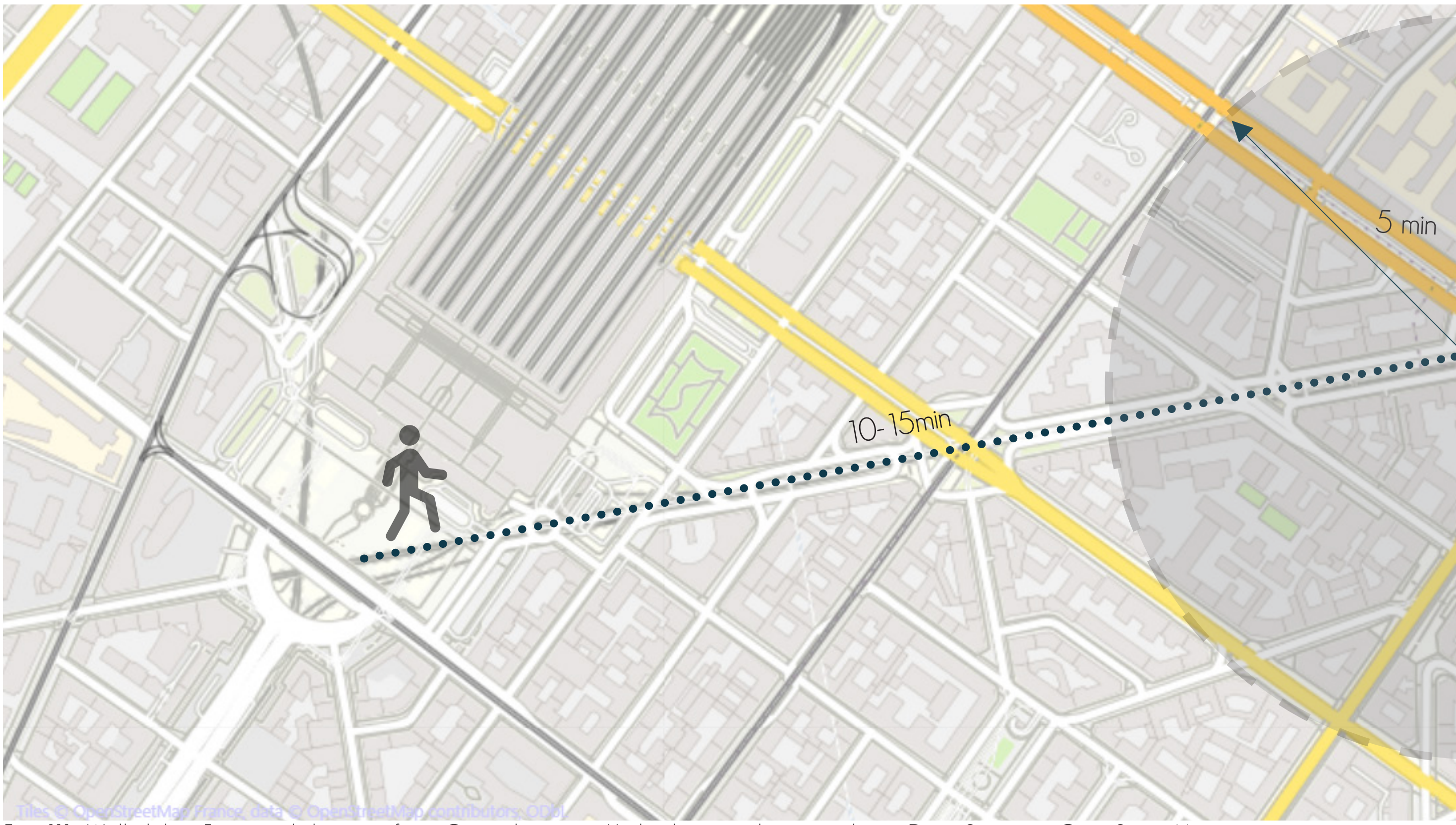


Fig. 111. Walkability 5min, and distance from Central station, Viale doria and sorroundings. Data Source: ©OpenStreetMap

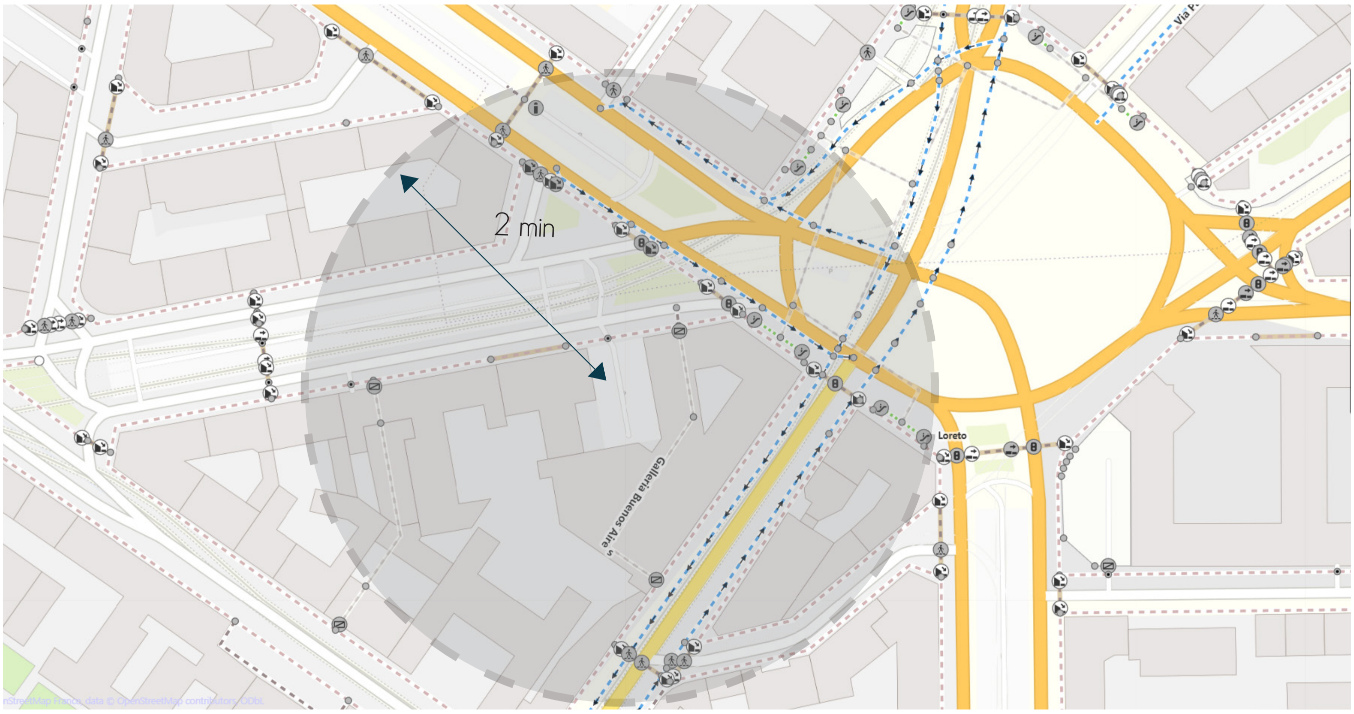
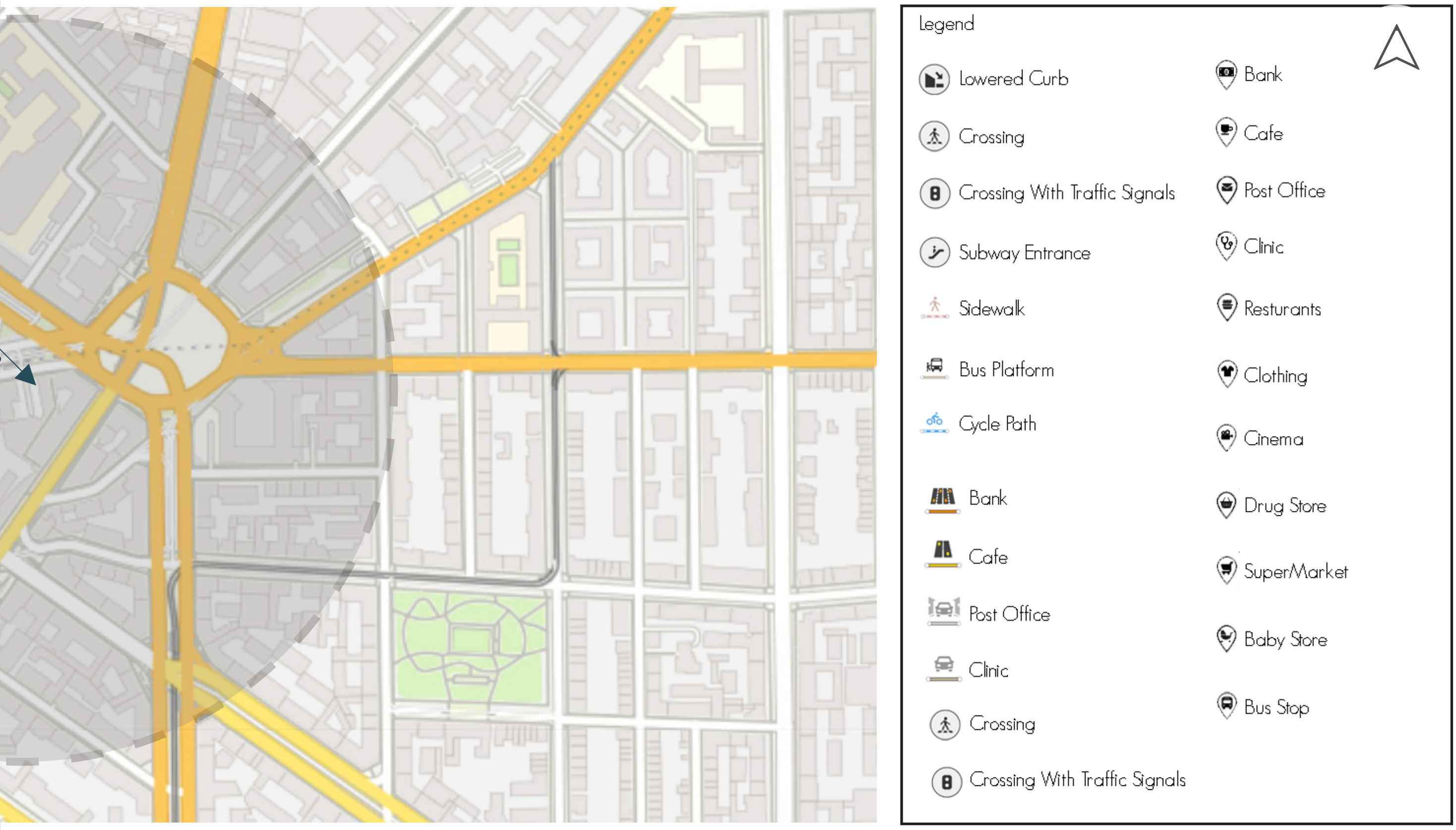


Fig. 112. Services available in the surronding area,Ratio 2min walking Map Source: ©OpenStreetMap



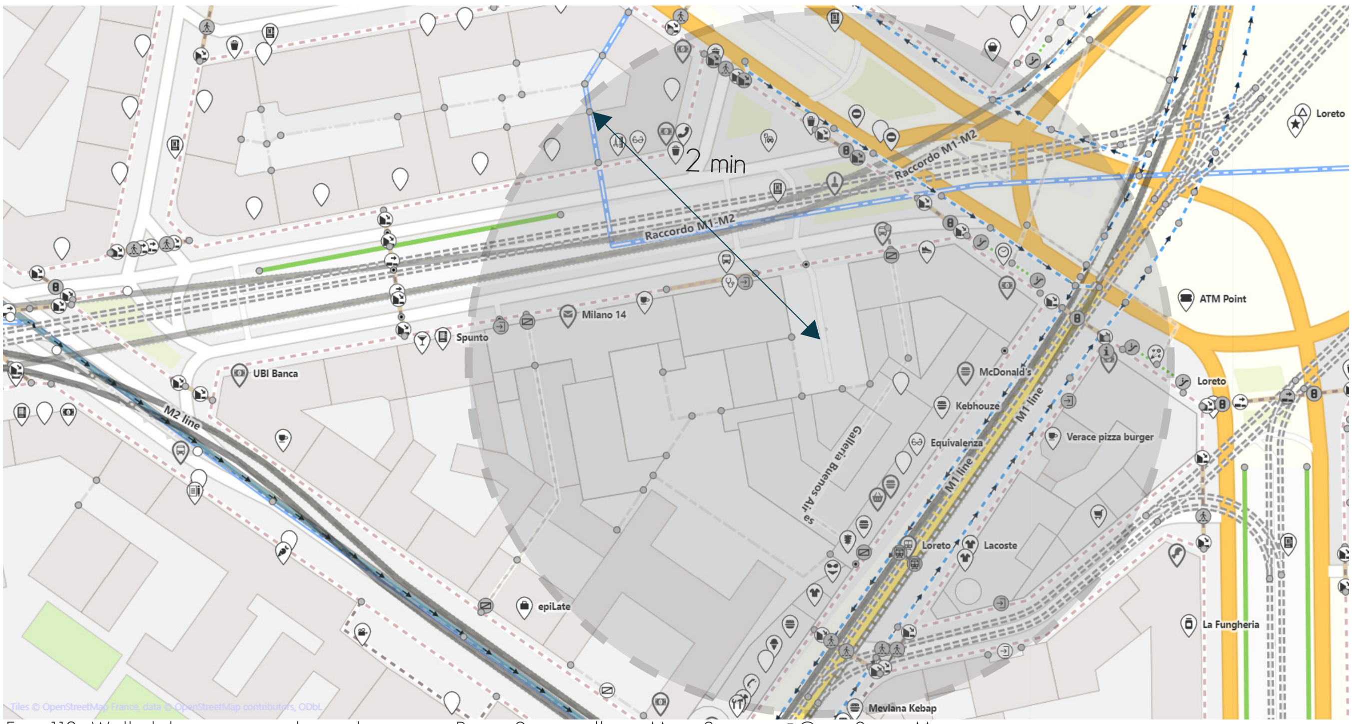


Fig. 113. Walkability map, paths and services,Ratio 2min walking Map Source: ©OpenStreetMap

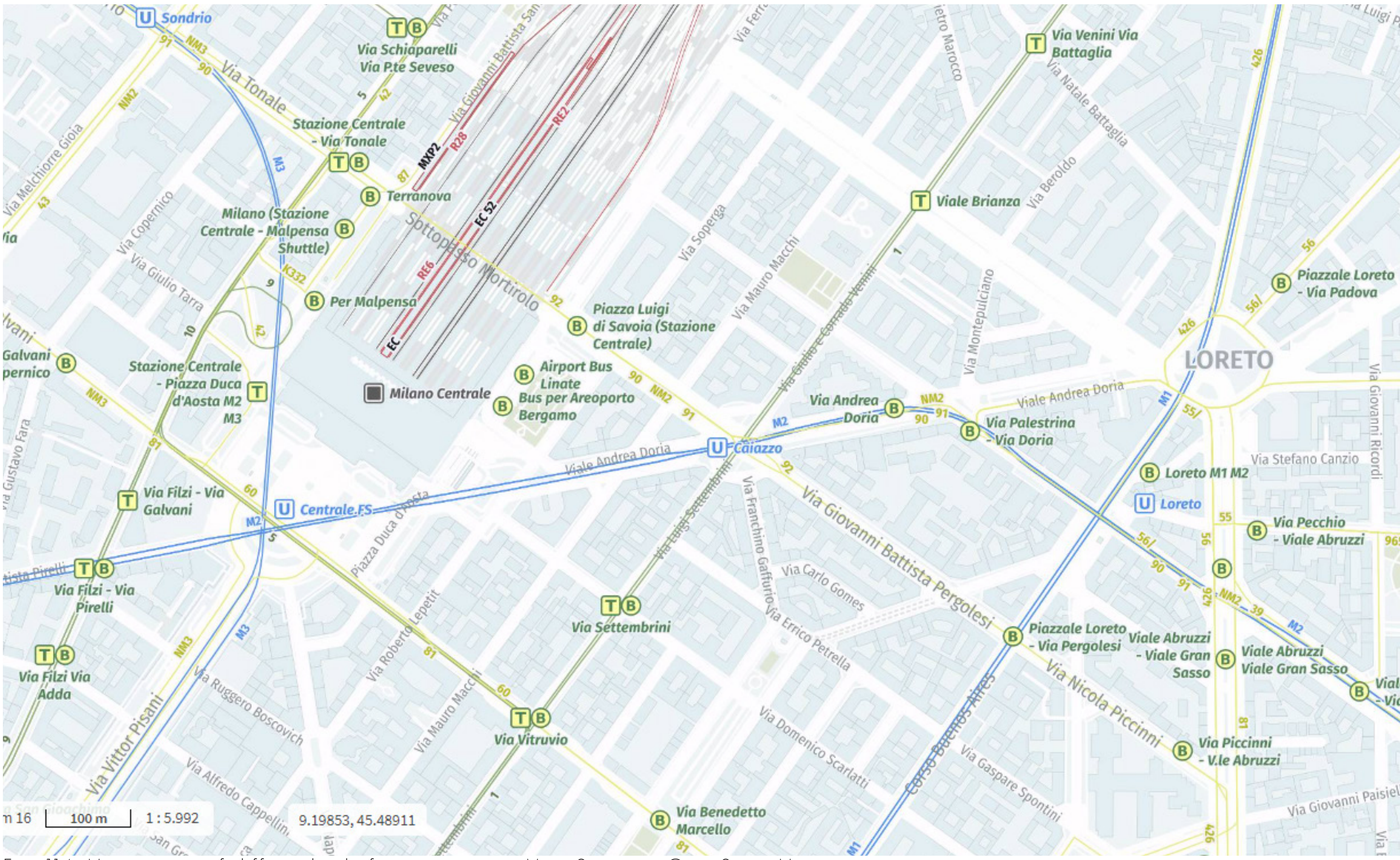
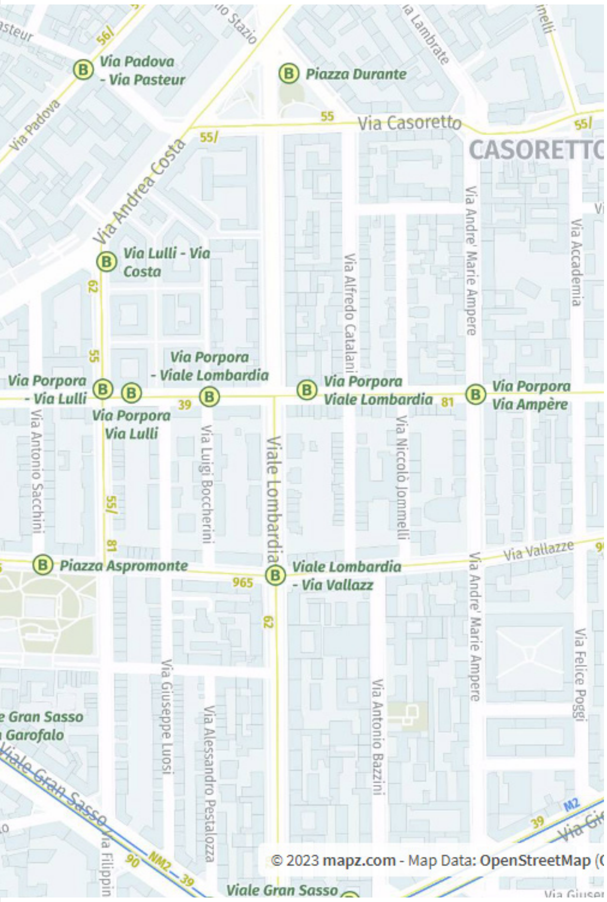


Fig. 114. Mian roauts of differnt kind of trasportations Map Source: ©OpenStreetMap

Fig. 115. Roads. Source: ©OpenStreetMap



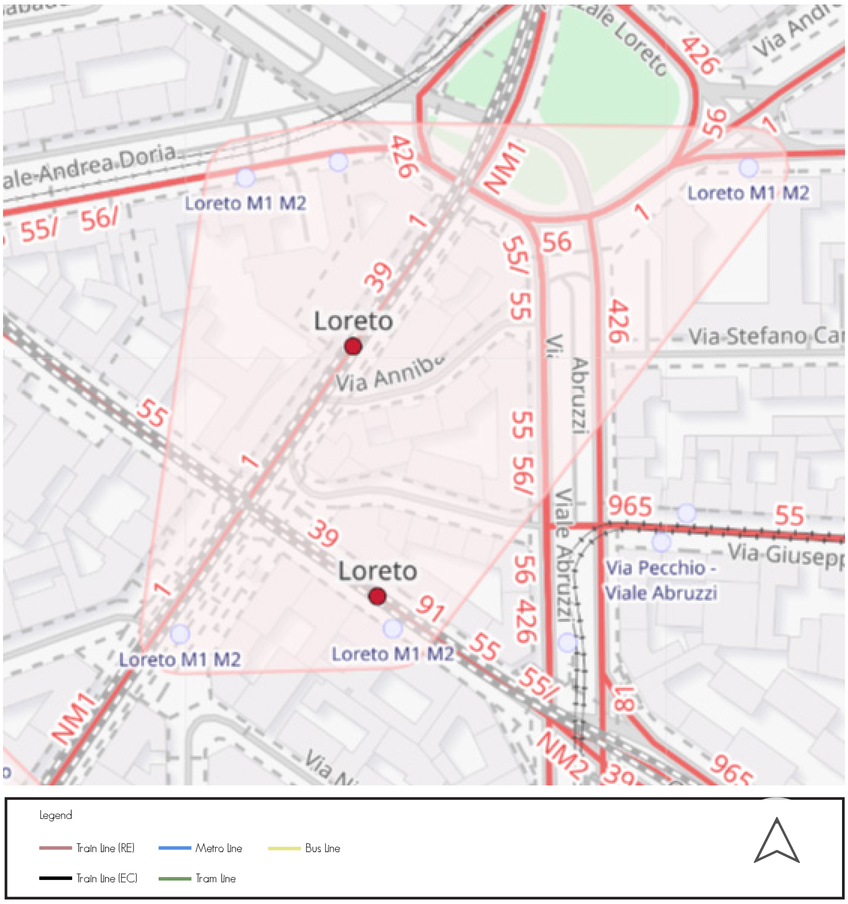
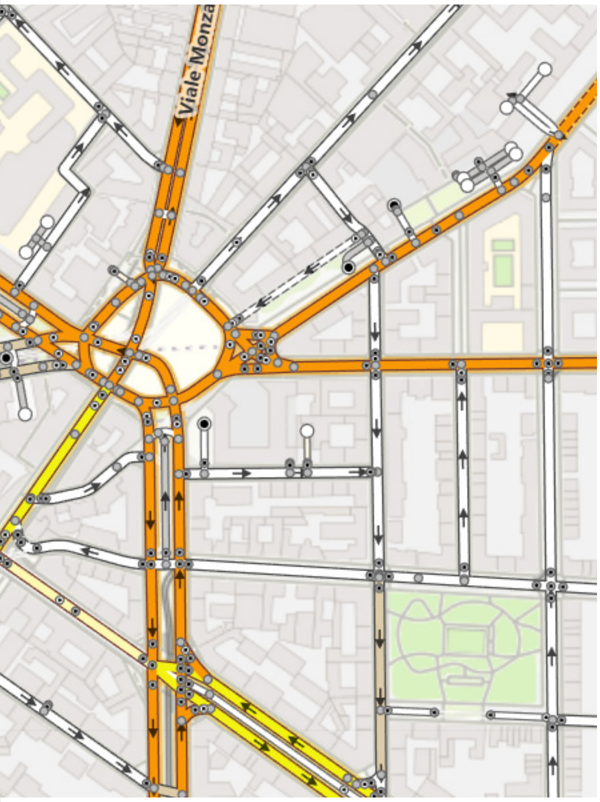


Fig. 116. Loreto metro station entrances. Map Source: ©OpenStreetMap



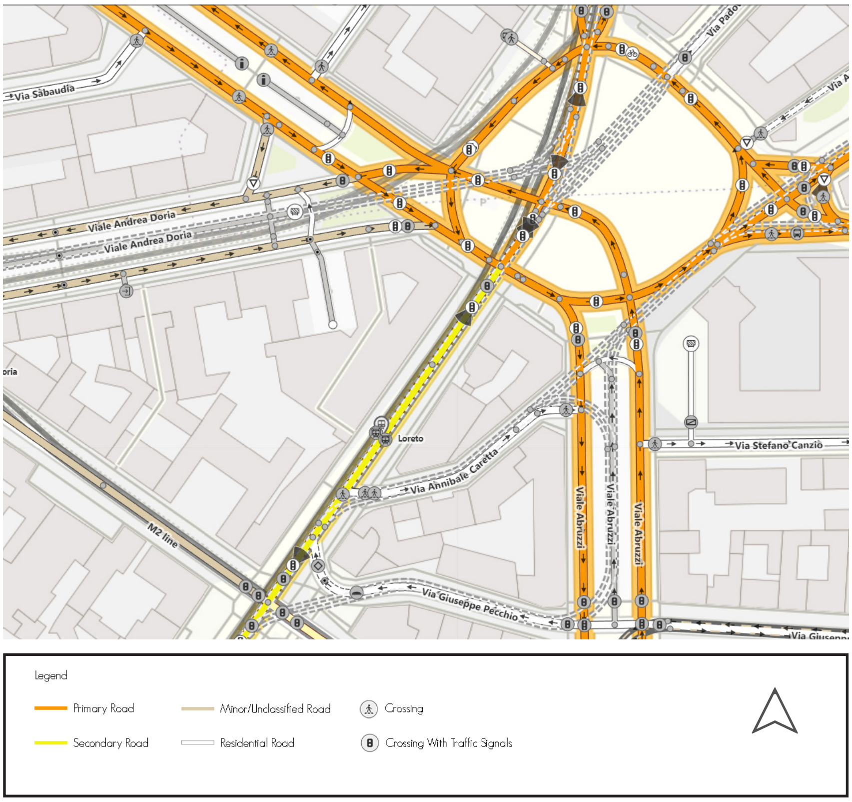


Fig. 117. Traffic roads in the area. Map Source: ©OpenStreetMap

4.6.2. LEGAL FRAMEWORK

It is important to adhere to the norms and specifications outlined in the Piano delle Regole/PdR (Plan of Rules of the PGT) as there are various contracts applicable to the area. The sector has some exceptions due to its unique morphology, which must be considered, especially since the project involves the development of a social residence building. In addition, administrative and soil protection constraints as well as protection and safeguard constraints must be taken into account, which may limit the project's size. The following maps illustrate these constraints.

Fig. 118. Administrative and soil protection constraints Map. Source: Piano delle Regole/PdR Plan R.05/2D

Fig. 119. Constraints of protection and safeguard. Map. Source: Piano delle Regole/PdR. Plan R.06/2D

Fig. 120. Site location

Fig. 121. Minimum distance between buildings.

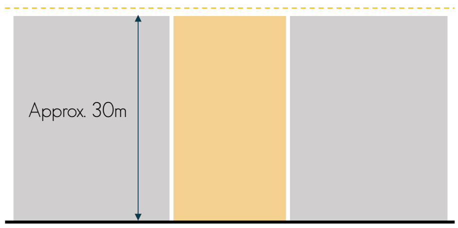


Fig. 122. Height restrictions.

The height limitation is related with the landscap regulation. For this reason the project site needs to be as maximum the same height as the adjacent buildings. (Le courbousier rue cooridor).

4.6.3. SWOT ANALYSIS

S	W	O	T
Strengths	Weaknesses	Opportunities	Threats

STRENGTHS-OPPORTUNITIES	WEAKNESSES-THREATS
The site has an incredibly strategic position.	Air pollution
It is located at less than a 10 minutes walk from Centrale railway station,	Congested area
Good connectivity proximity to the city's main public transport hub	Noise pollution due to the traffic
The site is 100 metres from the MM1 and MM2 underground line station Loreto, which connects Doria to destinations like Duomo (city centre), Porta Nuova (CBD) and Città Studi (University campus) in about 10 minutes.	Presence of tall buildings at E, SE and SW potentially blocking views and light in winter
Accessibility, Doria is 40 minutes from the airport via the Malpensa express train, and regional trains connect Centrale to the Rho-Fiera exposition site in just 25 min.	Unsteady and unreliable wind
The site is also easily accessible via private transport, as it is not far to motorway access points (8 km from A4 Milano-Venezia, 9 km from A1 Milano-Bologna). Various bike sharing stations are within walking distance	Periods of high levels of suspended particulate matter in Milano area
Doria is located in an area not far from undergoing significant urban transformation and is surrounded by relevant urban renewal projects and opportunities,	
Potentially very attractive location for mixed-use development including offices, , resitdential buildings retail and hotels.	

Table. 04. SWOT Analysis

Fig. 123. Site street view

Fig. 124. Site internal view

Fig. 125. Aereal view. Source: GoogleEarth

4.6.4. CLIMATE ANALYSIS

Having knowledge of the local climate is essential when making environmentally conscious design decisions. Milan's climate is warm temperate with fully humid summers, as classified by the Köppen-Geiger Climate Classification world map, which is based on historical data of temperature and precipitation. This is further specified by the Köppen-Geiger subtype classification of Cfb, as illustrated in a climate world map. To gain a more in-depth understanding of Milan's climate, an Energy-plus Weather (EPW) data file was used in ClimateStudio software to analyse the city's urban context. The data was collected from nearby weather stations situated outside Milan's urban area, and the EPW file was processed to evaluate Milan's climate.

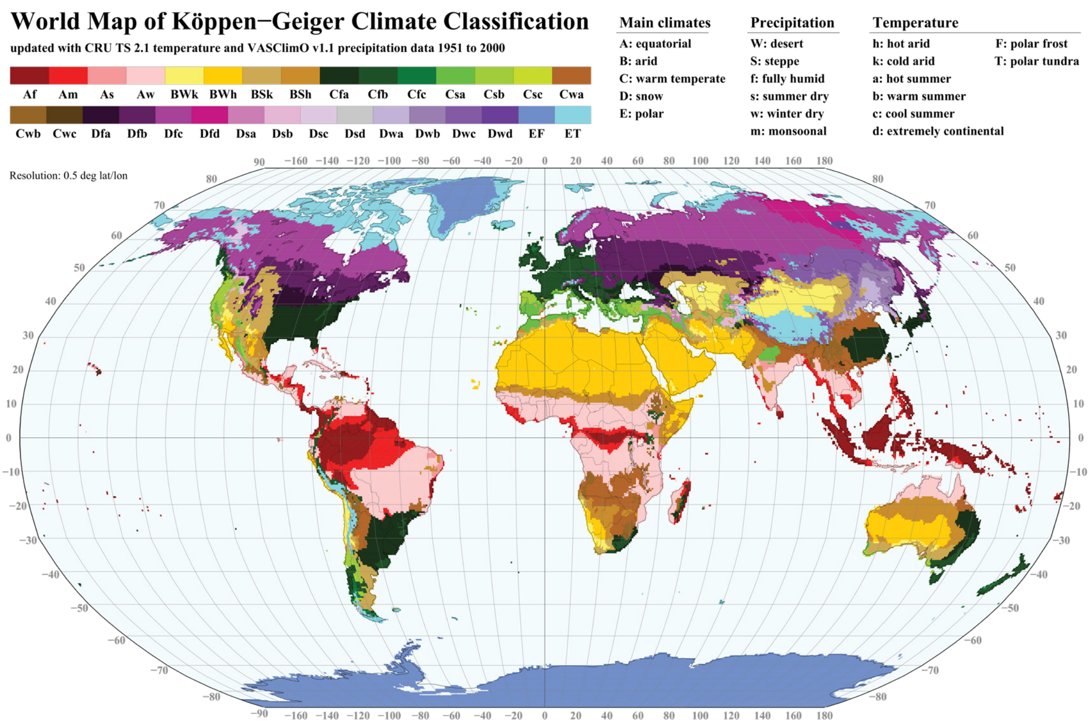


Fig. 126. World Map of the Köppen-Geiger climate classification. Source: Kottek et al., 2006.

DRYBULB TEMPERATURE

The average temperature in Milan depends on the time of year. In general, with hot summers and cold winters In the summer months (June-August), the average high temperature ranges from 25-30°C, while the average low temperature ranges from 15-20°C. In the winter months (December-February), the average high temperature ranges from 5-10°C, while the average low temperature ranges from 0-5°C.

Overall, the annual average temperature in Milan is around 14°C.

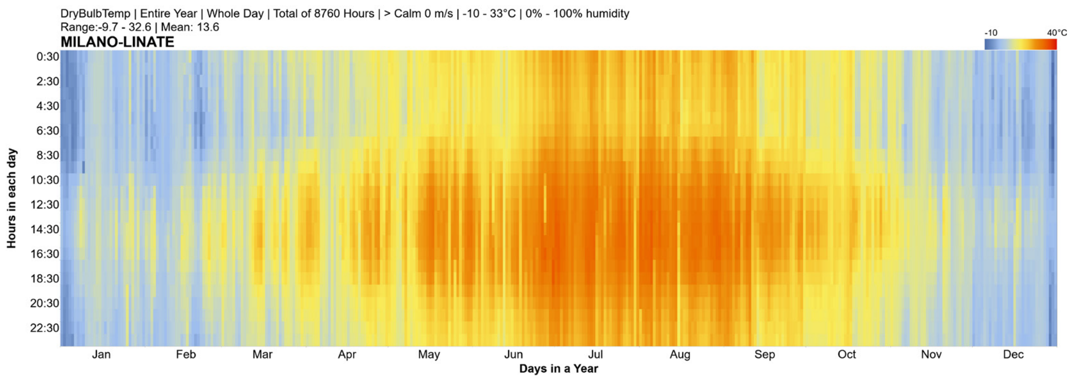


Fig. 127. DryBulb temperature in Milan. Source: EnergyPlus EPW file.

GLOBAL HORIZONTAL RADIATION

(GHR) is a measure of the amount of solar radiation that reaches the Earth's surface on a horizontal plane. In Milan, Italy, GHR is an important parameter for understanding the needs for shading systems during both summer and winter seasons and the amount of solar energy that can be harvested by photovoltaic (PV) systems for predicting the potential for solar power generation.

The GHR in Milan varies depending on the time of day, season, and weather conditions. In general, the GHR is highest during the summer months, when the sun is higher in the sky and the days are longer. During the winter months, the GHR is lower due to the shorter days and lower angle of the sun. The yearly average is around 150 Wh/m2. Milan is located in a region with a temperate climate, which means that there can be considerable variability in the GHR due to cloud cover and other weather conditions. However, the city receives a relatively high amount of sunlight throughout the year.

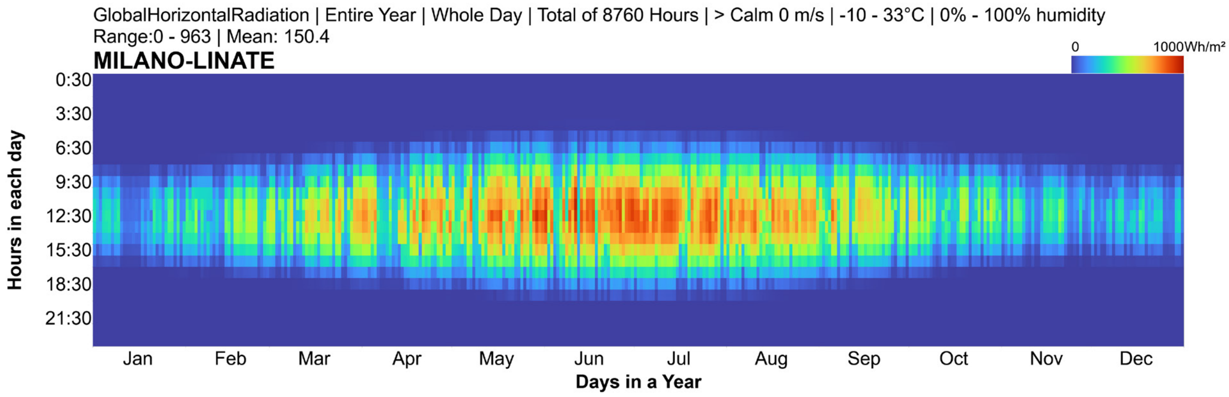


Fig. 128. Global Horizontal Radiation in Milan. Source: EnergyPlus EPW file.

RELATIVE HUMIDITY

According to data from the EnergyPlus weather data for Milan, the relative humidity varies from 16% to 100% with an annual average of around 77%. The RH can vary significantly depending on the time of year and weather conditions. During the summer months, RH can reach as high as 90%, while during the winter months, it can drop to as low as 40%. High RH levels can contribute to discomfort during hot weather and can promote the growth of mold and mildew in buildings.

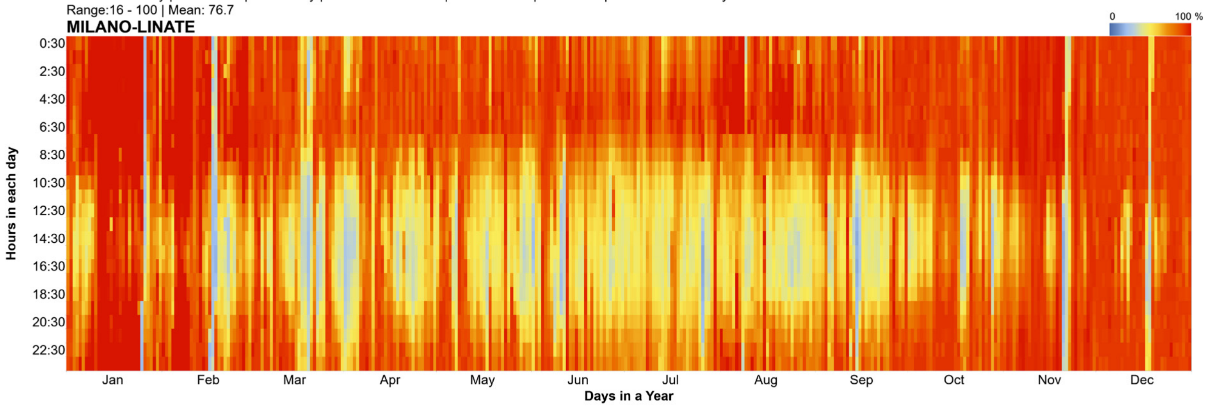
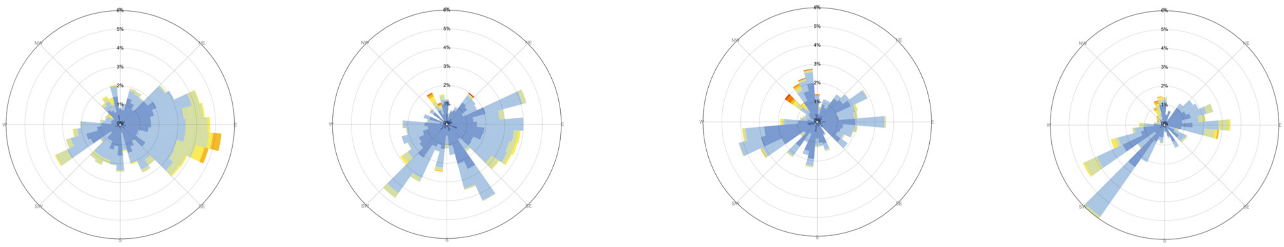


Fig. 129. Relative humidity in Milan. Source: EnergyPlus EPW file.

WIND ROSE

The file containing weather data provides detailed hourly information on wind speed and direction, which can be used to gain a deeper understanding of the local environment. By analysing meteorological wind data across different seasons and factoring in wind speed and direction, it is possible to forecast the prevailing wind patterns during various seasons and develop strategies accordingly. The figure displays four wind rose diagrams that feature wind speed data for each season. The diagrams demonstrate the most common wind directions and speeds for each season. The coloured grids that extend outwards in all directions represent the wind speed, measured in m/s, as indicated by the legend.



Spring Season - Wind rose (21st March-21st June) | Summer Season - Wind rose (21st June-21st September) | Aultman Season - Wind rose (21st September-21st December) | Winter Season - Wind rose (21st December-21st March)

Fig. 130. Wind rose by season, wind speed (m/s). Source: EnergyPlus EPW file.

SHADOW ANALYSIS

<u>Context analysis per hour :</u> The following is an analysis of the path of the sun in Milan for four different times of the year: March 21st, June 21st, September 21st, and December 21st. The study was conducted analysing the shadows that are projected on the empty project area from the adjacent surrounding buildings comparing different hours of the day and specifying points with the highest numbers of hours of direct sunlight. Therefore, we must consider which areas of shadow we will have to take into account. On the ground floor in December, the situation resulted in critical conditions. Hence, the ground floor will be used as a co-working area instead of a residential one.

Fig. 131. Context shadow analysis per hour by season (ground floor). Source: EnergyPlus EPW file.

<u>Context analysis per season :</u>The following is an analysis of the path of the sun in Milan for four different times of the year: March 21st, June 21st, September 21st, and December 21st. The study was conducted analysing the shadows that are projected on the project area with a volume in the project site, first from the adjacent surrounding buildings and second the shadows the volume is casting on its surroundings.

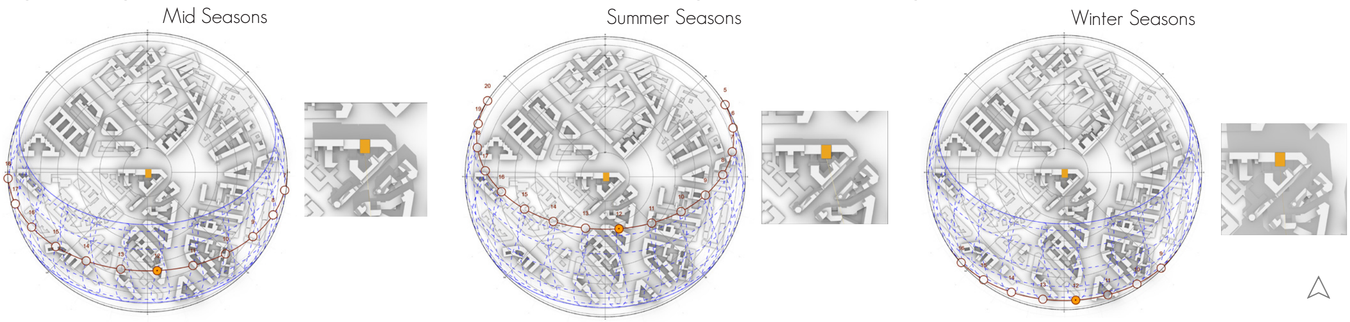


Fig. 132. Context shadow per season (with volume). Source: EnergyPlus EPW file.

4.7

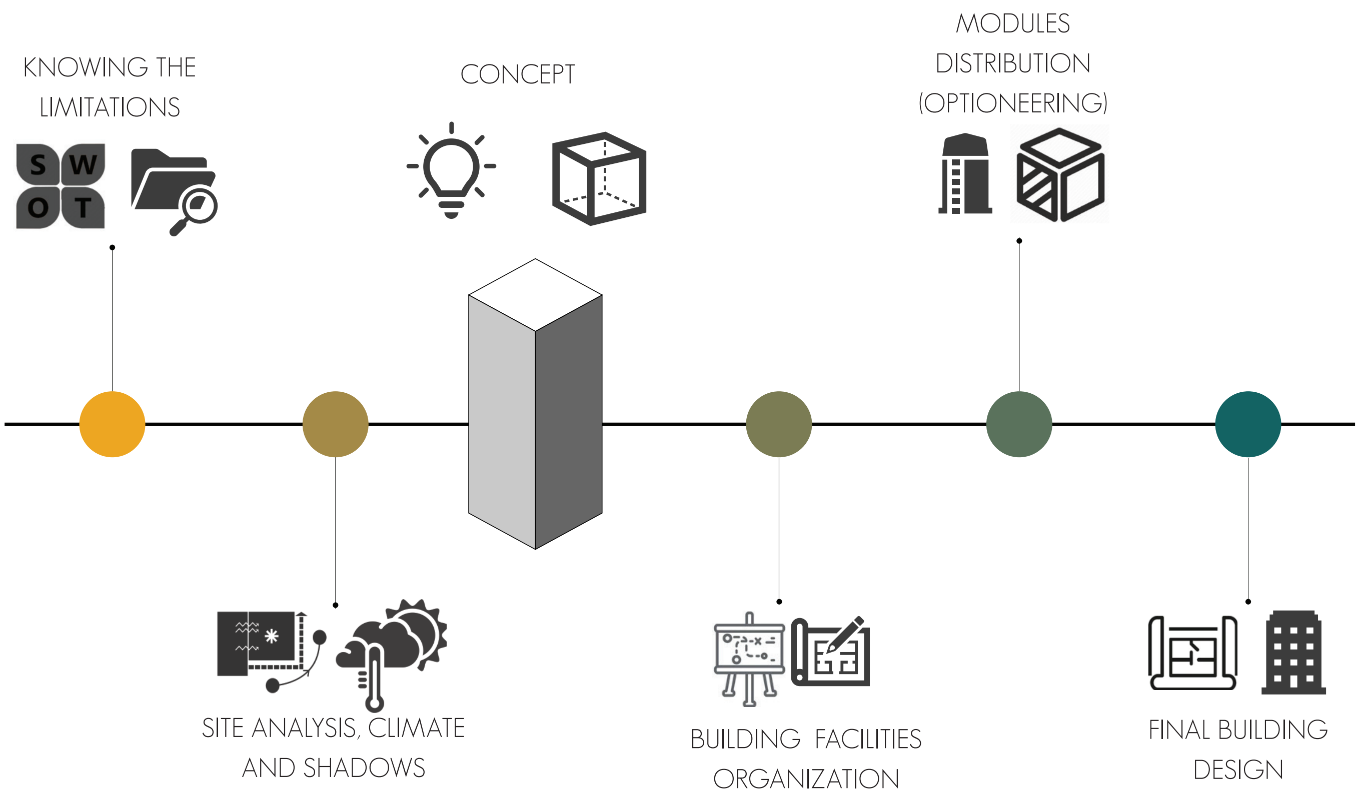
DESIGN DEVELOPMENT PROCESS

4.7.1. THE MASTER PLANNING PROCESS

After selecting the project site, the next step was to focus on designing the master plan. This involved a thorough site analysis to understand any restrictions that may impact the project's design, such as shape, shadows, and location advantages. Since the project site was chosen to be in a restricted area, the goal was to showcase the adaptability of the modular building design.

The following diagram illustrates the process that was followed to develop the master plan. The first stage was to identify the limitations and advantages of the site, followed by a detailed site analysis study. The concept stage involved exploring possible shapes and ideas for organizing the modules. The next stage was defining complementary functions and how they would be distributed within the building.

After this, the modules were distributed and various options were studied for organizing and assembling them according to the possible functions they would serve. Finally, the final proposal, which took into account all the aforementioned studies and analyses.



4.7.2. BUILDING CONCEPT

The building concept was developed in two stages, with a focus on functionality and aesthetics. During the functional stage, we analyzed the site's limitations and determined the optimal location for the vertical core. The building regulations mandated restrictions on the size of openings, allowing only for front and back-facing windows within 5 meters of either side and the back. To maximize natural daylight performance, we decided to move the volume of the building in the front to provide better views and openings to the side. We have included graphical representations of these steps in the following floor plan diagrams.

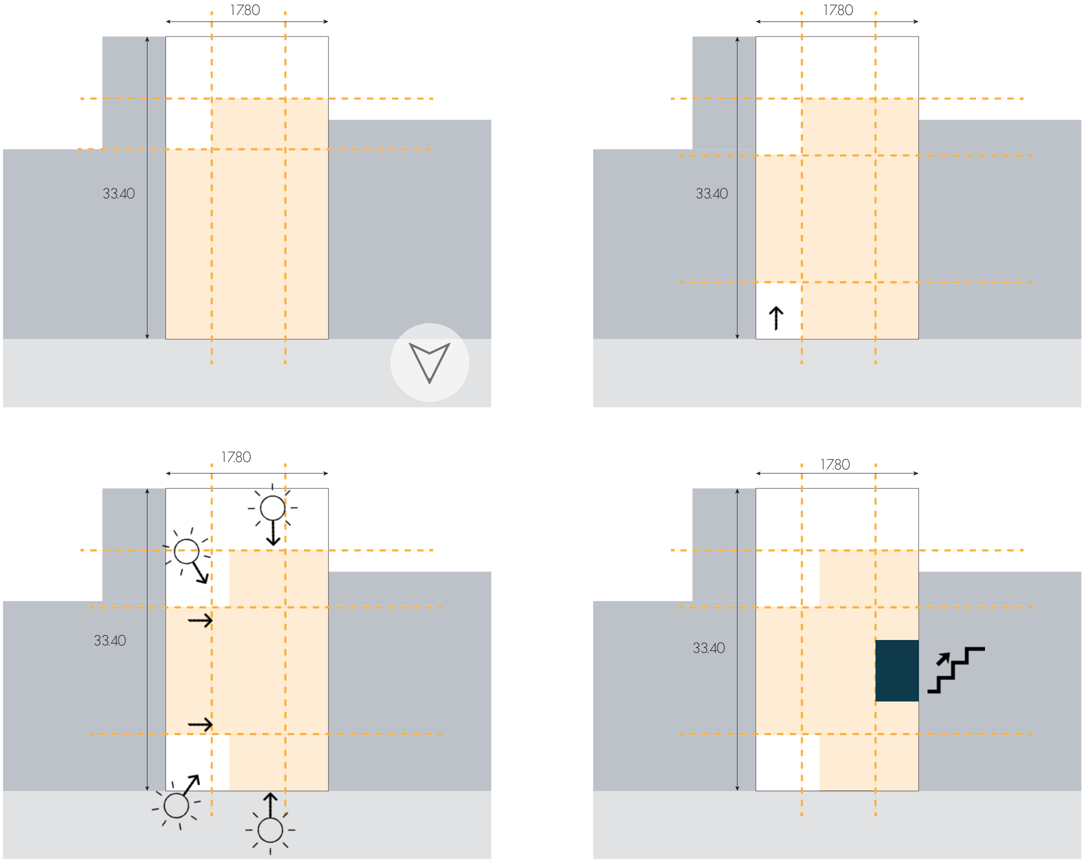


Fig. 133. Floor plan conceptual sckemes

The three following modules, explain the volume trasformation according to the restrictions.

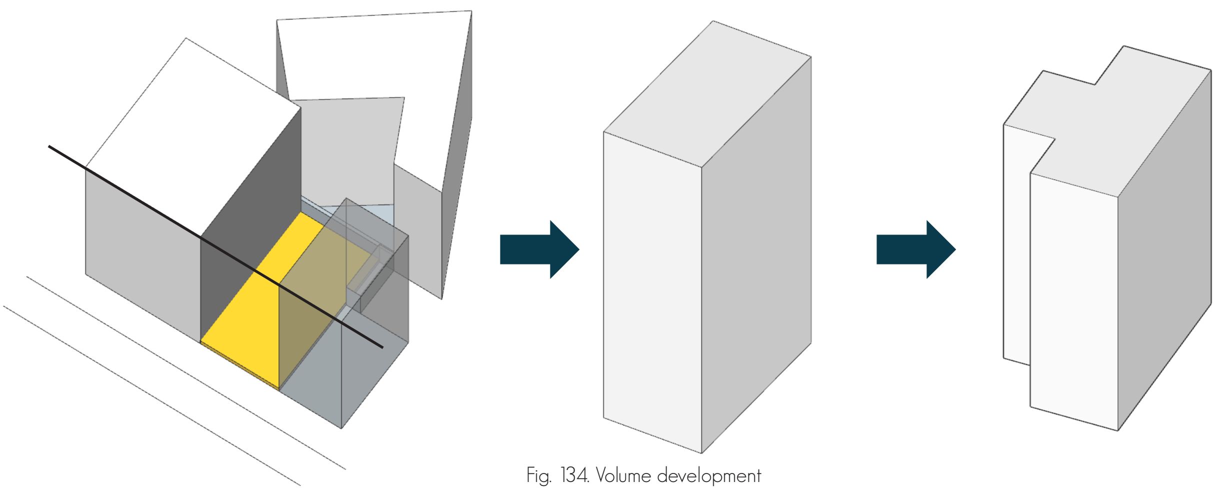


Fig. 134. Volume development

After defining the possible openings and the main core of the building, we adopt the JENGA mindset of modular construction. This involves adding or subtracting volumes in a way that promotes interaction and harmony between similar or different types of modules. By utilizing this approach, we can create a cohesive structure that is flexible, adaptable and aesthetically pleasing.

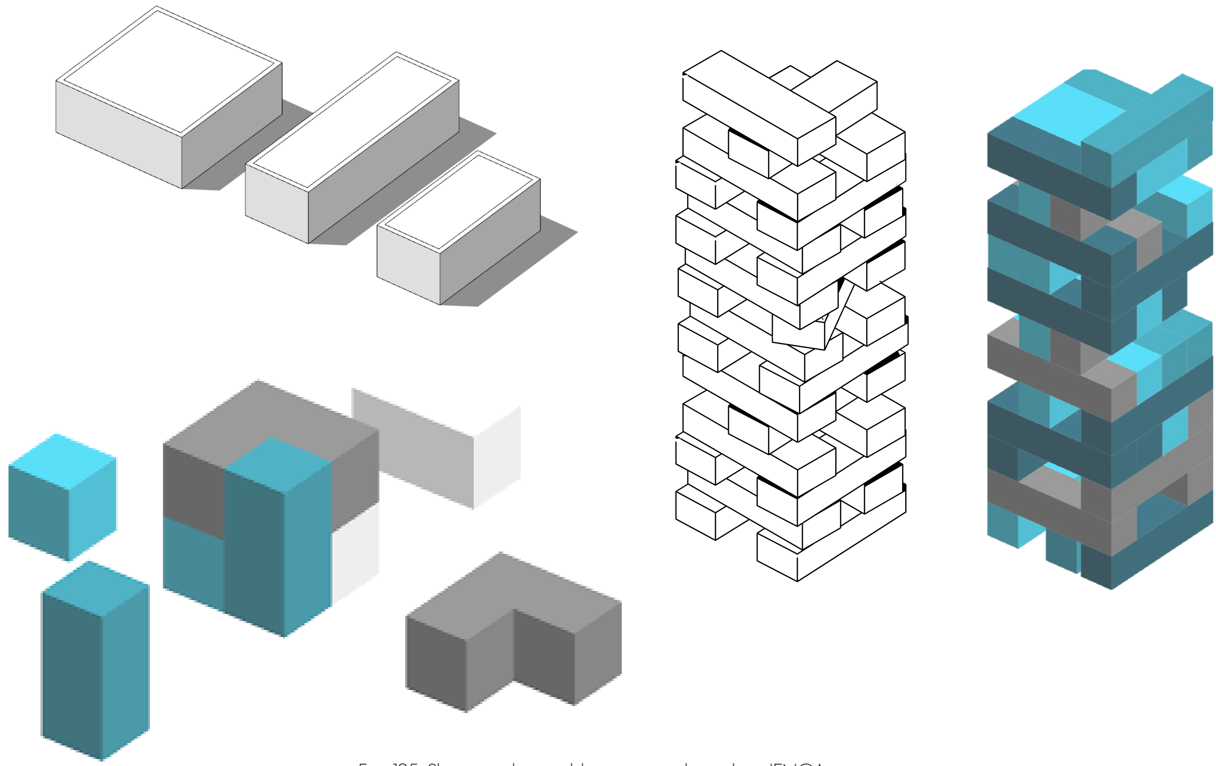


Fig. 135. Shape and assembling concept, based on JENGA.

By removing and adding volumes, it was determined that creating balconies would provide better opportunities for housing units. These balconies can serve as an extension of the internal area of the modules, creating an outdoor environment that seamlessly connects with the indoor spaces. This concept of extraction not only provides this service to some modules but also generates movement and dynamism to the facades. As an aesthetic concept, it was decided to organize the volumes in a way that they interlock like fingers while maintaining a distinct finish for each part. The materials used for the construction can be connected in a color sense, further enhancing the overall aesthetic appeal of the design.

Fig. 136. Interconnection between models, aesthetic concept.

4.7.3. OPTIONEERING BY FUNCTION

During this stage of the project, the focus was on studying how the building could conform to different types of modules. Various housing typologies that could be implemented on the site were examined, resulting in the development of six distinct cases. It's important to note that each of these options was carefully crafted on the site, taking into account all relevant restrictions and the overarching concept idea. The aim was to identify the most effective solutions that would meet the project goals and the needs. (The levels described are only the residential floors).

Fig. 137. 3D Case 01

CASE 01:

The main goal was to create a building with a cohabitating concept, featuring five different types of units with the same floor plan on each level. The idea was to offer apartments of varying sizes to cater to the needs of different individuals. The total of 90 users and total area of 1458sqm.

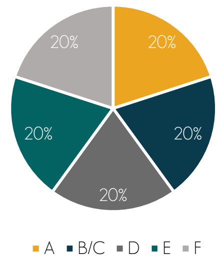


Fig. 138. % Module type Case 01

LEVEL	A	B/C	D	E	F	TOTAL	APT. AREA PER FLOOR
1ST	1	1	1	1	1	5	243
2nd	1	1	1	1	1	5	243
3rd	1	1	1	1	1	5	243
4th	1	1	1	1	1	5	243
5th	1	1	1	1	1	5	243
6th	1	1	1	1	1	5	243

	TYPE	#	M2	%	MAX # PEOPLE	TOTAL AREA PER APT.
A	STUDIO FLAT	6	21	20%	2	126.00
B/C	APT. MEDIUM 1 ROOM	6	52	20%	3	312.00
D	STUDIO-LARGE	6	40	20%	2	240.00
E	APT. MEDIUM 2 ROOMS	6	52	20%	3	312.00
F	FAMILY UNIT	6	78	20%	5	468.00
TOTAL		30		100.0%	90	1458.00

Table. 05. Module Building distribution, Case 01

Fig. 139. Floor plan Case 01

Fig. 140. 3D Case 02

CASE 02:

The approach was to have different sizes of studios for coworkers, students, or young couples, using modules A, B, and D. The plan was to have a typical floor plan for all the levels, with a total of 96 users, 36 modules, and a total area of 1482 sqm.

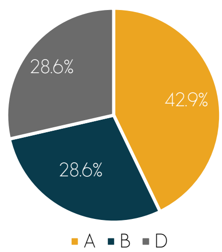


Fig. 141. % Module type Case 02

LEVEL	A	B/C	D	E	F	TOTAL	APT. AREA PER FLOOR
1ST	3	2	2	0	0	7	247
2nd	3	2	2	0	0	7	247
3rd	3	2	2	0	0	7	247
4th	3	2	2	0	0	7	247
5th	3	2	2	0	0	7	247
6th	3	2	2	0	0	7	247

	TYPE	#	M2	%	MAX # PEOPLE	TOTAL AREA PER APT.
A	STUDIO FLAT	18	21	42.9%	2	378.00
B	APT. MEDIUM 1 ROOM	12	52	28.6%	3	624.00
D	STUDIO-LARGE	12	40	28.6%	2	480.00
TOTAL		36		100.0%	96	1482.00

Table. 06. Module Building distribution, Case 02

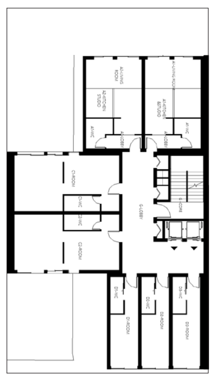


Fig. 142. Floor plan Case 02

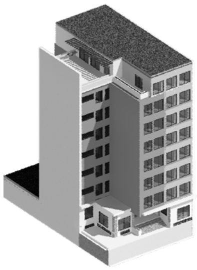


Fig. 143. 3D Case 03

CASE 03:

As with the concept of Case 1, the approach in this case involved cohabitation, but with the opportunity of adding small families in Module E. This idea allows for the offering of different sizes of small and medium apartments, with a total of 90 users, 36 modules, and a total residential area of 1428 sqm.

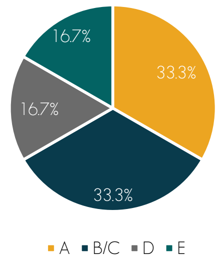


Fig. 144. % Module type Case 03

LEVEL	A	B/C	D	E	F	TOTAL	APT. AREA PER FLOOR
1ST	2	2	1	1	0	6	238
2nd	2	2	1	1	0	6	238
3rd	2	2	1	1	0	6	238
4th	2	2	1	1	0	6	238
5th	2	2	1	1	0	6	238
6th	2	2	1	1	0	6	238

	TYPE	#	M2	%	MAX # PEOPLE	TOTAL AREA PER APT.
A	STUDIO FLAT	12	21	33.3%	2	252.00
B/C	APT. MEDIUM 1 ROOM	12	52	33.3%	3	624.00
D	STUDIO-LARGE	6	40	16.7%	2	240.00
E	APT. MEDIUM 2 ROOMS	6	52	16.7%	3	312.00
Total		36		100.0%	90	1428.00

Table. 07. Module Building distribution, Case 03

Fig. 145. Floor plan Case 03

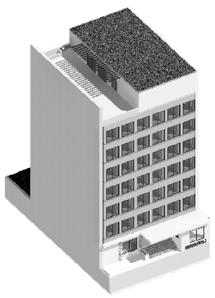


Fig. 146. 3D Case 04

CASE 04:

This is a special case where the entire building consists of the same type of unit. In this instance, the focus was on providing Module A as a student housing building, designed for individual use for each unit or in the case of a young couple. The building has a total of 120 users and covers an area of 1260 sqm.

LEVEL	A	B/C	D	E	F	TOTAL	APT. AREA PER FLOOR
1ST-6th	10	0	0	0	0	10	210

	TYPE	#	M2	%	MAX # PEOPLE	TOTAL AREA PER APT.
A	STUDIO FLAT	60	21	100.0%	2	1260.00
Total		60			120	1260.00

Table. 08. Module Building distribution, Case 04

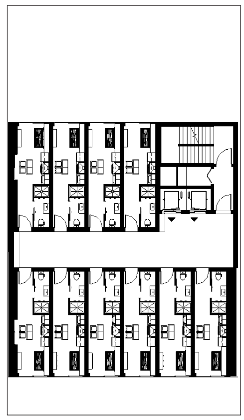


Fig. 147. Floor plan Case 04

Fig. 148. 3D Case 05

CASE 05:

On the other hand, this case is focused on being a multi-family apartment building only having the module F, with a typical floor plan. It has a total of 90 users (considering adults and kids) and a total floor area of 1404 sqm, with a total of 18 units.

LEVEL	A	B/C	D	E	F	TOTAL	APT. AREA PER FLOOR
1st-6th	0	0	0	0	3	3	234

	TYPE	#	M2	%	MAX # PEOPLE	TOTAL AREA PER APT.
F	FAMILY	18	78	100.0%	5	1404.00
Total		18			90	1404.00

Table. 09. Module Building distribution, Case 04

Fig. 149. Floor plan Case 05

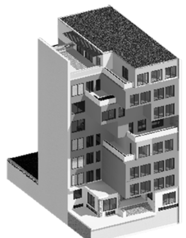


Fig. 150. 3D Case 06

CASE 06:

The focus of this case was the distribution of all module types, with the idea of creating different household and housing typologies, as well as different floor plan distributions by floor. This building has a total residential area of 1534 sqm, a total of 92 residents, and a total of 31 modules.

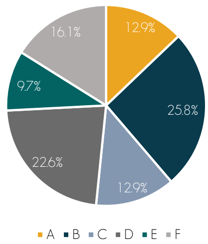


Fig. 151. % Module type Case 06

CASE 6 MIX ABCDEF	A	B	C	D	E	F	TOTAL	APT. AREA PER FLOOR
1ST	0	2	0	2	0	1	5	158
2nd	0	2	0	0	0	2	4	156
3rd	1	2	0	1	0	1	5	139
4th	0	0	2	0	2	0	4	208
5th	0	1	1	2	0	1	5	210
6th	0	1	1	2	1	0	5	184
Rooftop	3	0	0	0	0	0	3	63

	TYPE	#	M2	%	MAX # PEOPLE	TOTAL AREA PER APT.
A	STUDIO FLAT	4	21	12.9%	2	84.00
B	APT. MEDIUM 1 ROOM	8	52	25.8%	3	416.00
C	APT. MEDIUM 1 ROOM	4	52	12.9%	3	208.00
D	STUDIO-LARGE	7	40	22.6%	2	280.00
E	APT. MEDIUM 2 ROOMS	3	52	9.7%	3	156.00
F	FAMILY UNIT	5	78	16.1%	5	390.00
TOTAL		31		100.0%	92	1534.00

Table. 10. Module Building distribution, Case 06

Fig. 152. Floor plan Case 06

The different types of modules that have been designed can be aggregated into various options that can be situated in this plot area. This shows the adaptability of the modules depending on the needs of the users or investors. The following table shows the options, comparing also the baseline daylight related to the building. In conclusion, the approach of the project will be based on CASE 6, which can fit different types of households and house typologies.

CASE 1 ABDEF	CASE 2 ABD	CASE 3 ABDE	CASE 4 ALL A	CASE 5 ALL F	CASE 6 ABCDE-MIX

Table. 11. Optioneering summary table, volumes, floor plans and daylight (in level 3)

4.7
CHOSEN PROPOSAL

After studying various aspects of the site and conducting optioneering for different types of aggregations that could be placed on the site, it was crucial to define a proposal that accounted for the site's limits and restrictions. The chosen proposal is focused on providing different housing typologies for various users, as defined by the targeted users in this research.
The proposal is developed over 6 residential floors, distributed among 3 floor plan types, where the module is located in a way to allow the opportunity to have balconies in some of the apartments. The basement is included for residents' services, storage cabinets, gym, general laundry room, and bike parking. The ground floor level houses the social-working areas, study area, waiting area, co-working space, and garden, which are part of the facilities offered to residents. The rooftop provides social-recreational activities, including a community room, gaming room (designed in a modular size), and a terrace with a grill area. The schematic on the left shows all the floors of the building and how they are distributed showing the floor area by floor and the total area of 3014sqm. The table below shows the distribution of the modules on the residential floors.

LEVEL	A	B	C	D	E	F	TOTAL	APT. AREA PER FLOOR
1ST	0	1	1	2	0	1	5	262
2nd	1	1	1	1	0	1	5	243
3rd	1	1	1	1	1	0	5	217
4th	0	1	1	2	0	1	5	262
5th	1	1	1	1	0	1	5	243
6th	1	1	1	1	1	0	5	217
Rooftop	2	0	0	0	0	1	3	120

TYPE		#	M2	%	MAX # PEOPLE	TOTAL AREA PER APT.
A	STUDIO FLAT	6	21	18.2%	2	126.00
B	APT. MEDIUM 1 ROOM	6	52	18.2%	3	312.00
C	APT. MEDIUM 1 ROOM	6	52	18.2%	3	312.00
D	STUDIO-LARGE	8	40	24.2%	2	320.00
E	APT. MEDIUM 2 ROOMS	2	52	6.1%	3	104.00
F	FAMILY UNIT	5	78	15.2%	5	390.00
Total		33		100%	95	1564.00

Table. 12. Module distribution in residential level, chosen proposal.

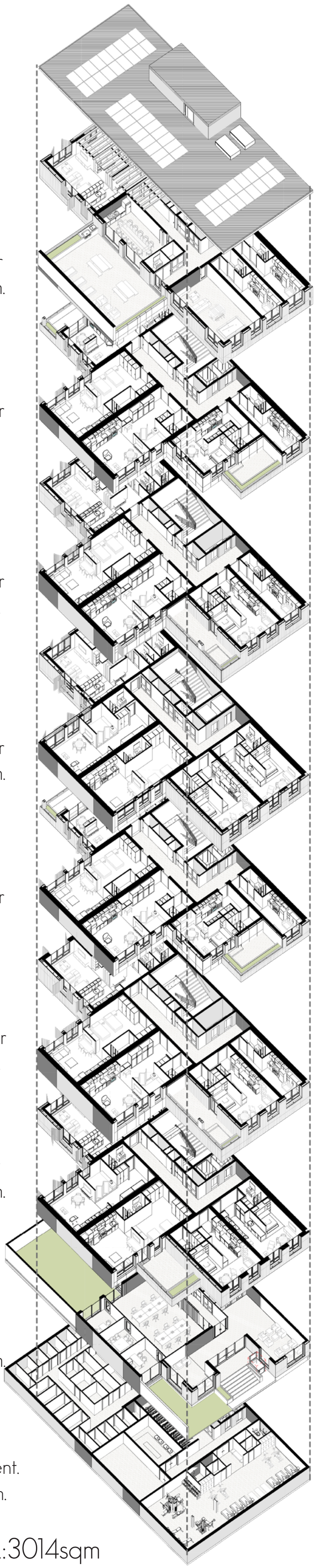


Fig. 154. 3D building level areas

Fig. 155. 3D propsal

The distribution of the units emphasizes their multifunctionality and adaptability through modular design. The proposed development encompasses a residential area of 1564 square meters and caters to 95 users across 33 units.

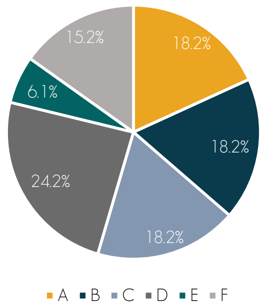
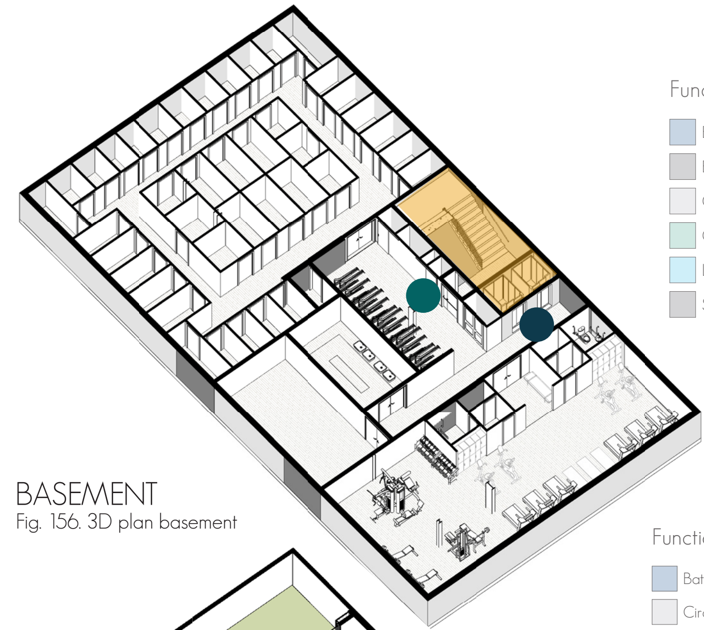


Fig. 155. % Module Type Case 06

FUNCTIONS DISTRIBUTIONS


BASEMENT
Fig. 156. 3D plan basement

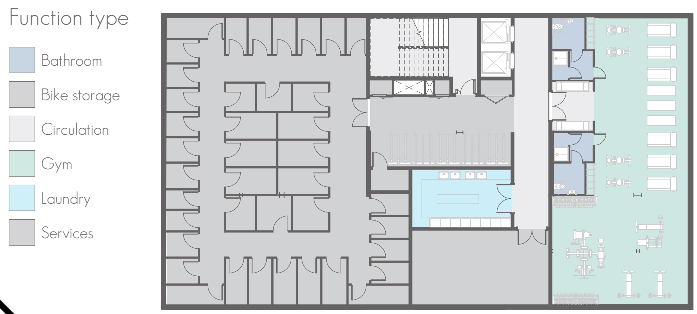
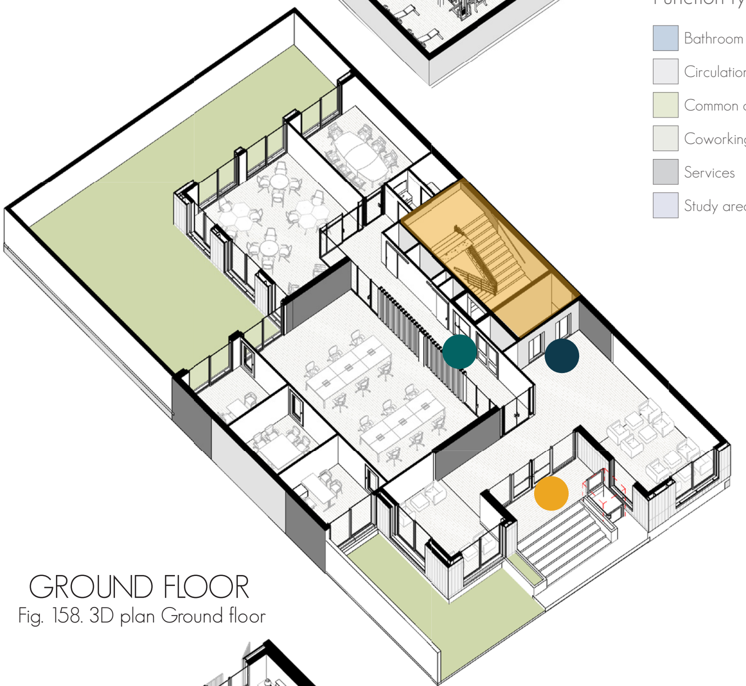


Fig. 157. Function type-basement


GROUND FLOOR
Fig. 158. 3D plan Ground floor

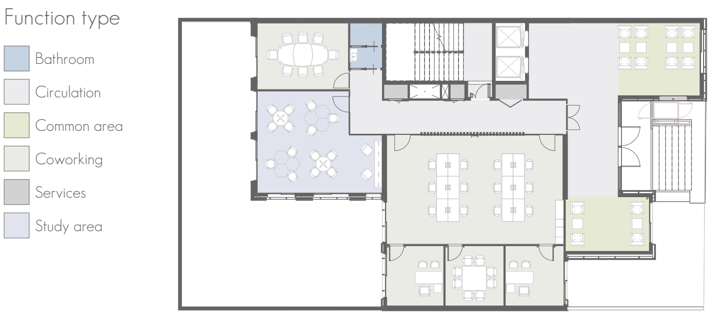


Fig. 159. Function type Ground floor

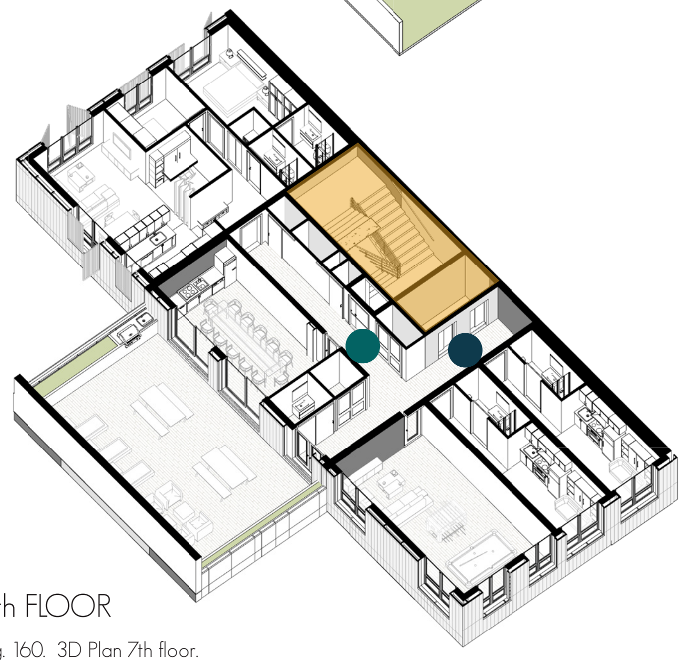

7th FLOOR
Fig. 160. 3D Plan 7th floor.

Fig. 161. Function type 7th floor

Fig. 162. Module type 7th floor

1ST & 4TH FLOOR

Fig. 163. 1st& 4th floor 3D plan

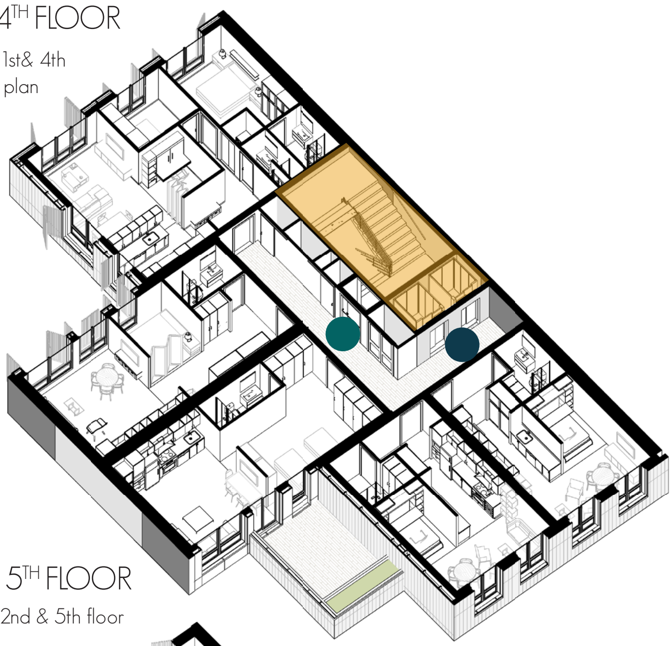


Fig. 164. Function type 1st & 4th floor

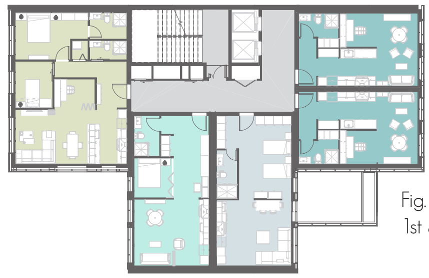


Fig. 165. Module type- 1st & 4th floor

2ND & 5TH FLOOR

Fig. 166. 2nd & 5th floor 3D plan

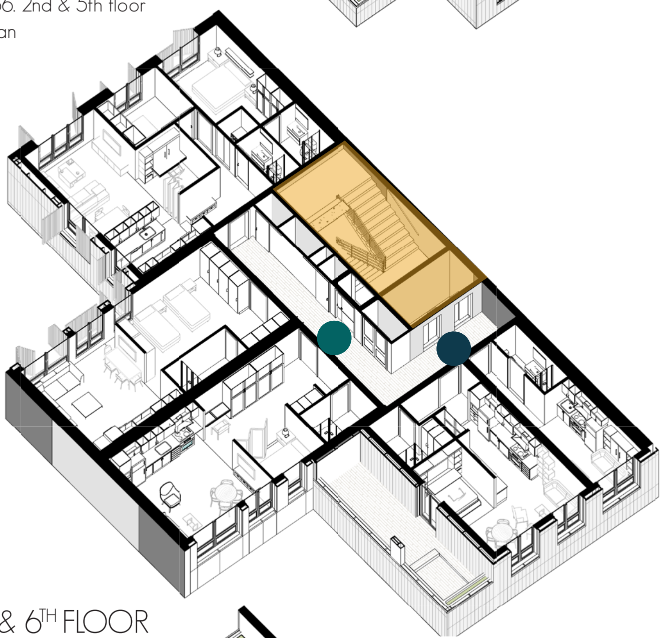


Fig. 167. Function type 2nd & 5th floor

Fig. 168. Module type- 2nd & 5th floor

3RD & 6TH FLOOR

Fig. 169. 3rd & 6th floor 3D plan

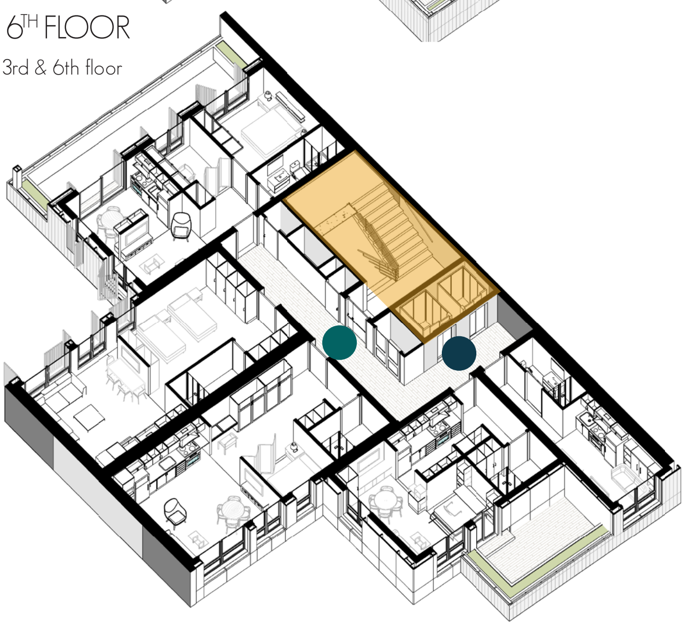
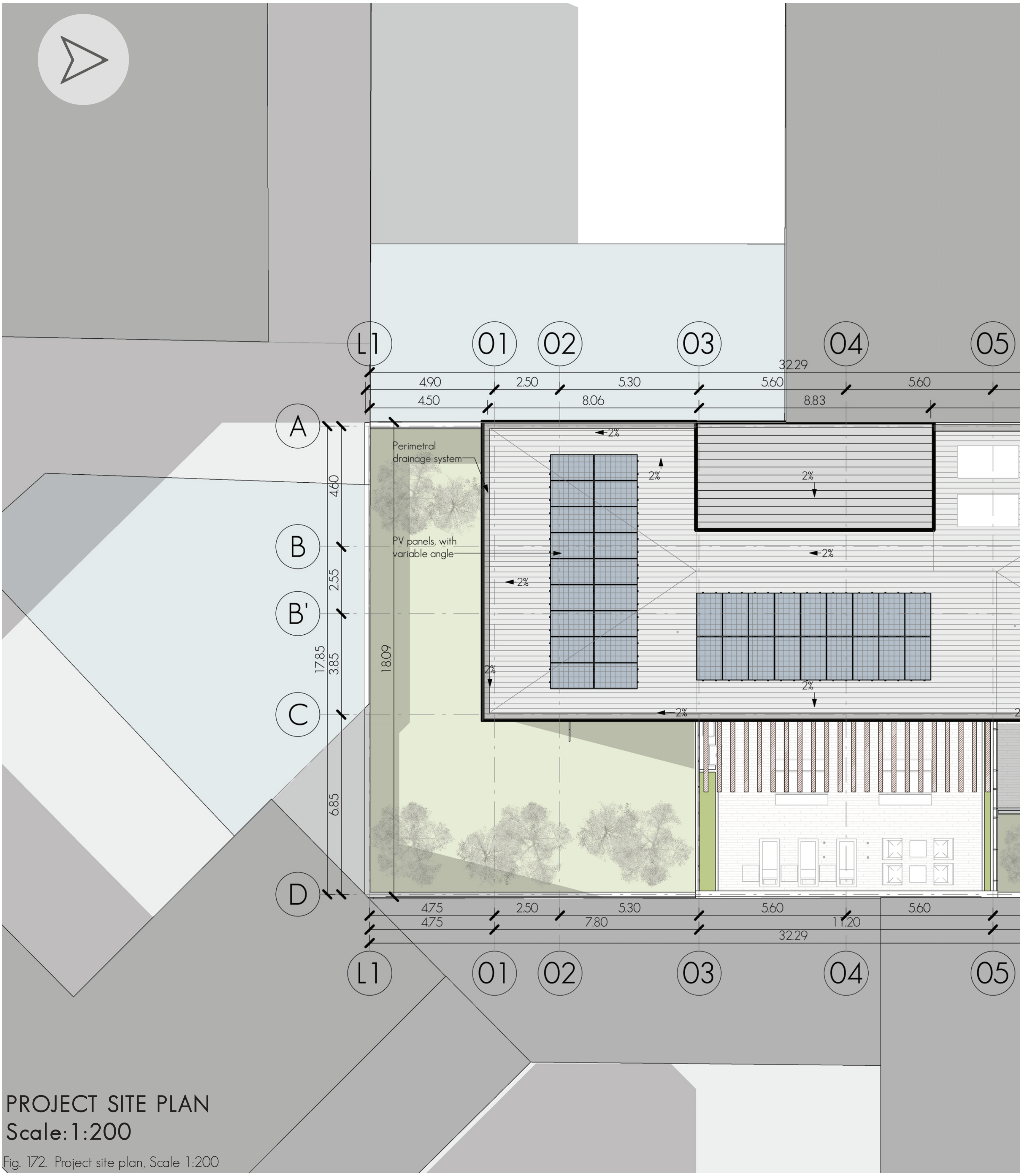


Fig. 170. Function type 3rd & 6th floor

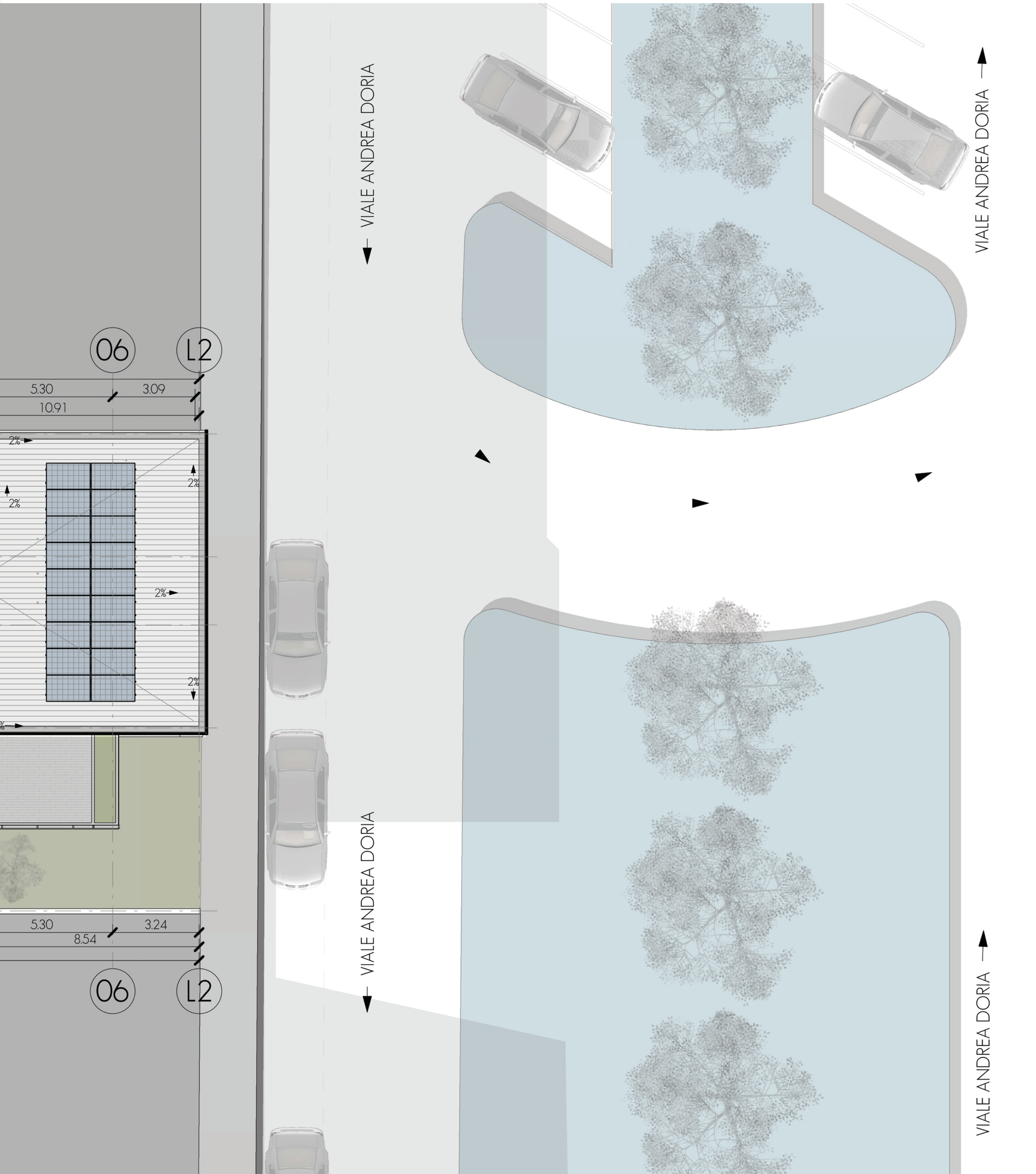
Fig. 171. Module type- 3rd & 6th floor

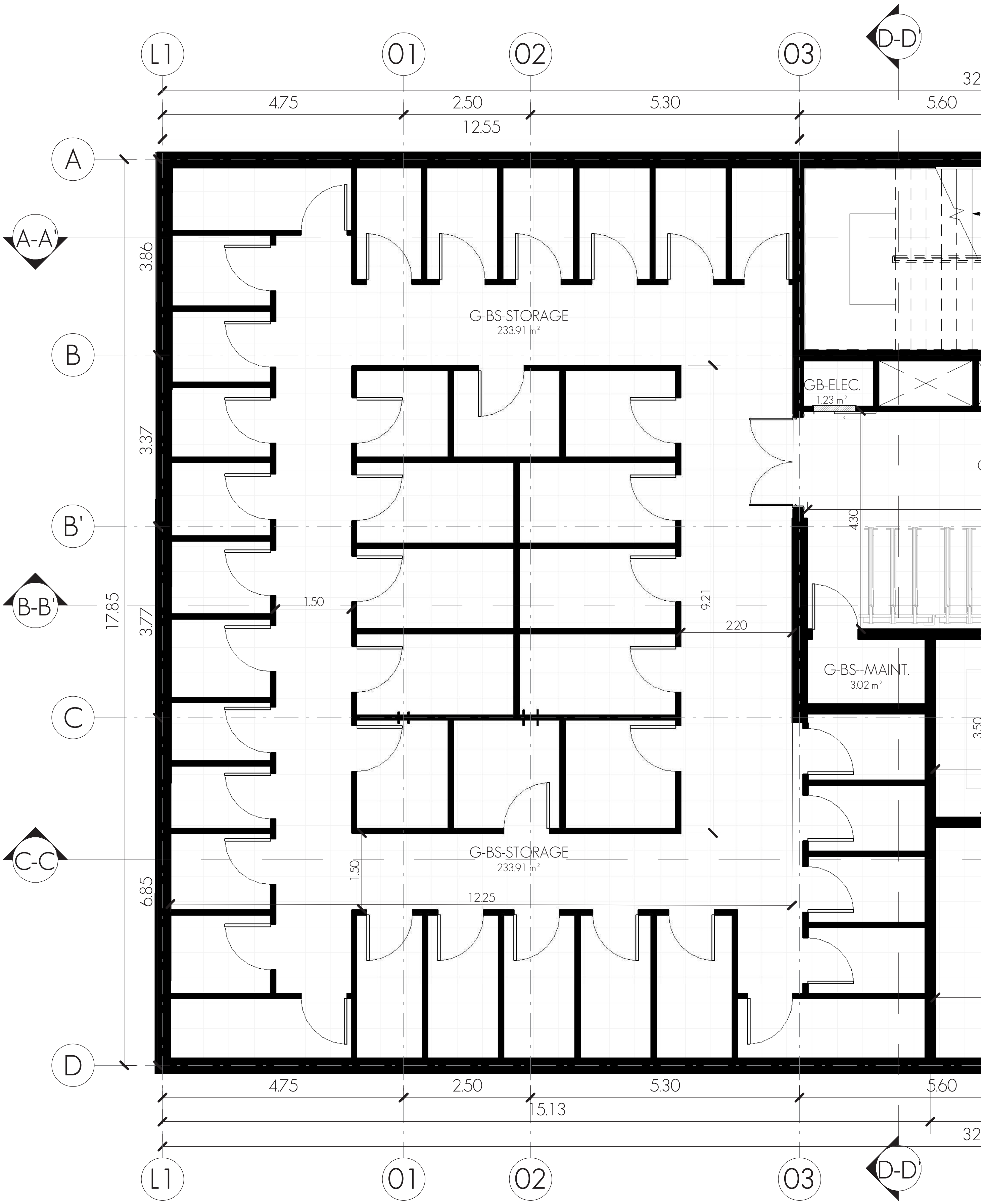
4.8 ARCHITECTURAL PLANS

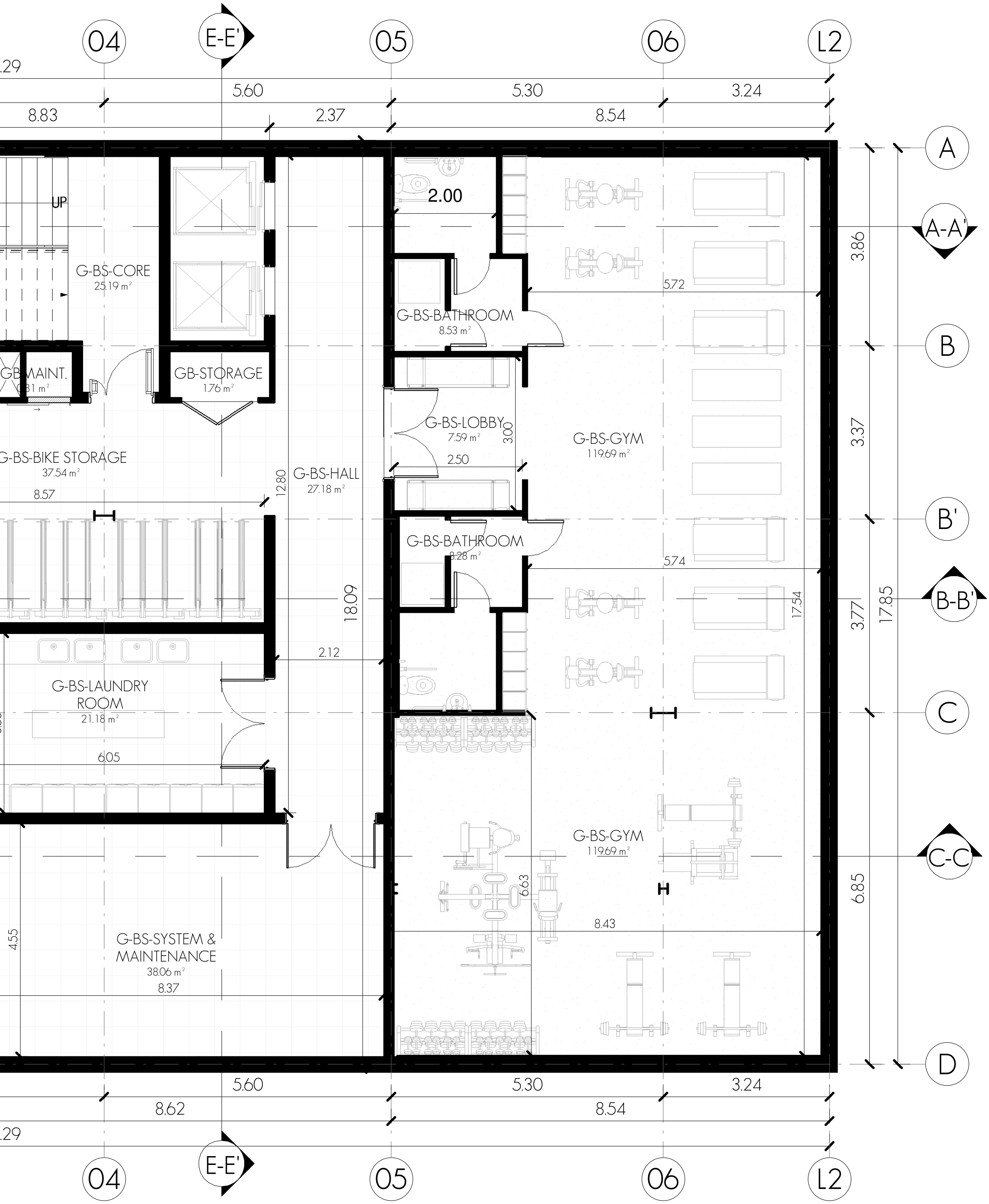


PROJECT SITE PLAN
Scale:1:200

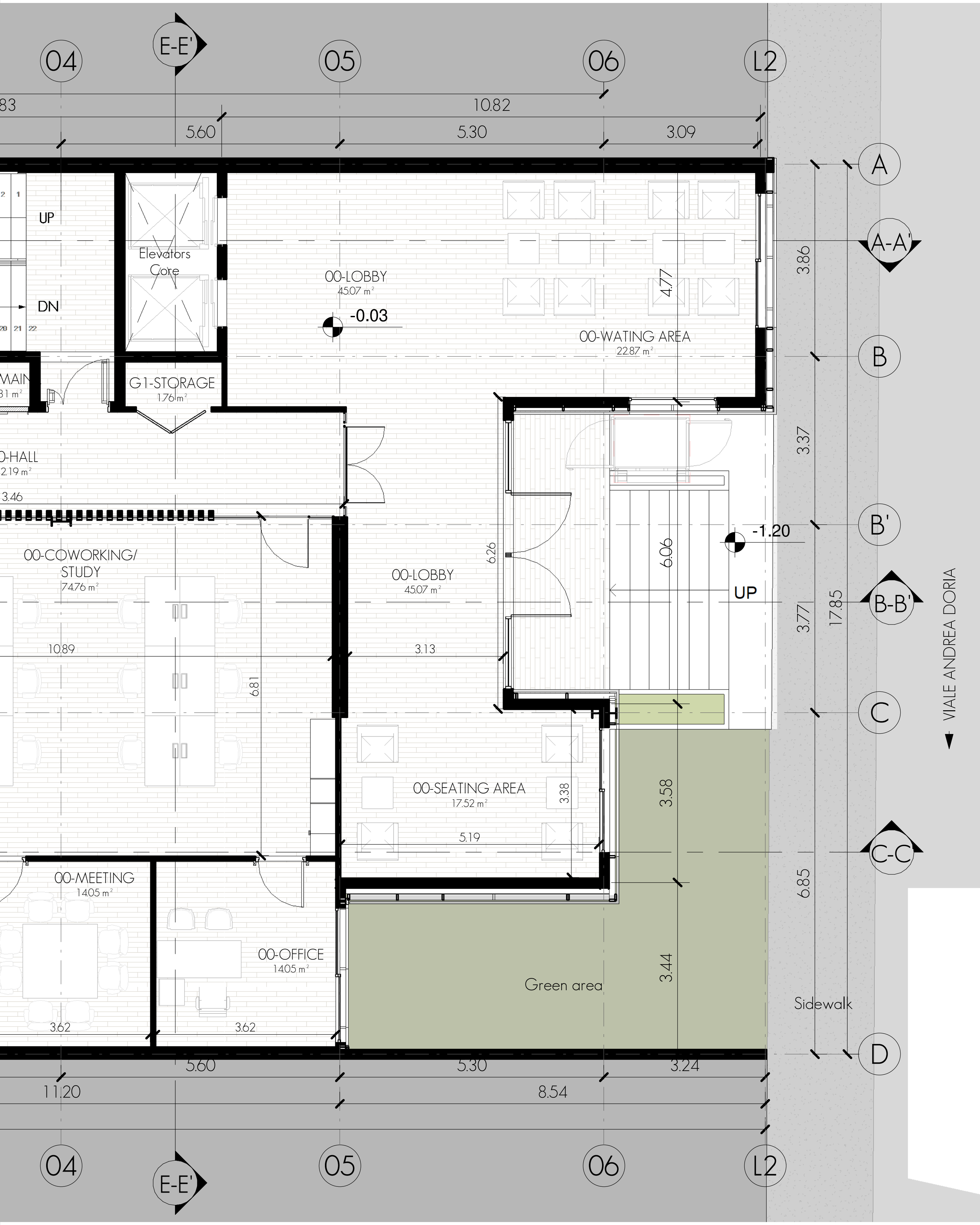
Fig. 172. Project site plan, Scale 1:200


VIALE ANDREA DORIA
VIALE ANDREA DORIA
VIALE ANDREA DORIA
VIALE ANDREA DORIA
06
L2
5.30
3.09
10.91
2%
2%
2%
2%
2%
5.30
3.24
8.54
06
L2


L1
01
02
03
D-D'
4.75
2.50
5.30
5.60
12.55
A
A-A'
B
B'
B-B'
C
C-C
D
3.86
3.37
3.77
6.85
17.85
G-BS-STORAGE
233.91 m²
GB-ELEC.
1.23 m²
4.30
1.50
9.21
2.20
G-BS--MAINT.
3.02 m²
12.25
15.13


04
E-E'
05
06
L2
5.60
5.30
3.24
8.83
2.37
8.54
A
A-A'
B
B'
B-B'
C
C-C
D
UP
G-BS-CORE
25.19 m²
2.00
G-BS-BATHROOM
8.53 m²
5.72
GB-STORAGE
1.76 m²
G-BS-LOBBY
7.59 m²
3.00
2.50
G-BS-GYM
119.69 m²
G-BS-BIKE STORAGE
37.54 m²
8.57
G-BS-HALL
27.18 m²
12.80
18.09
G-BS-BATHROOM
8.28 m²
5.74
17.54
3.86
3.37
3.77
17.85
2.12
G-BS-LAUNDRY
ROOM
21.18 m²
6.05
G-BS-GYM
119.69 m²
6.63
6.85
8.43
4.55
G-BS-SYSTEM &
MAINTENANCE
38.06 m²
8.37
8.62


00-MEETING ROOM
23.33 m²
00-WC
5.55 m²
00-STUDY AREA
43.28 m²
00-OFFICE
13.66 m²
G1-ELEC.
1.33 m²
Green area
Green area
-0.23
-0.03
-0.03
A-A'
B-B'
C-C
D-D'
29.05
32.29
17.85
18.09



E-E'
04
05
06
L2
10.82
5.60
5.30
3.09
A
A-A'
B
B'
B-B'
C
C-C
D
UP
DN
Elevators Core
00-LOBBY
45.07 m²
-0.03
4.77
3.86
00-WATING AREA
22.87 m²
G1-STORAGE
1.76 m²
3.37
00-COWORKING/ STUDY
74.76 m²
00-LOBBY
45.07 m²
6.26
6.06
-1.20
UP
17.85
3.77
VIALE ANDREA DORIA
10.89
3.13
6.81
00-SEATING AREA
17.52 m²
3.38
3.58
5.19
00-MEETING
14.05 m²
00-OFFICE
14.05 m²
6.85
3.44
Green area
Sidewalk
3.62
3.62
5.60
5.30
3.24
11.20
8.54

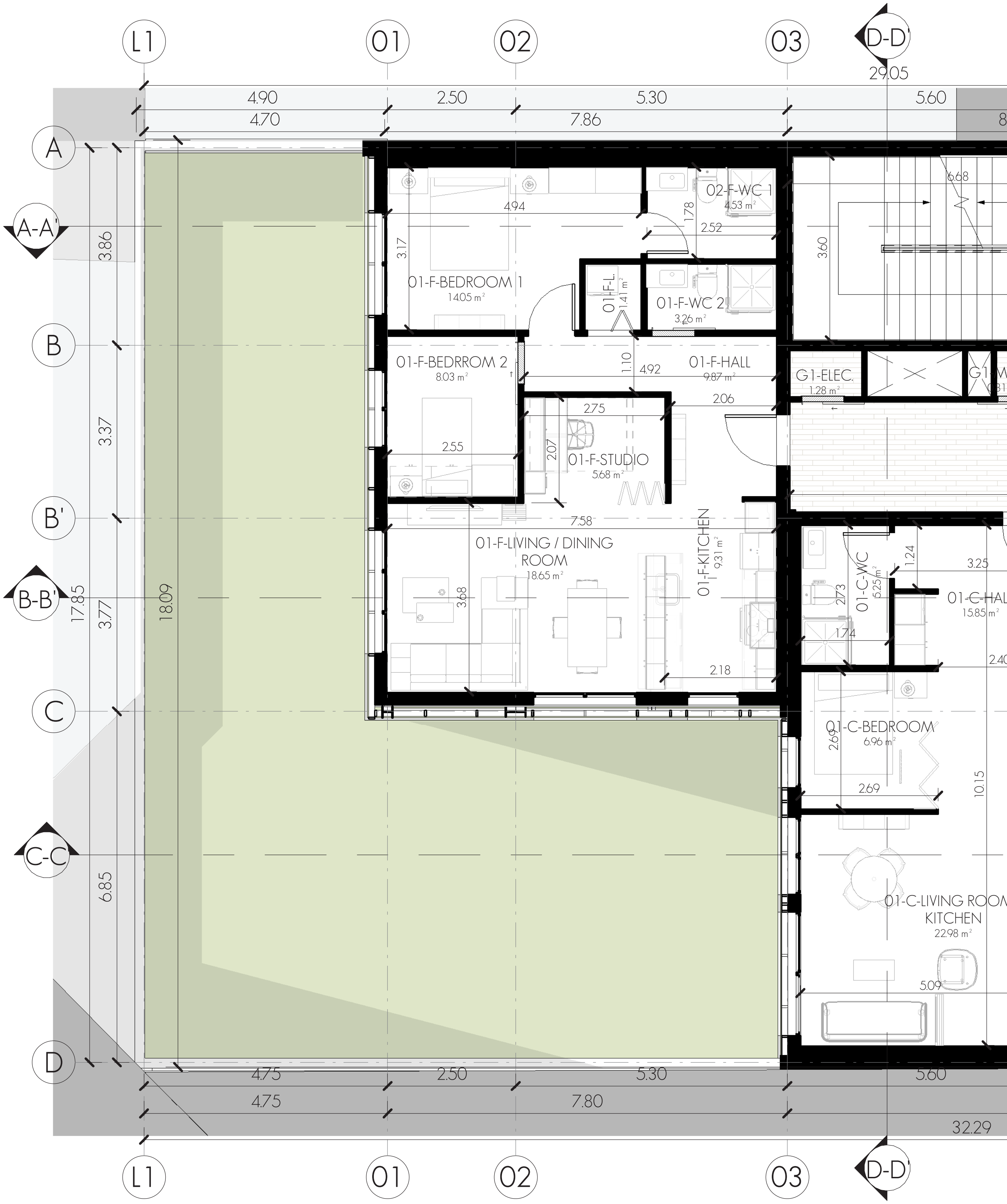
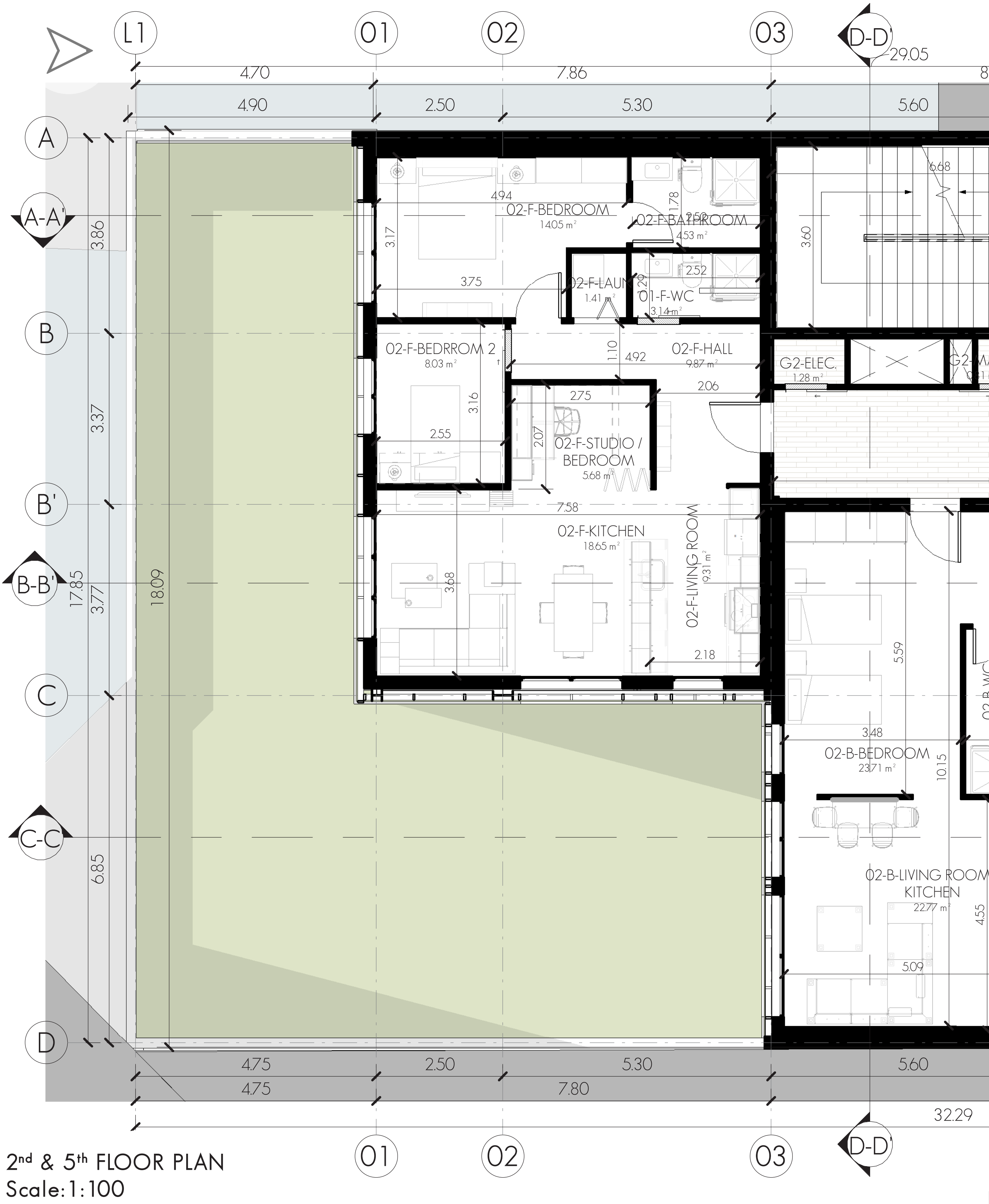


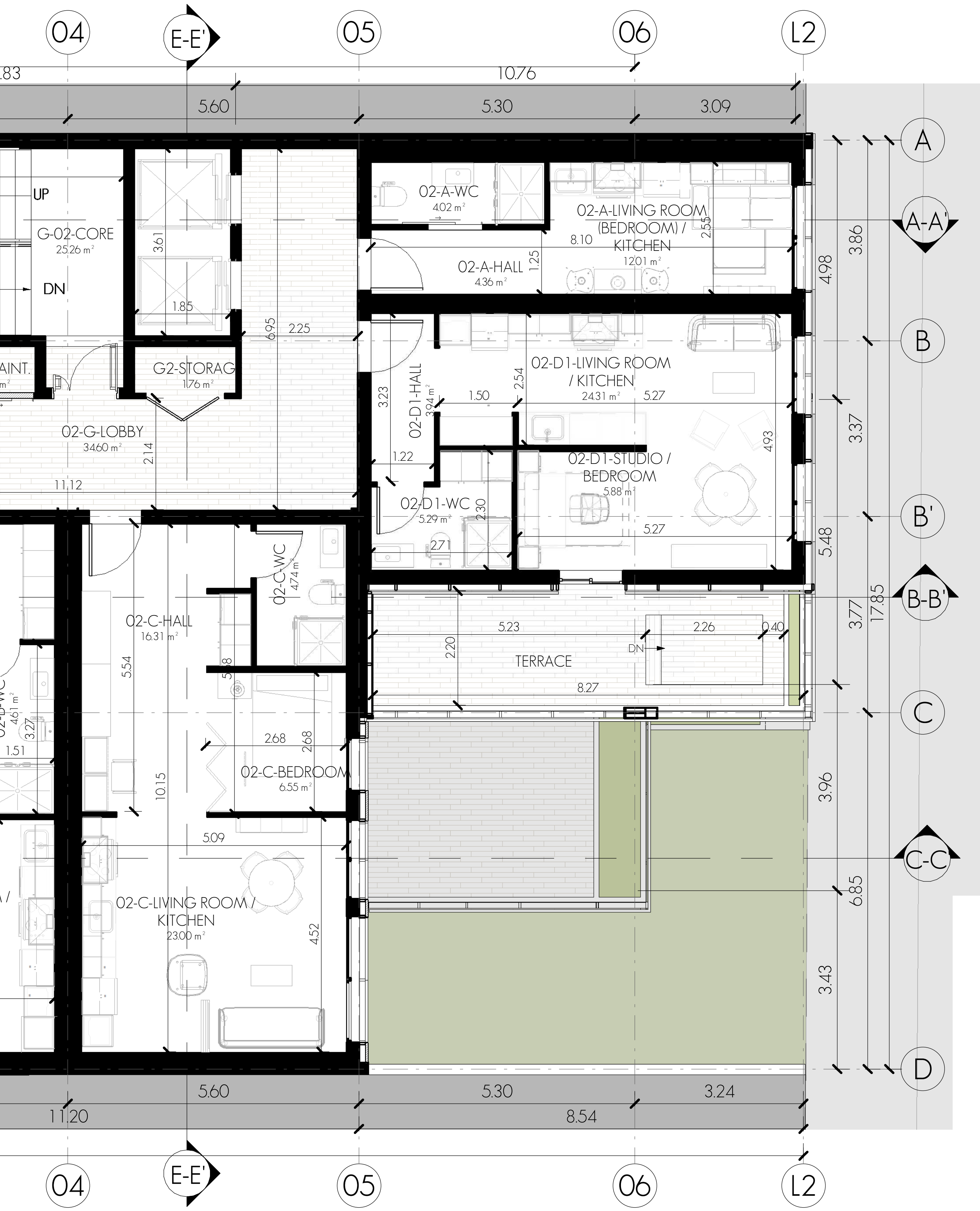
Fig. 175. 1st & 4th floor plan, Scale 1:100


04
E-E'
05
06
L2
A
A-A'
B
B'
B-B'
C
C-C'
D
G-01-CORE
25.26 m²
UP
DN
G1-STORAGE
1.76 m²
01-G-LOBBY
34.60 m²
01-D1-STUDIO / BEDROOM
5.62 m²
01-D1-WC
5.29 m²
01-D1-HALL
4.06 m²
01-D1-LIVING ROOM / KITCHEN
24.49 m²
01-D1-KITCHEN
10.68 m²
01-D1-LIVING ROOM
13.81 m²
01-D1-WC
5.29 m²
01-D1-STUDIO / BEDROOM
5.62 m²
01-B-WC
4.61 m²
01-B-BEDROOM
24.18 m²
01-B-LIVING ROOM / KITCHEN
22.75 m²
TERRACE



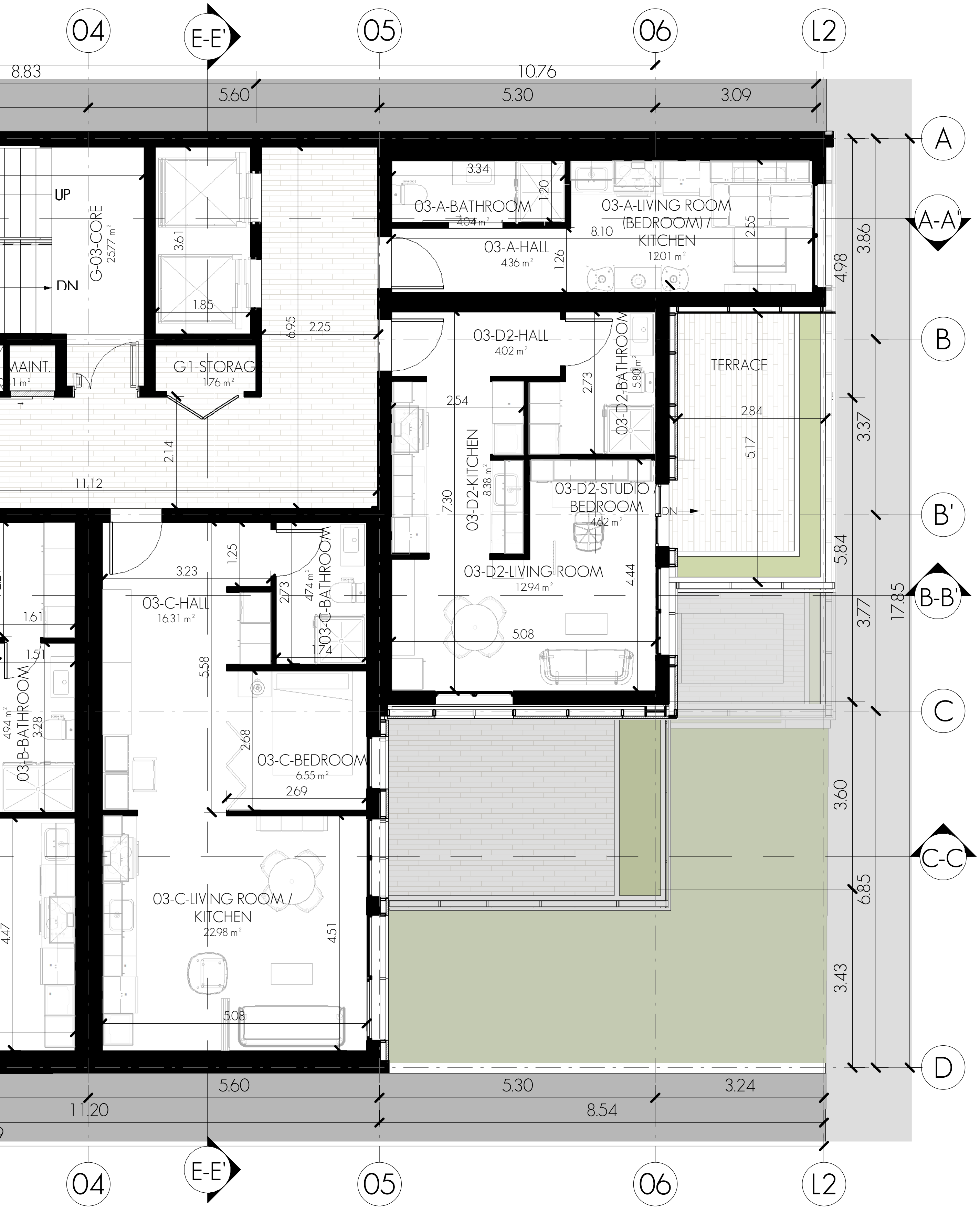
2nd & 5th FLOOR PLAN
Scale:1:100

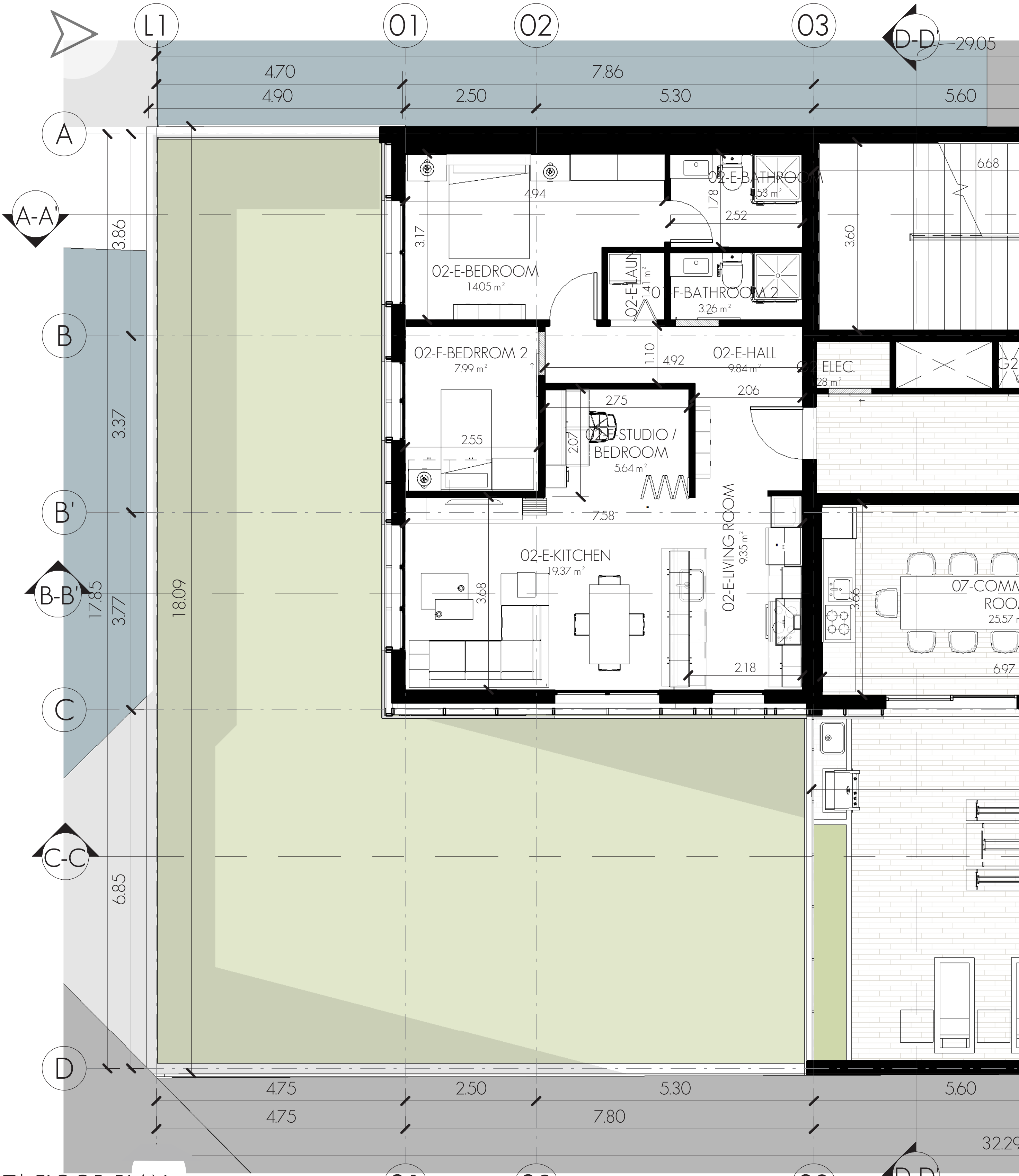
Fig. 176. 2nd & 5th floor plan, Scale 1:100


04
E-E'
05
06
L2
10.76
5.60
5.30
3.09
A
A-A'
B
B'
B-B'
C
C-C
D
G-02-CORE
25.26 m²
UP
DN
02-A-WC
4.02 m²
02-A-LIVING ROOM
(BEDROOM) /
KITCHEN
12.01 m²
02-A-HALL
4.36 m²
G2-STORAG
1.76 m²
02-G-LOBBY
34.60 m²
02-D1-LIVING ROOM
/ KITCHEN
24.31 m²
02-D1-HALL
3.94 m²
02-D1-STUDIO /
BEDROOM
5.88 m²
02-D1-WC
5.29 m²
TERRACE
02-C-HALL
16.31 m²
02-C-WC
4.74 m²
02-C-BEDROOM
6.55 m²
02-C-LIVING ROOM /
KITCHEN
23.00 m²
3.24
11.20
8.54
17.85

3rd & 6th FLOOR PLAN
Scale:1:100

Fig. 177. 3rd & 6th floor plan, Scale 1:100


04
E-E'
05
06
L2
8.83
10.76
5.60
5.30
3.09
A
A-A'
B
B'
B-B'
C
C-C
D
UP
DN
G-03-CORE
25.77 m²
3.61
1.85
6.95
2.25
MAINT.
G1-STORAG
1.76 m²
2.14
11.12
03-A-BATHROOM
4.04 m²
3.34
1.20
03-A-LIVING ROOM
(BEDROOM) /
KITCHEN
12.01 m²
8.10
2.55
03-A-HALL
4.36 m²
1.26
03-D2-HALL
4.02 m²
2.73
03-D2-BATHROOM
5.80 m²
2.54
03-D2-KITCHEN
8.38 m²
7.30
03-D2-STUDIO /
BEDROOM
4.62 m²
DN
03-D2-LIVING ROOM
12.94 m²
4.44
5.08
TERRACE
2.84
5.17
3.23
1.25
03-C-HALL
16.31 m²
2.73
4.74 m²
03-C-BATHROOM
1.74
1.61
1.51
5.58
03-B-BATHROOM
4.94 m²
3.28
2.68
03-C-BEDROOM
6.55 m²
2.69
03-C-LIVING ROOM /
KITCHEN
22.98 m²
4.51
4.47
5.08
4.98
3.86
3.37
5.84
3.77
17.85
3.60
6.85
3.43
5.60
5.30
3.24
11.20
8.54
04
E-E'
05
06
L2



7th FLOOR PLAN

Scale: 1:100

Fig. 178. 7th floor plan, Scale 1:100


04
E-E'
05
06
L2
8.83
10.76
5.60
5.30
3.09
A
A-A'
B
B'
B-B'
C
C-C
D
G-02-CORE
25.77 m²
02-A-BATHROOM
3.52
4.02 m²
02-A-LIVING ROOM
(BEDROOM) /
KITCHEN
12.01 m²
02-A-HALL
4.36 m²
3.30
8.16
MAINT.
G2-STORAGE
1.76 m²
02-G-LOBBY
40.23 m²
G7-STORAGE
2.49 m²
07-GAMING ROOM
41.21 m²
07-WC
3.20 m²
TERRACE
11.24
6.73
2.12
1.60
4.63
4.69
3.86
3.37
6.03
3.77
17.85
3.90
6.85
3.23
11.20
8.54
3.24

SECTION A-A'
Scale:1:200

Fig. 179. Section A-A' Sacle: 1:200

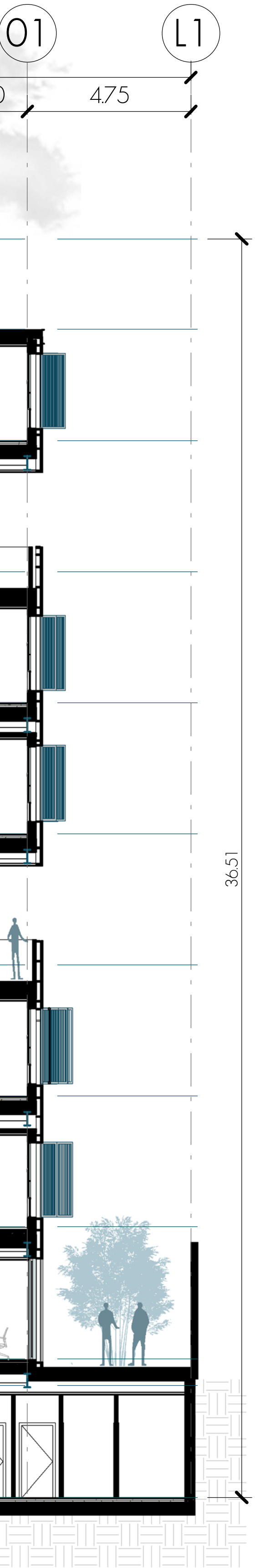
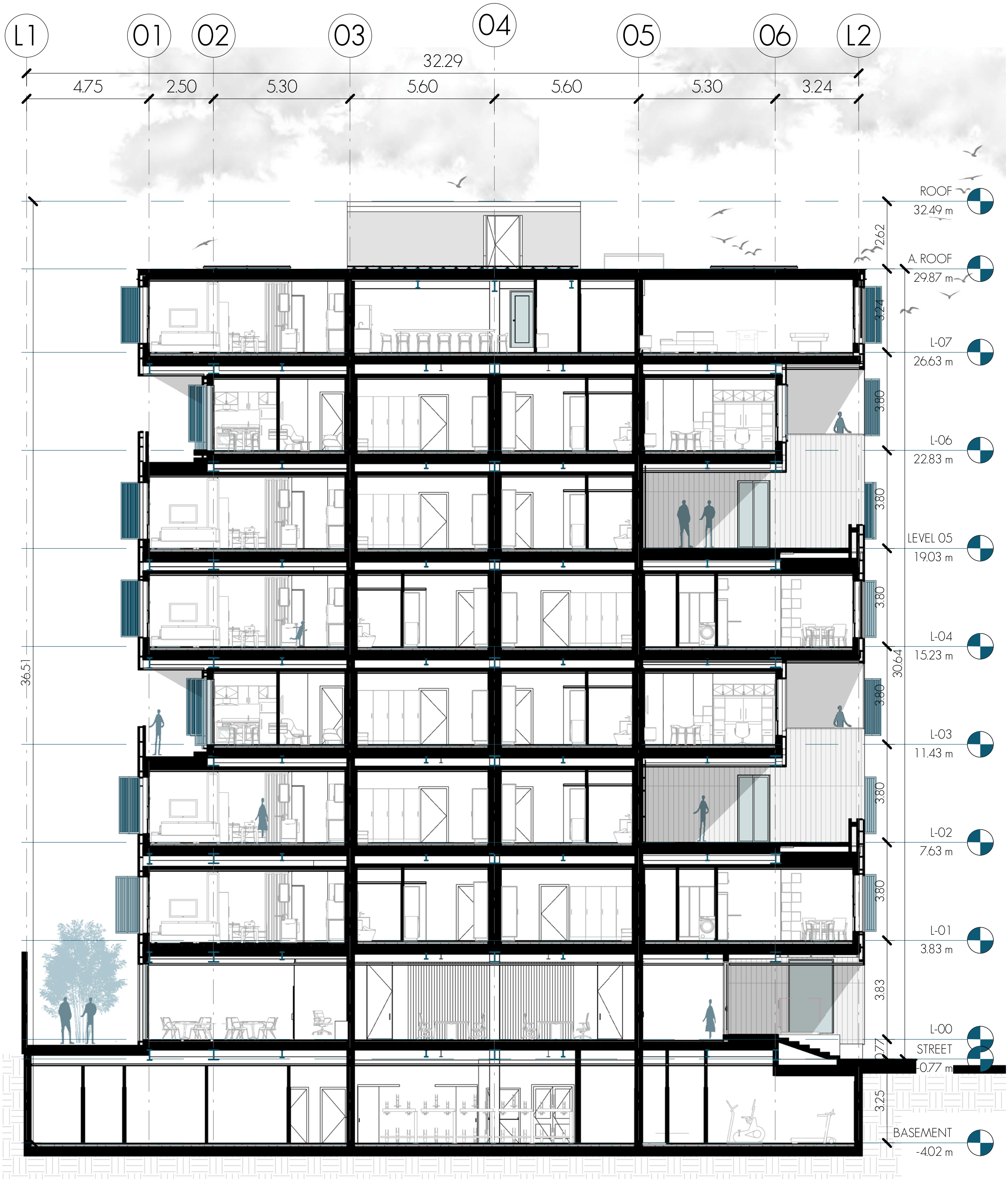


Fig. 180. Balcony view, north facade.

Fig. 181. South elevation, and graden.



SECTION B-B'

Scale: 1:200

Fig. 182. Section B-B' Sacle: 1:200

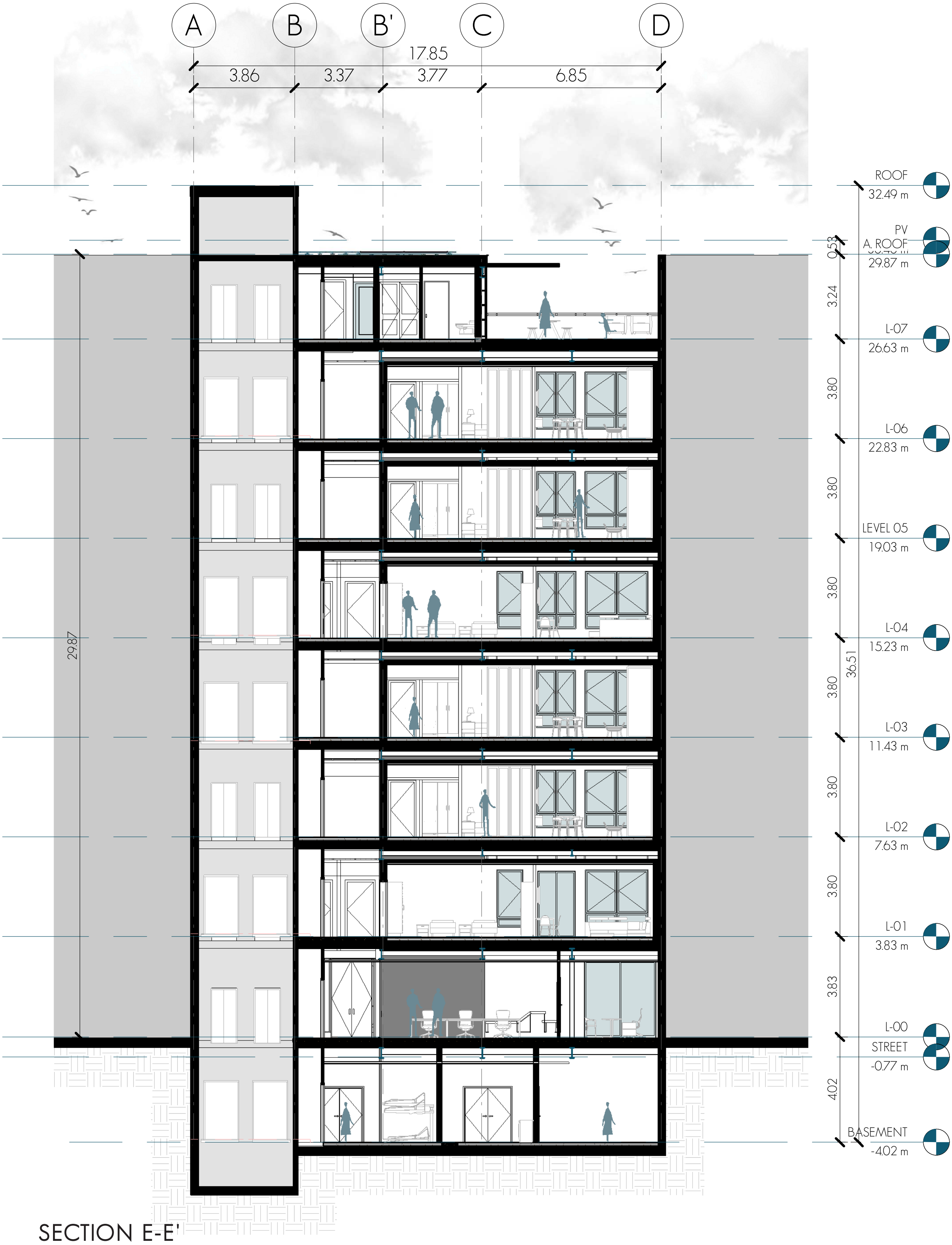
SECTION C-C'

Scale: 1:200

Fig. 183. Section C-C' Sacle: 1:200

SECTION D-D'
Scale:1:200

Fig. 184. Section D-D' Sacle: 1:200



SECTION E-E'

Scale: 1:200

Fig. 185. Section E-E' Sacle: 1:200

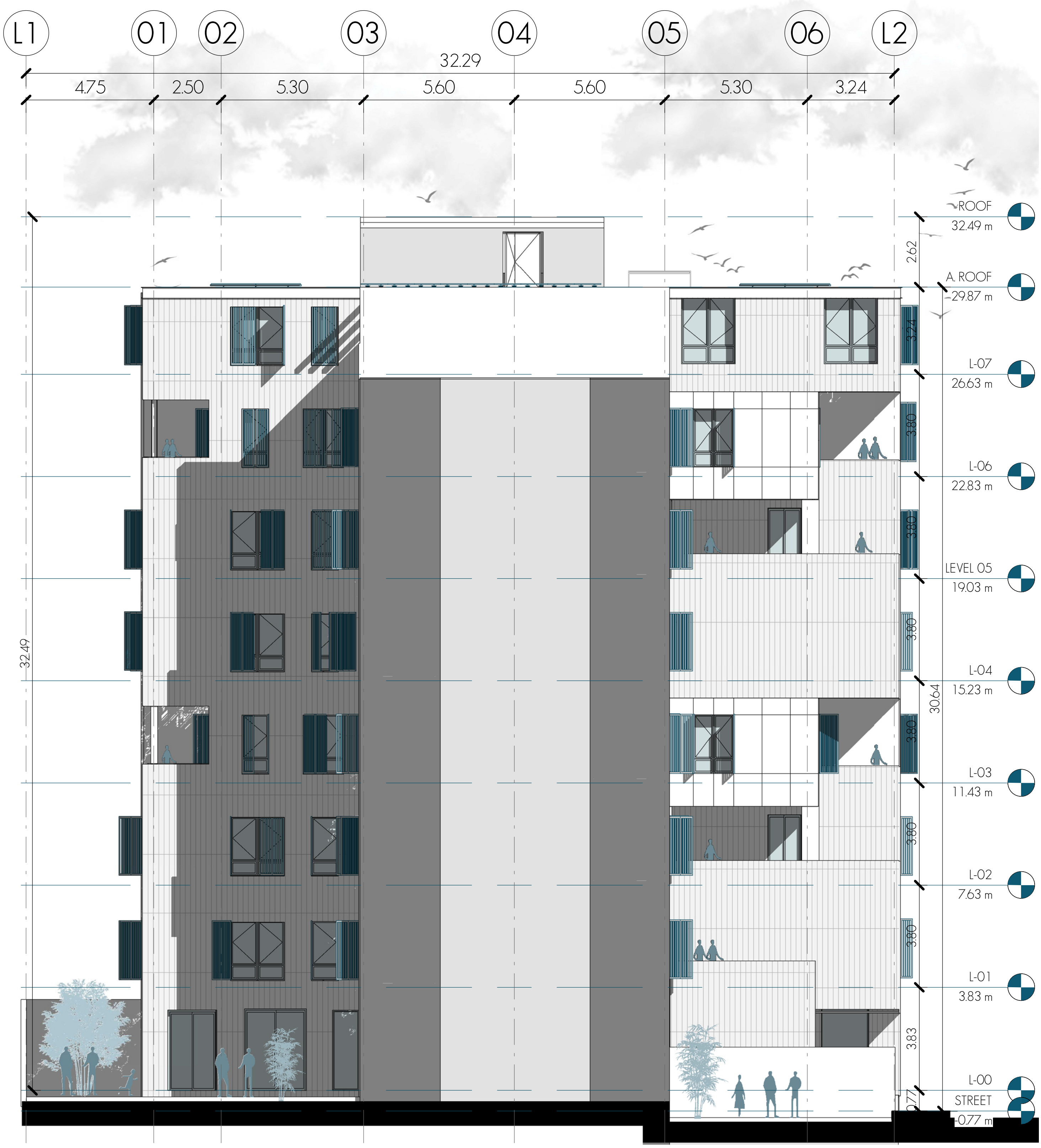
NORTHERN FACADE
Scale:1:200

Fig. 186. Northern Facade, Sacle: 1:200

SOUTHERN FACADE

Scale:1:200

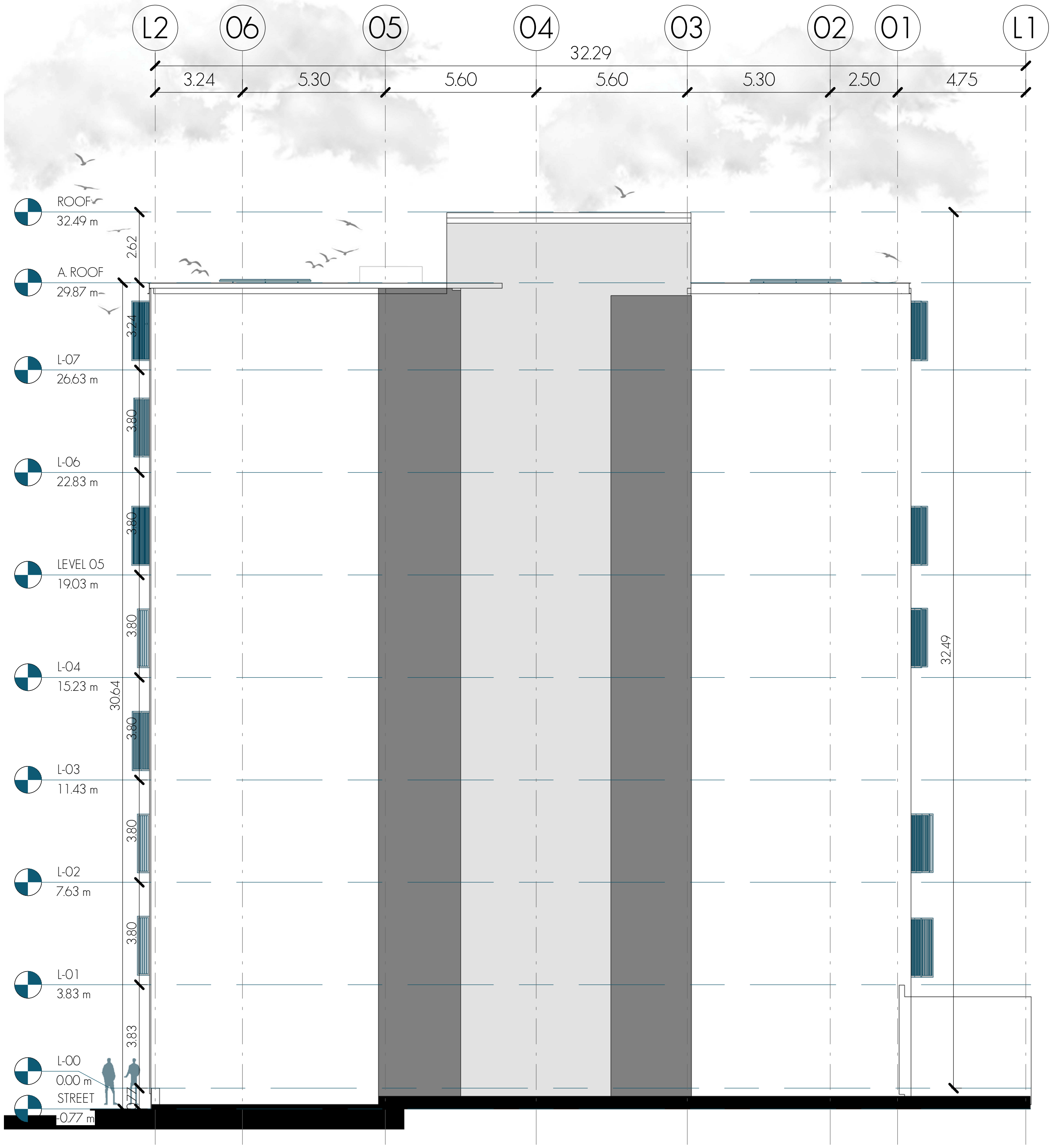
Fig. 187. Southern Facade, Sacle: 1:200



EASTERN FACADE

Scale:1:200

Fig. 188. North Facade, Sacle: 1:200



WESTERN FACADE

Scale:1:200

Fig. 189. Western Facade, Sacle: 1:200

EXTERIOR RENDERS

Fig. 190. Render-No

orth facade view.


Fig. 191. Render-Main entrance

Fig. 192. Render-South Facade and backyard.

Fig. 193. Render-Balconies distribution North Facade

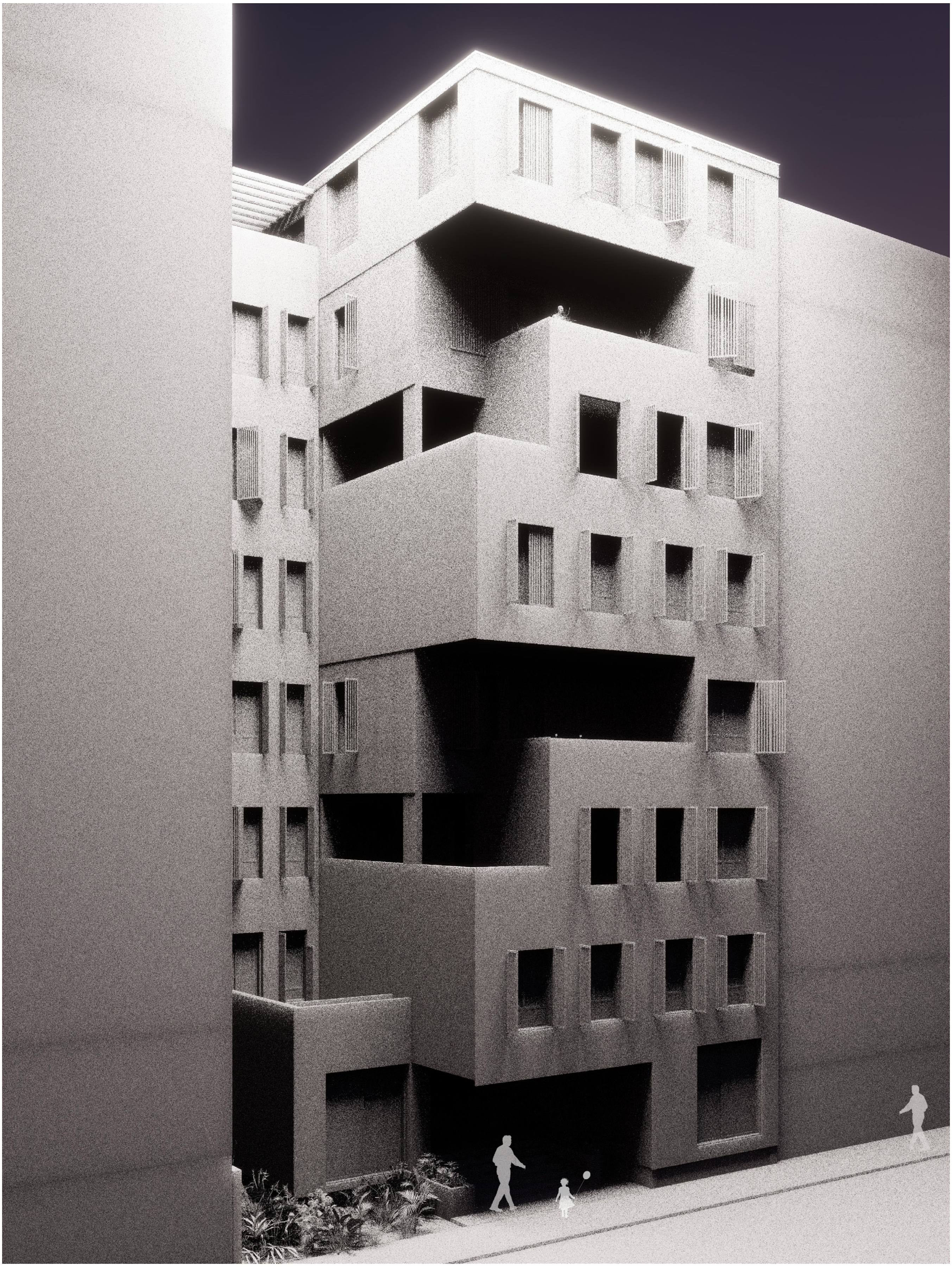


Fig. 194. Render-North Facade street view

INTERIOR RENDERS

Fig. 195. Render-Kitchen vi

iew- Module F

Fig. 196. Render-Dining room and studio view- Module F

Fig. 197. Render-Living room view- Module F

Fig. 198. Render-Living room view- Module E

Fig. 199. Render-Living room view- Module E

Fig. 200. Render-Bedroom view- Module F

5

TECHNICAL SPECIFICATIONS

Construction technologies refer to the various methods, materials, and equipment used in the process of designing, planning, building, and maintaining structures. These technologies have evolved significantly over the years, allowing for faster, safer, and more efficient construction projects. The construction industry has embraced a range of new technologies that have transformed the way we build. Today, construction technologies not only improve the speed and quality of construction projects, but they also help to reduce waste, lower costs, and enhance sustainability.

Once the structural design of the modules is completed, the next step is to design the frame structure that will support them. This involves analyzing the loads transferred from the modules to the frame structure and designing the main and secondary beams and columns accordingly. The frame structure must be strong enough to withstand the loads from the modules and provide a stable foundation for the building.

The schematic design of the foundations and load-bearing walls is the next stage of the structural design process. The foundations must be designed to support the weight of the building and transfer the loads to the ground. Load-bearing walls must also be designed to withstand the loads transferred from the modules and the frame structure. Shear walls are also designed to resist lateral forces such as wind and seismic loads.

One of the main construction technologies that need to be analyzed is stratigraphy, the study of the thermal performance of walls and slabs in buildings. It involves examining the layers of material that make up the structure and analyzing their properties in relation to the temperature gradient, moisture, and heat flows inside the building.

5.1

CONSTRUCTION TECHNOLOGIES

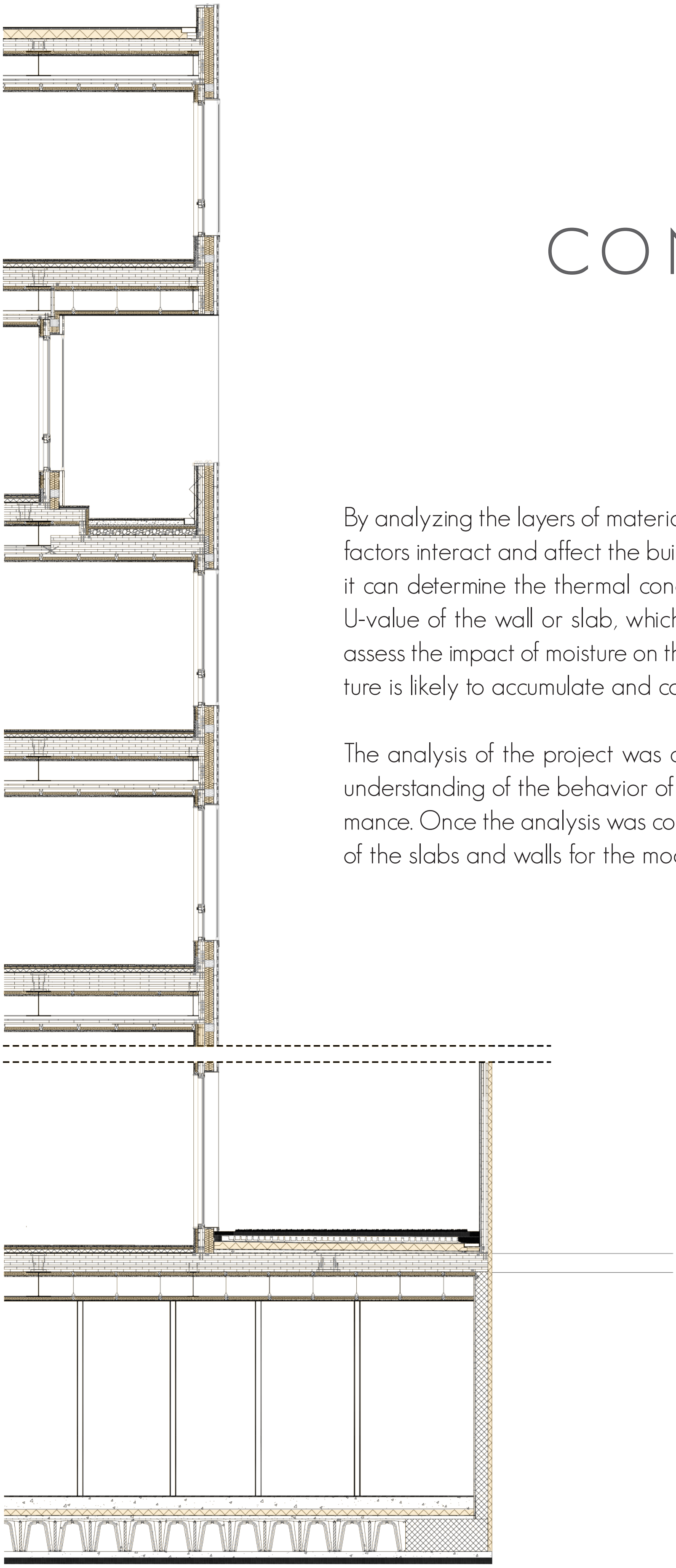
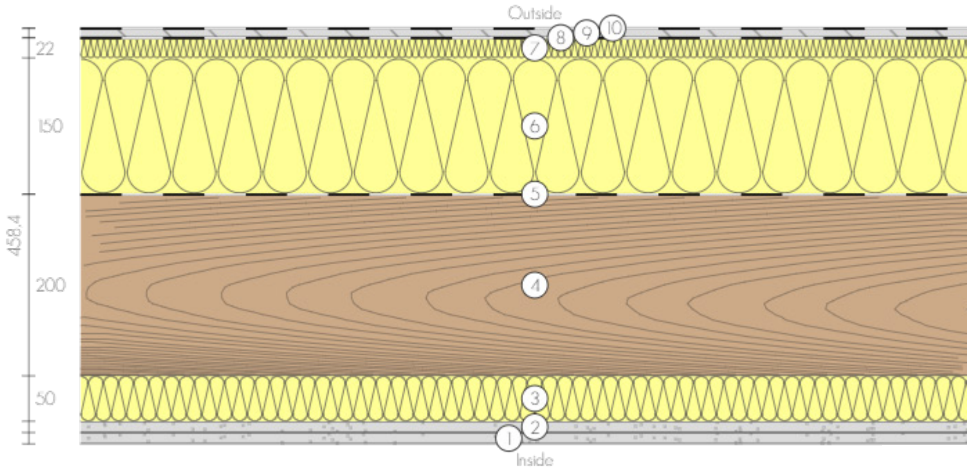


Fig. 201. Detailed building section

By analyzing the layers of material in the walls and slabs, it can be seen how these factors interact and affect the building's overall thermal performance. For example, it can determine the thermal conductivity of each layer and calculate the overall U-value of the wall or slab, which measures its insulation effectiveness. It can also assess the impact of moisture on the structure, such as identifying areas where moisture is likely to accumulate and cause damage.

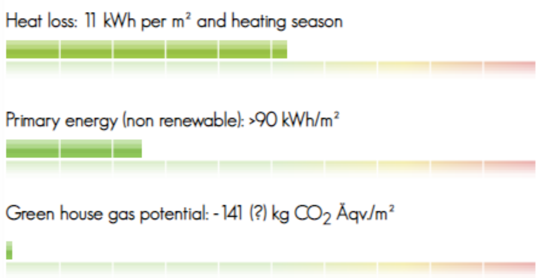
The analysis of the project was carried out using **UBAKUS** which provided an understanding of the behavior of the layers of materials in terms of overall performance. Once the analysis was complete, the materials were utilized in the creation of the slabs and walls for the modules.

5.1.1. FINAL ROOF

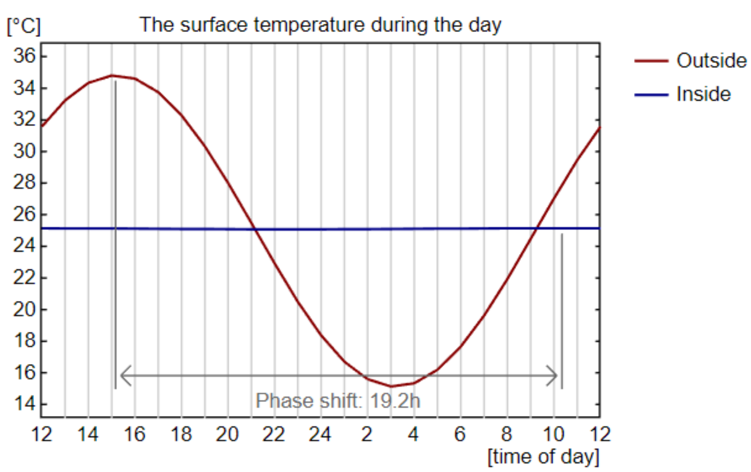


#		Material	λ [W/mK]	R [m²K/W]	Temp. [°C] min	max	sd-value [m]	Condensate [kg/m²] [%]	Weight [kg/m²]	Heat capacity [J/(kg*K)]
		Thermal contact resistance		0,100 (0,250)	19,2	20,0				
1	1,25 cm	Gypsum board	0,250	0,050	19,0	19,2	0,05	-	8,5	960
2	1,25 cm	Gypsum board	0,250	0,050	18,8	19,0	0,05	-	8,5	960
3	5 cm	Mineral wool 040	0,040	1,250	14,6	18,8	0,05	-	1,0	830
4	20 cm	Cross Laminated Timber	0,130	1,538	9,5	14,6	8,00	-	100,0	1600
5	0,05 cm	Vapor Barrier	0,220	0,002	9,5	9,5	10,00	-	0,1	1700
6	15 cm	Mineral wool 040	0,040	3,750	-3,1	9,5	0,15	-	3,0	830
7	2,2 cm	Homatherm EnergiePlus comfort	0,043	0,512	-4,8	-3,1	0,07	-	4,1	2100
8	0,05 cm	Breather membrane sd=0,1m	0,500	0,001	-4,8	-4,8	0,10	-	0,3	1000
9	1 cm	Sandasphalt	0,582	0,017	-4,9	-4,8	0,50	-	16,8	1000
10	0,043 cm	DuPont AirGuard Reflective	0,200	0,002	-4,9	-4,9	0,86	-	0,1	0
		Thermal contact resistance		0,040	-5,0	-4,9				
	45,843 cm	Whole component		7,313			19,83	-	142,5	

Table. 13. Final roof U value calculation



U-VALUE: 0,137 W/(M²K)



Amount of heat that escapes through one square meter of this component during the heating period. Please note: Due to internal and solar gains, the heating demand is lower than the heat loss.

Non-renewable primary energy (= energy from fossil fuels and nuclear energy) that was used to produce the new building materials ("cradle to gate").

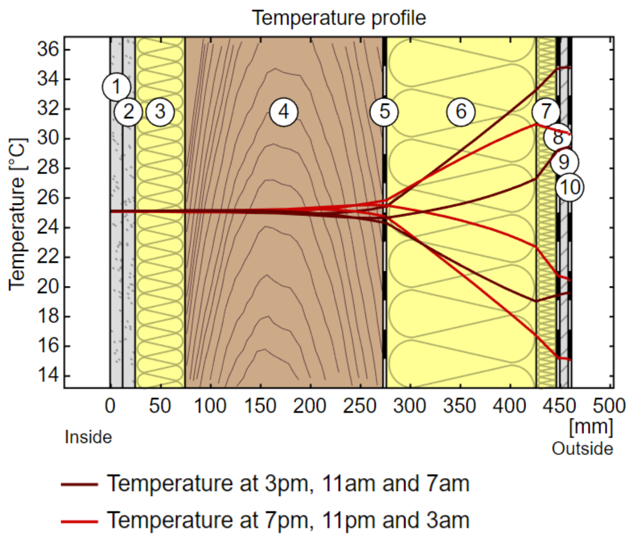
For the production of the building materials used, more greenhouse gases were withdrawn from the atmosphere than emitted.

Fig. 202. Final roof, stratigraphy behavior, U value calculation.

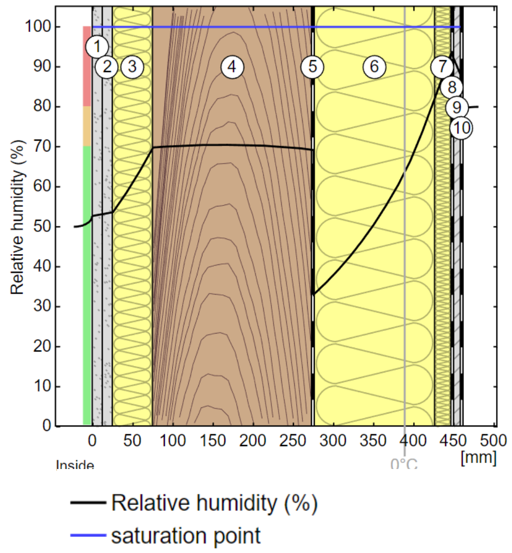
Heat storage capacity (whole component): 206 kJ/m^{2}K
Thermal capacity of inner layers: 129 kJ/m^{2}K

The following figure shows the relative humidity inside the component, 100% = condensate.

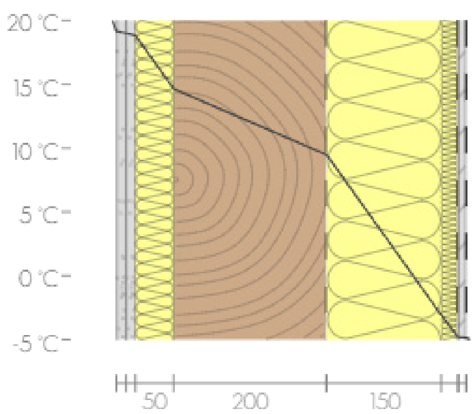
Internal heat behaviour

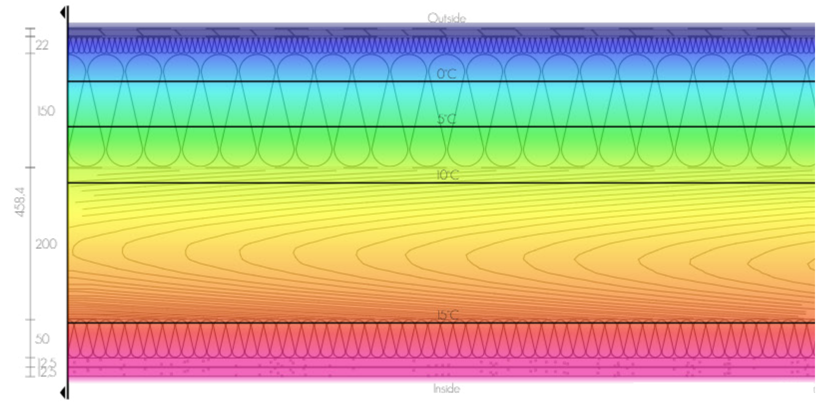


Moisture behaviour

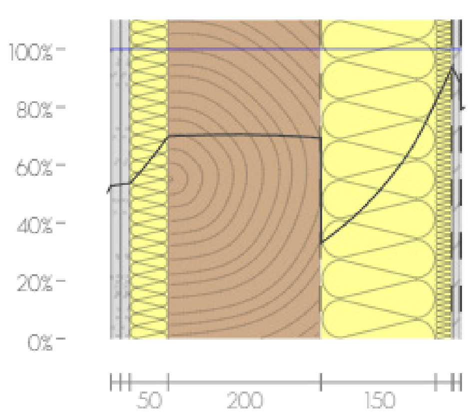


The drawings below shows the cross-section of the temperature behavior in the stratigraphy.





The drawings below shows the cross-section of the humidity behavior in the stratigraphy.



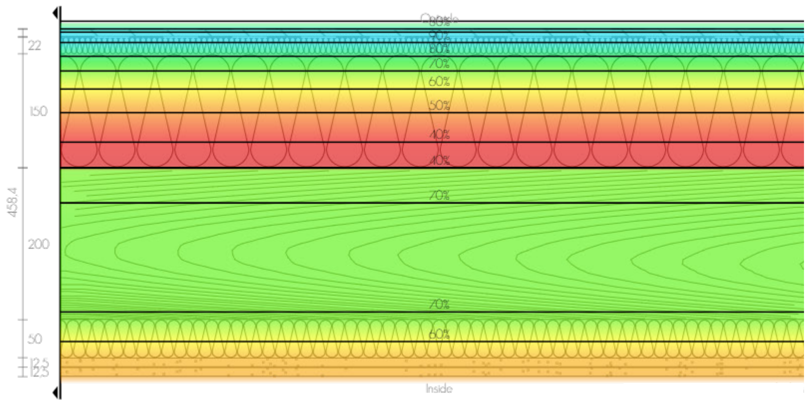
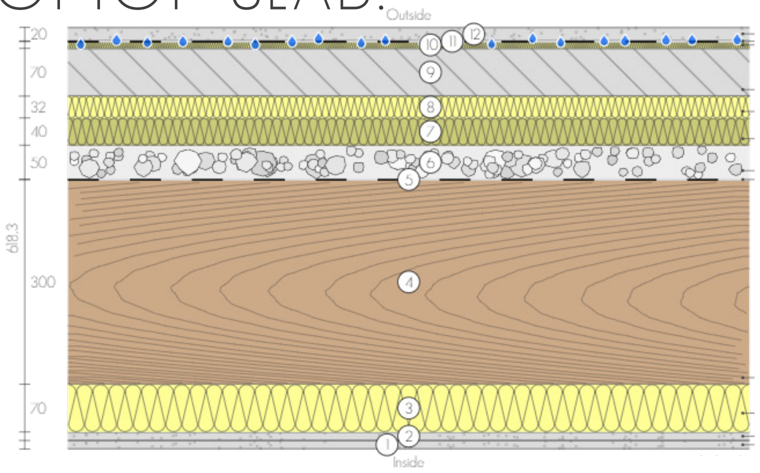


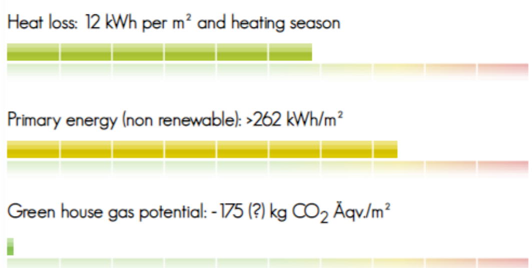
Fig. 203. Final roof, stratigraphy thermal and humidity behavior.

5.1.2. ROOFTOP SLAB.



#		Material	λ [W/mK]	R [m²K/W]	Temp. [°C] min	max	sd-value [m]	Condensate [kg/m²]	[%]	Weight [kg/m²]	Heat capacity [J/(kg*K)]
		Thermal contact resistance		0,100 (0,250)	19,1	20,0					
1	1,25 cm	Gypsum board	0,250	0,050	18,9	19,1	0,05	-		8,5	960
2	1,25 cm	Gypsum board	0,250	0,050	18,7	18,9	0,05	-		8,5	960
3	7 cm	mineral wool 040	0,040	1,750	12,3	18,7	0,07	-		1,4	830
4	30 cm	Cross Laminated Timber	0,130	2,308	3,8	12,3	12,00	-		150,0	1600
5	0,05 cm	Vapor retarder sd=2,3m	0,220	0,002	3,7	3,8	2,30	-		0,1	1700
6	5 cm	gravel	2,150	0,023	3,7	3,7	2,50	-		120,0	900
7	4 cm	Impact sound insulation	0,035	1,143	-0,6	3,7	0,04	-		4,8	1030
8	3,2 cm	PAVAPOR	0,040	0,800	-3,5	-0,6	0,16	-		4,3	2100
9	7 cm	Cement screed	1,400	0,050	-3,7	-3,5	1,05	-		140,0	1000
10	1 cm	Rigid foam EPS	0,035	0,286	-4,7	-3,7	0,05	0,052	17	0,3	2500
11	0,08 cm	EPDM waterproofing membrane	0,250	0,003	-4,8	-4,7	4,80	-		0,9	1000
12	2 cm	Tiles (ceramic)	0,720	0,028	-4,9	-4,8	6,00	-		40,0	840
		Thermal contact resistance		0,040	-5,0	-4,9					
	61,83 cm	Whole component		6,633			29,07	0,052		478,9	

Table. 14. Rooftop U value calculation



Amount of heat that escapes through one square meter of this component during the heating period. Please note: Due to internal and solar gains, the heating demand is lower than the heat loss.

Non-renewable primary energy (= energy from fossil fuels and nuclear energy) that was used to produce the new building materials ("cradle to gate").

For the production of the building materials used, more greenhouse gases were withdrawn from the atmosphere than emitted.

U-VALUE: 0,151 W/(M²K)

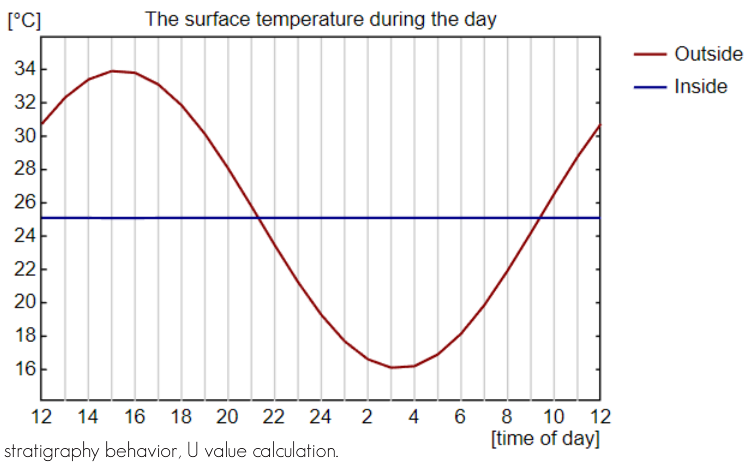
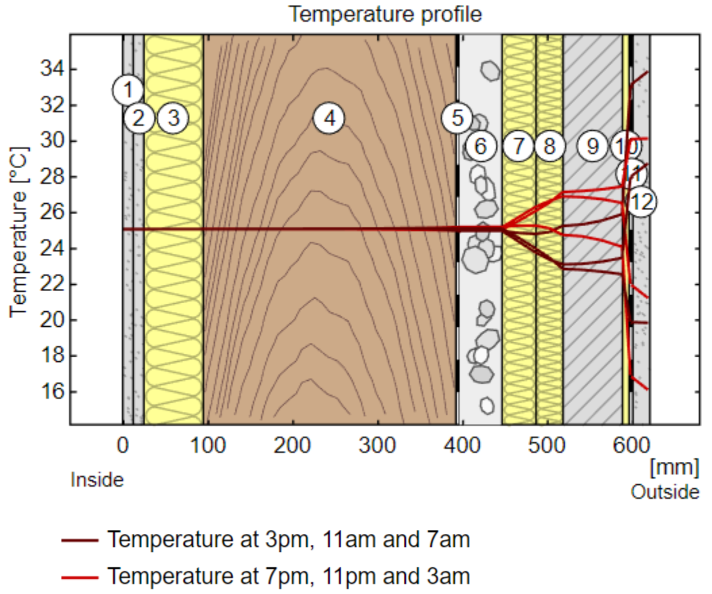


Fig. 204. Rooftop slab stratigraphy behavior, U value calculation.

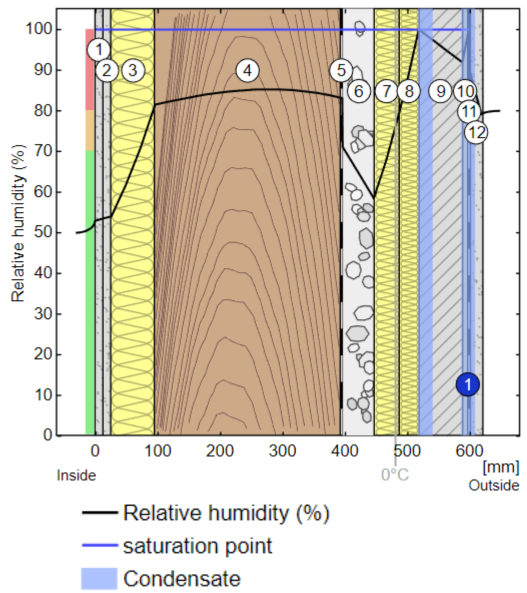
Heat storage capacity (whole component): 555 kJ/m²K
Thermal capacity of inner layers: 194 kJ/m²K

The following figure shows the relative humidity inside the component, 100% = condensate.

Internal heat behaviour

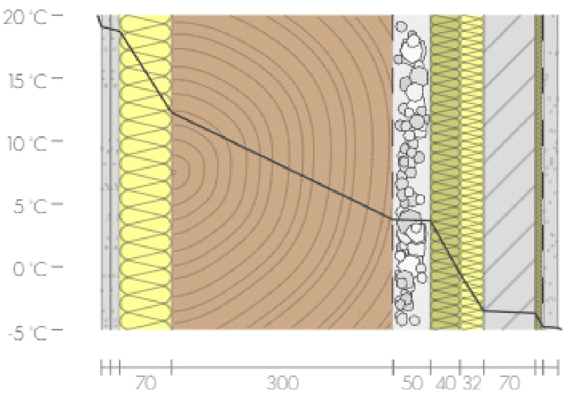


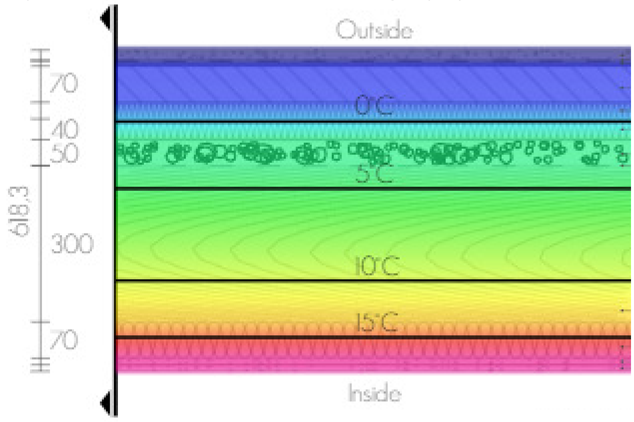
Moisture behaviour



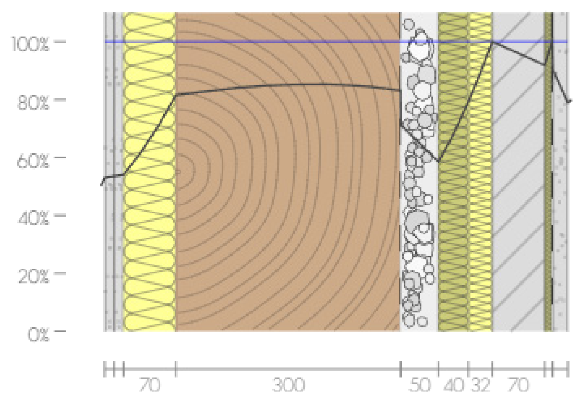
1. Condensate amount: 0,052 kg/m²; Affected layers: EPDM waterproofing membrane, Rigid foam EPS

The drawings below illustrate the cross-section of the temperature behavior in the stratigraphy.





The drawings below show the cross-section of the humidity behavior in the stratigraphy.



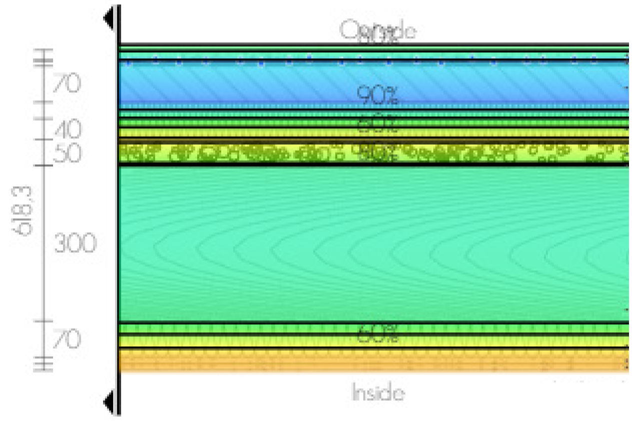
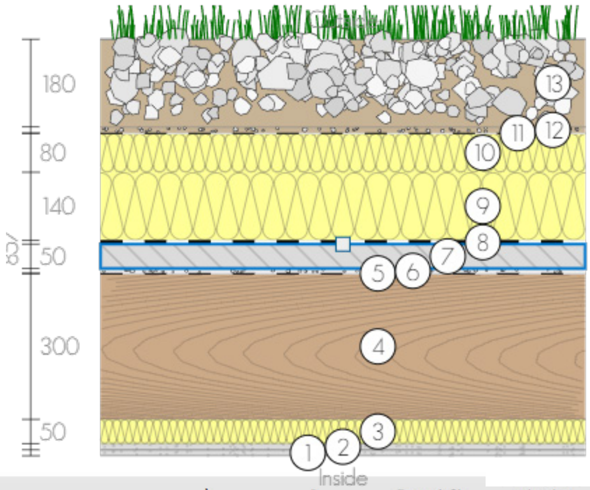


Fig. 205. Rooftop stratigraphy thermal and humidity behavior.

5.1.3. GREEN ROOF



#		Material	λ [W/mK]	R [m²K/W]	Temp. [°C] min	max	sd-value [m]	Condensate [kg/m²] [%]	Weight [kg/m²]	Heat capacity [J/(kg*K)]
		Thermal contact resistance		0,100 (0,250)	19,4	20,0				
1	1,25 cm	Gypsum board	0,250	0,050	19,2	19,4	0,05	-	8,5	960
2	1,25 cm	Gypsum board	0,250	0,050	19,1	19,2	0,05	-	8,5	960
3	5 cm	Independent studs with 50mm mineral wool in stud c	0,041	1,220	16,1	19,1	0,05	-	2,8	1130
4	30 cm	Cross Laminated Timber	0,130	2,308	10,3	16,1	12,00	-	150,0	1600
5	0,05 cm	Vapor barrier sd=100m	0,220	0,002	10,3	10,3	100,00	-	0,1	1700
6	1 cm	gravel 16/32	0,700	0,014	10,3	10,3	0,03	-	18,0	1000
7	5 cm	Cement screed	1,400	0,036	10,2	10,3	0,75	-	100,0	1000
8	0,8 cm	BITUMAT PVC Waterproofing Membrane	0,170	0,047	10,0	10,2	640,00	-	8,4	1000
9	14 cm	Homatherm HDP protect	0,041	3,415	1,5	10,0	0,42	-	19,6	2100
10	8 cm	swissor EPS Perimeter Drain	0,033	2,424	-4,6	1,5	5,60	-	2,4	0
11	0,05 cm	Breather membrane sd=0,05m	0,500	0,001	-4,6	-4,6	0,05	-	0,4	1000
12	1,3 cm	Geotextil, offen	0,500	0,026	-4,6	-4,6	0,04	-	11,2	600
13	18 cm	Soil	1,750	0,103	-4,9	-4,6	9,00	-	306,0	1000
		Thermal contact resistance		0,040	-5,0	-4,9				
	85,7 cm	Whole component		9,835			768,04	-	635,8	

Table. 15. Green roof U value calculation

Heat loss: 8 kWh per m² and heating season

Primary energy (non renewable): >217 kWh/m²

Green house gas potential: -203 (?) kg CO_2 Äqv./m²

Amount of heat that escapes through one square meter of this component during the heating period. Please note: Due to internal and solar gains, the heating demand is lower than the heat loss.

Non-renewable primary energy (= energy from fossil fuels and nuclear energy) that was used to produce the new building materials ("cradle to gate").

For the production of the building materials used, more greenhouse gases were withdrawn from the atmosphere than emitted.

U-VALUE: 0,102 W/(M²K)

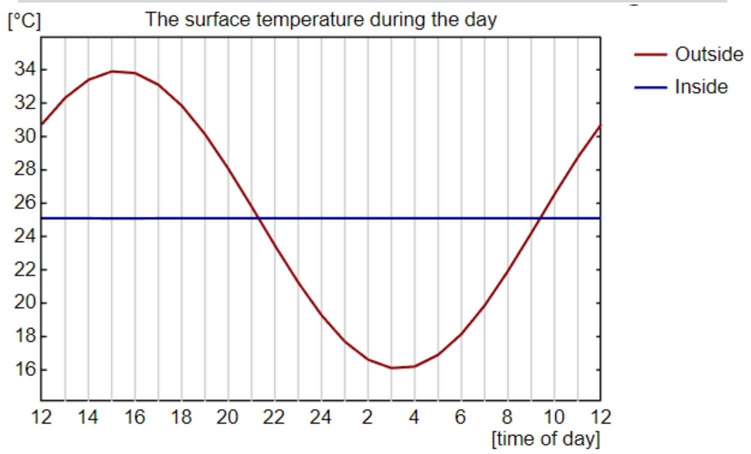
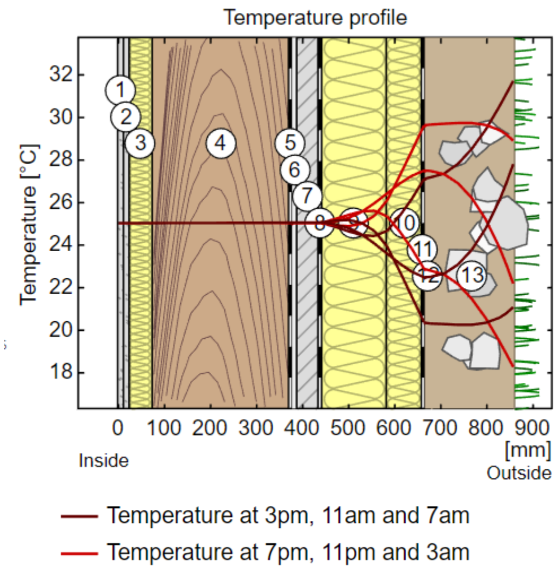


Fig. 206. Green roof, stratigraphy behavior, U value calculations.

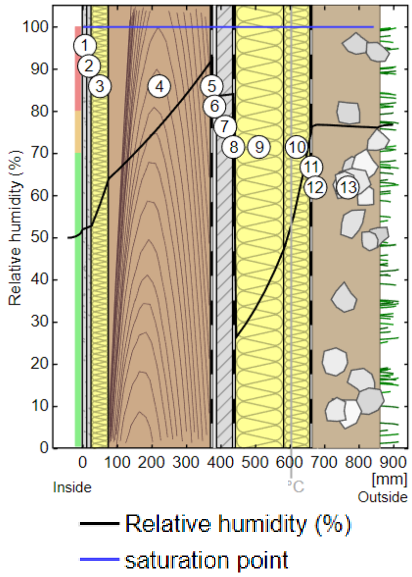
Heat storage capacity (whole component): 743 kJ/m²K
Thermal capacity of inner layers: 296 kJ/m²K

Internal heat behaviour

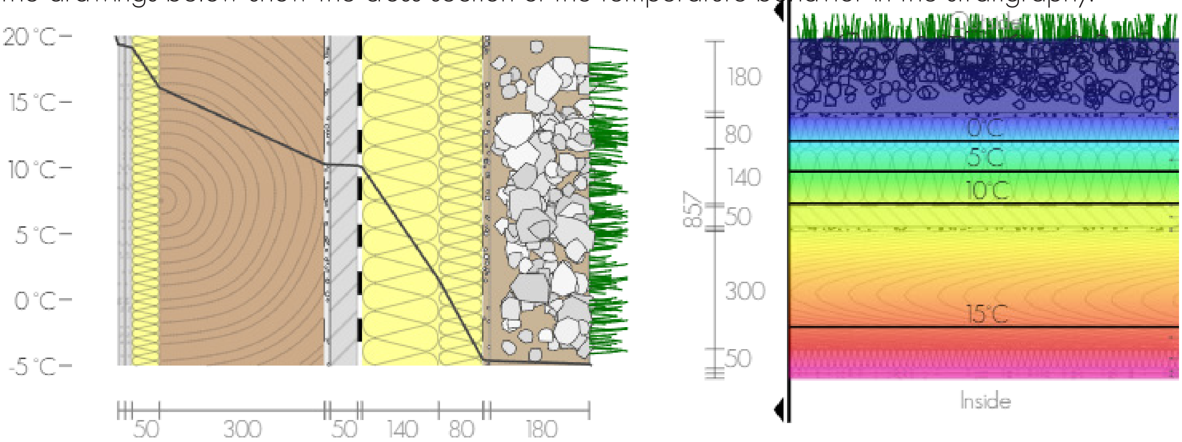


The following figure shows the relative humidity inside the component, 100% = condensate.

Moisture behaviour



The drawings below show the cross-section of the temperature behavior in the stratigraphy.



The drawings below illustrate the cross-section of the humidity behavior in the stratigraphy.

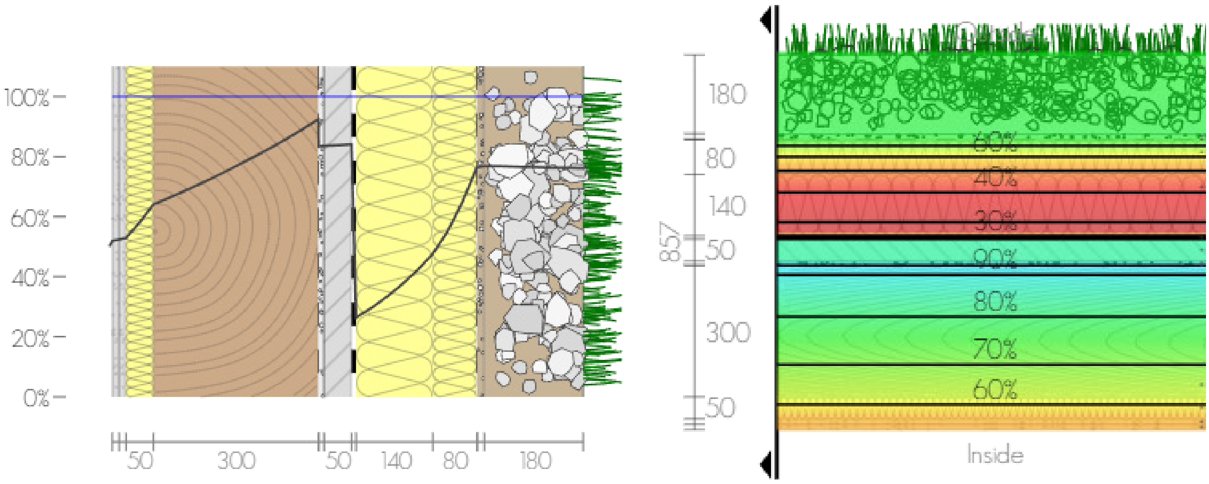
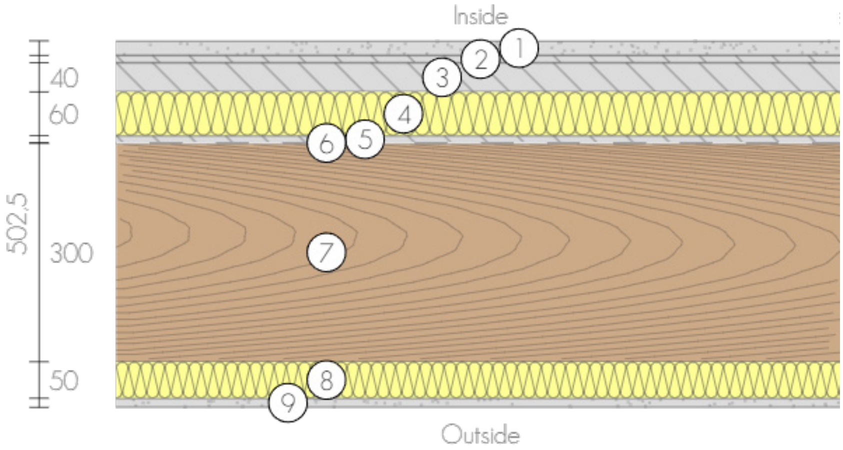


Fig. 207. Green roof, stratigraphy thermal and humidity behavior.

5.1.4. MODULE SLAB



#		Material	λ [W/mK]	R [m²K/W]	Temp. [°C] min	max	sd-value [m]	Condensate [kg/m²] [%]	Weight [kg/m²]	Heat capacity [J/(kg*K)]
		Thermal contact resistance		0,170 (0,250)	20,0	20,0				
1	2 cm	Tiles (ceramic)	1,200	0,017	20,0	20,0	3,00	-	40,0	840
2	1 cm	Self-leveling Beton Ultraplan	0,036	0,278	20,0	20,0	0,15	-	0,4	1880
3	4 cm	Radiant heating panels Betonradiant	0,260	0,154	20,0	20,0	2,80	-	54,0	1880
4	6 cm	Gutex Thermofibre	0,040	1,500	20,0	20,0	0,12	-	2,1	2100
5	1 cm	Self-leveling Beton Ultraplan	0,036	0,278	20,0	20,0	0,15	-	0,4	1880
7	30 cm	Cross Laminated Timber	0,130	2,308	20,0	20,0	60,00	-	150,0	1600
8	5 cm	mineral wool 040	0,040	1,250	20,0	20,0	0,10	-	1,0	830
9	1,25 cm	Gypsum board	0,250	0,050	20,0	20,0	0,13	-	8,5	960
		Thermal contact resistance		0,170 (0,040)	20,0	20,0				
	50,25 cm	Whole component		6,171			66,45	-	256,3	

Table. 16. Module slab U value calculation

Heat loss: 13 kWh per m² and heating season

Primary energy (non renewable): 223 kWh/m²

Green house gas potential: -196 kg CO_2 Äqv./m²

Amount of heat that escapes through one square meter of this component during the heating period. Please note: Due to internal and solar gains, the heating demand is lower than the heat loss.

Non-renewable primary energy (= energy from fossil fuels and nuclear energy) that was used to produce the new building materials ("cradle to gate").

For the production of the building materials used, more greenhouse gases were withdrawn from the atmosphere than emitted.

U-VALUE: 0,162 W/(M²K)

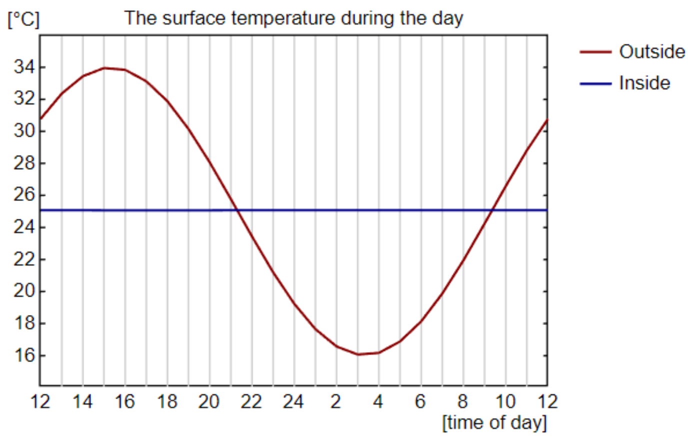
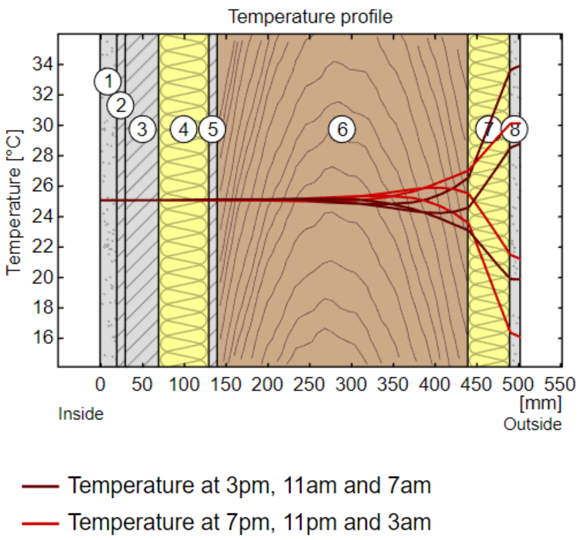


Fig. 208. Module slab, stratigraphy behavior, U value calculations.

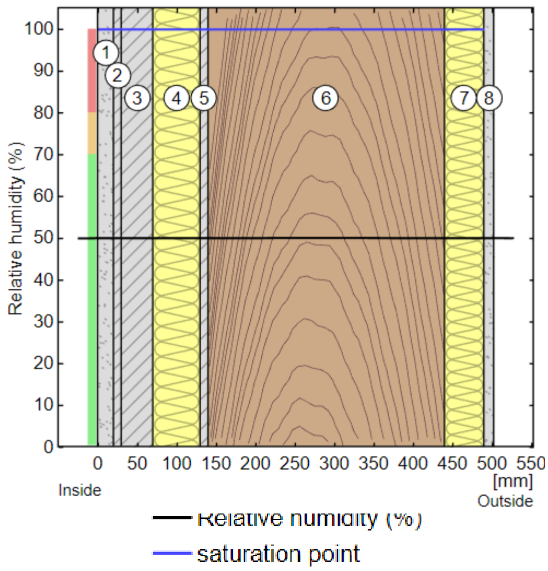
Heat storage capacity (whole component): 390 kJ/m²K
Thermal capacity of inner layers: 230 kJ/m²K

Internal heat behaviour

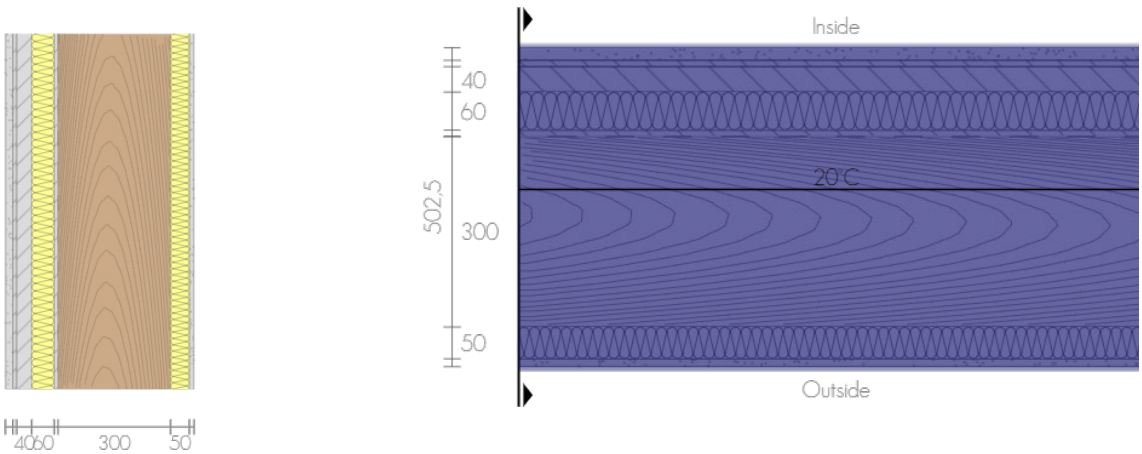


The following figure shows the relative humidity inside the component, 100% = condensate.

Moisture behaviour



The drawings below show the cross-section of the temperature behavior in the stratigraphy.



The drawing below illustrates the cross-section of the humidity behavior in the stratigraphy.

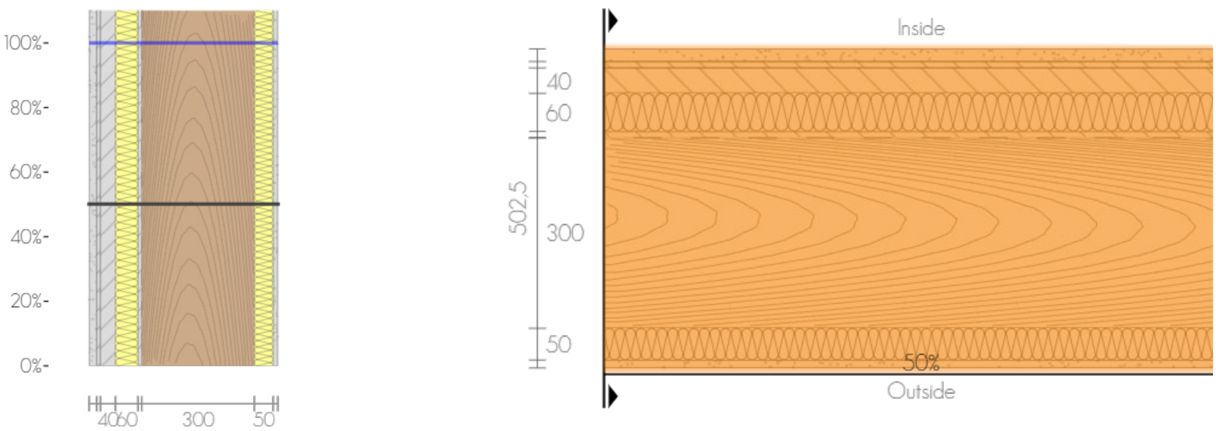
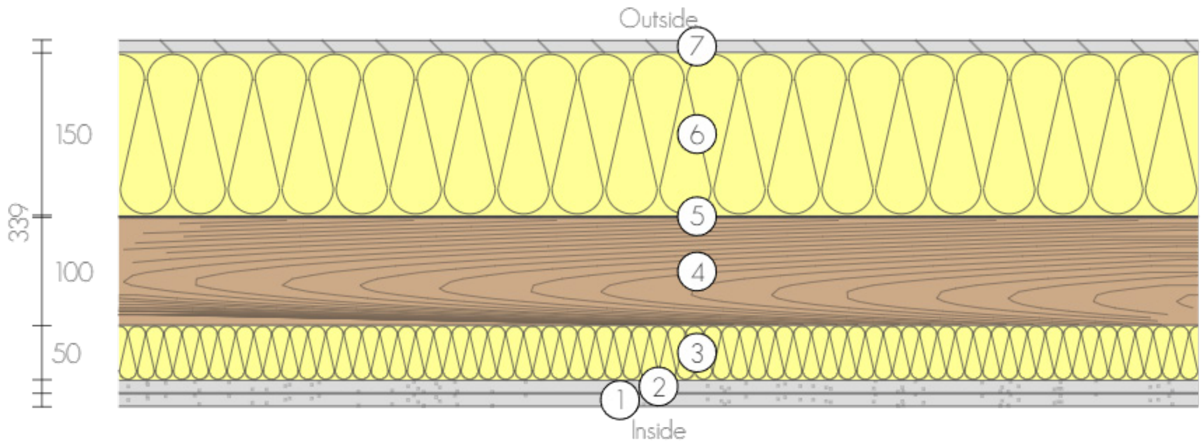


Fig. 209. Module slab, stratigraphy thermal and humidity behavior.

5.1.5. EXTERIOR WALL-FIBER CEMENT



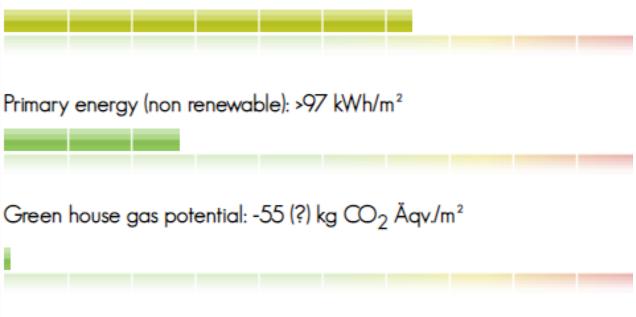
#		Material	λ [W/mK]	R [m²K/W]	Temp. [°C] min	max	sd-value [m]	Condensate [kg/m²] [%]	Weight [kg/m²]	Heat capacity [J/(kg*K)]
		Thermal contact resistance		0,130 (0,250)	19,0	20,0				
1	1,25 cm	Gypsum board	0,250	0,050	18,8	19,0	0,05	-	8,5	960
2	1,25 cm	Gypsum board	0,250	0,050	18,6	18,8	0,05	-	8,5	960
3	5 cm	Independent studs with 50mm mineral wool in stud c	0,041	1,220	13,6	18,6	0,05	-	2,8	1130
4	10 cm	Cross Laminated Timber	0,130	0,769	10,5	13,6	4,00	-	50,0	1600
5	0,2 cm	Vapour barrier	0,031	0,065	10,3	10,5	61,40	-	0,0	1700
6	15 cm	Independent studs held 15mm clear from CLT with 50	0,041	3,659	-4,6	10,3	0,15	-	8,3	1130
7	1,2 cm	Fiber cement board	0,190	0,063	-4,8	-4,6	4,80	-	18,6	0
		Thermal contact resistance		0,040	-5,0	-4,8				
	33,9 cm	Whole component		6,045			70,50	-	96,6	

Table. 17. Exterior wall- fibercement finishing- U value calculation

Heat loss: 13 kWh per m² and heating season

Primary energy (non renewable): >97 kWh/m²

Green house gas potential: -55 (?) kg CO_2 Äqv./m²



Amount of heat that escapes through one square meter of this component during the heating period. Please note: Due to internal and solar gains, the heating demand is lower than the heat loss.

Non-renewable primary energy (= energy from fossil fuels and nuclear energy) that was used to produce the new building materials ("cradle to gate").

For the production of the building materials used, more greenhouse gases were withdrawn from the atmosphere than emitted.

U-VALUE: 0,165 W/(M²K)

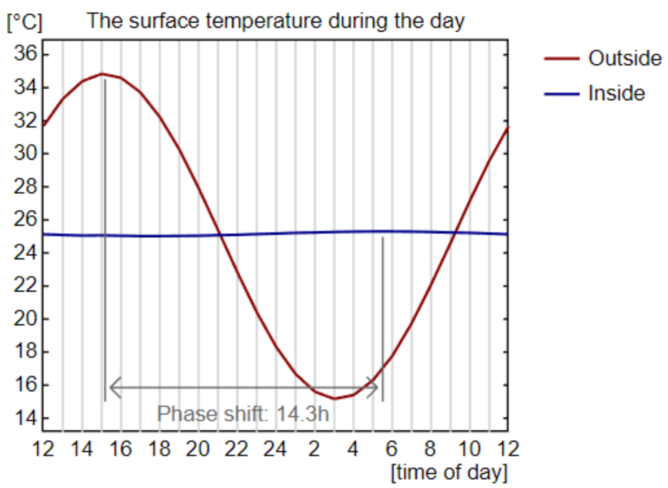
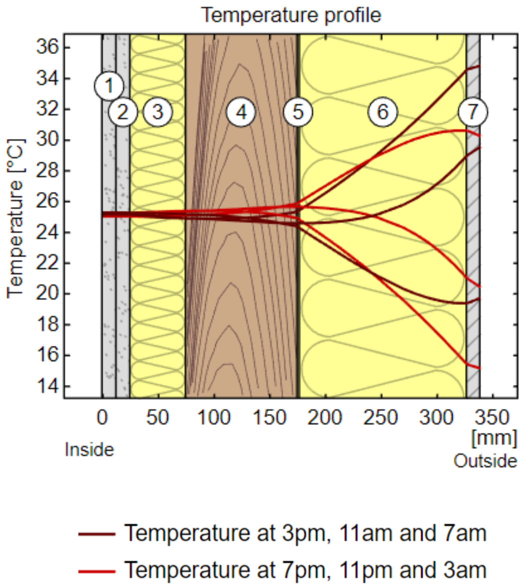


Fig. 210. Exterior wall- fibercement finishing, stratigraphy behavior, U value calculations.

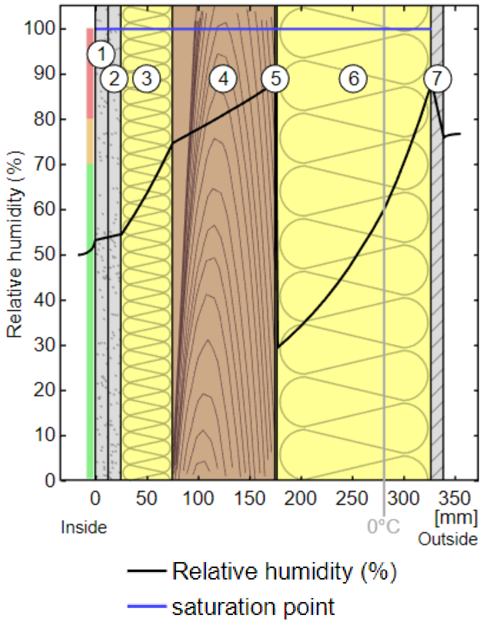
Heat storage capacity (whole component): 127 kJ/m^{2}K
Thermal capacity of inner layers: 77 kJ/m^{2}K

The following figure shows the relative humidity inside the component, 100% = condensate.

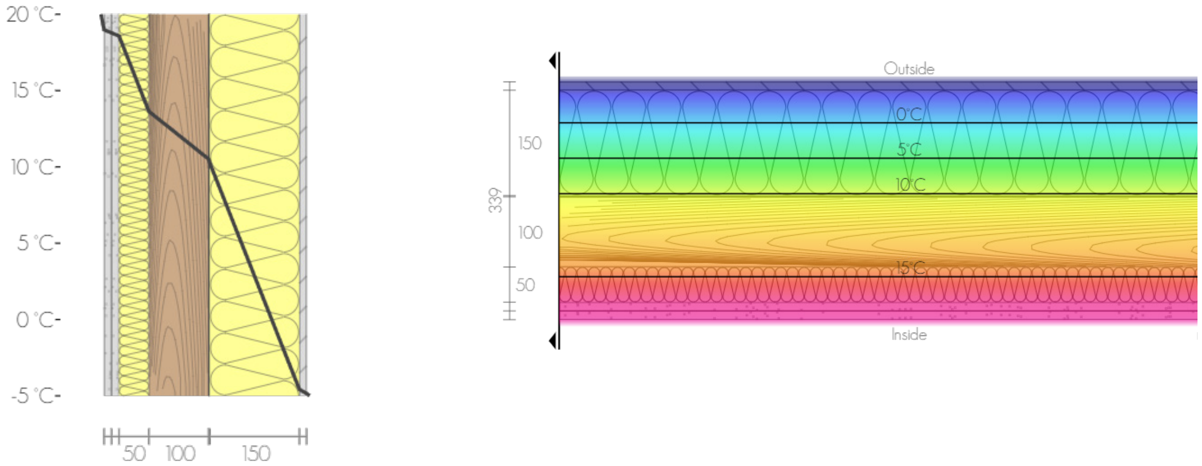
Internal heat behaviour



Moisture behaviour



The drawings below illustrate the cross-section of the temperature behavior in the stratigraphy.



The drawings below show the cross-section of the humidity behavior in the stratigraphy.

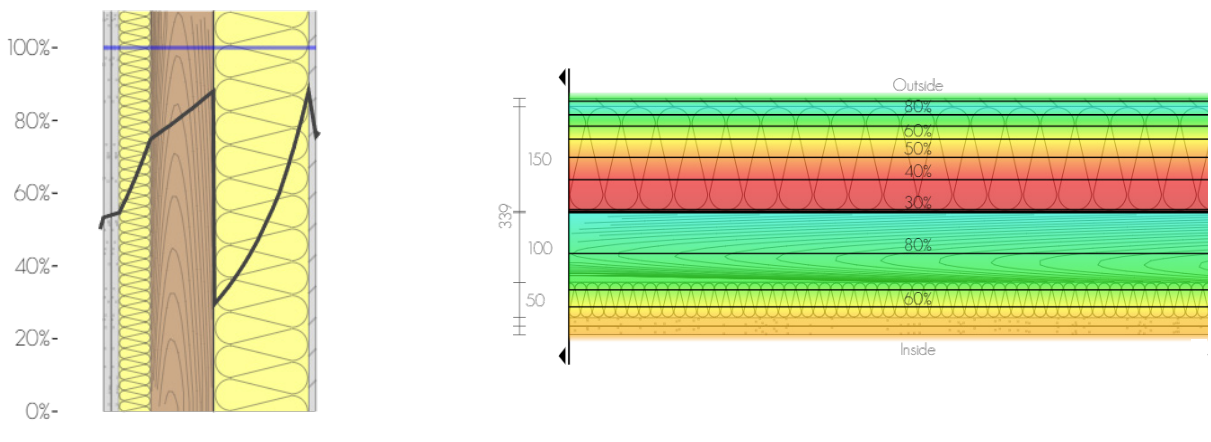
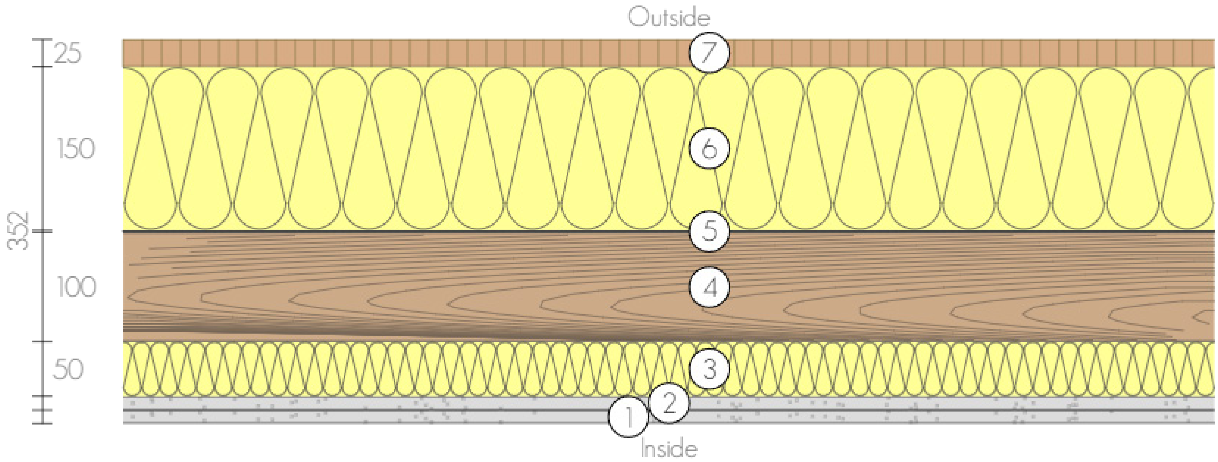


Fig. 211. External wall fiber-cement finishing, stratigraphy thermal and humidity behavior.

5.1.6. EXTERIOR WALL-3D FINISHING.



#		Material	λ [W/mK]	R [m²K/W]	Temp. [°C] min	max	sd-value [m]	Condensate [kg/m²] [%]	Weight [kg/m²]	Heat capacity [J/(kg*K)]
		Thermal contact resistance		0,130 (0,250)	19,0	20,0				
1	1,25 cm	Gypsum board	0,250	0,050	18,8	19,0	0,05	-	8,5	960
2	1,25 cm	Gypsum board	0,250	0,050	18,6	18,8	0,05	-	8,5	960
3	5 cm	Independent studs with 50mm mineral wool in stud c	0,041	1,220	13,8	18,6	0,05	-	2,8	1130
4	10 cm	Cross Laminated Timber	0,130	0,769	10,8	13,8	4,00	-	50,0	1600
5	0,2 cm	Vapour barrier	0,031	0,065	10,6	10,8	61,40	-	0,0	1700
6	15 cm	Independent studs held 15mm clear from CLT with 50	0,041	3,659	-3,8	10,6	0,30	-	8,3	1130
7	2,5 cm	3D TWIX siding boards.	0,090	0,278	-4,8	-3,8	0,28	-	12,5	1700
		Thermal contact resistance		0,040	-5,0	-4,8				
	35,2 cm	Whole component		6,260			66,13	-	90,5	

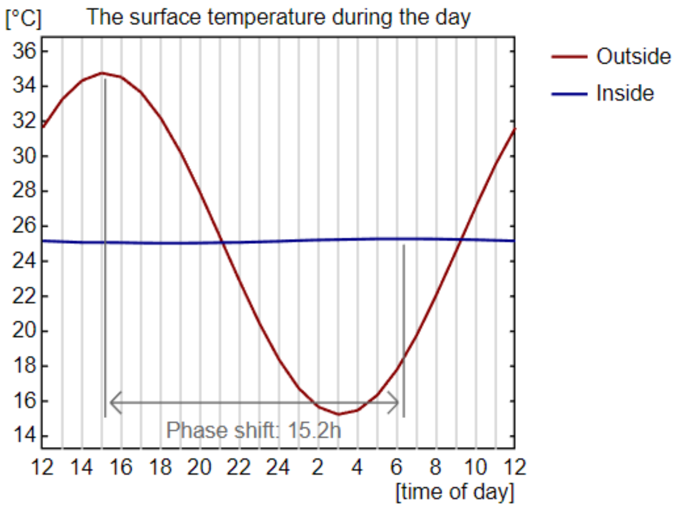
Table. 18. Exterior wall- 3d panel finishing -U value calculation

Heat loss: 12 kWh per m² and heating season

Primary energy (non renewable): >134 kWh/m²

Green house gas potential: -67 (?) kg CO_2 Äqv/m²

U-VALUE: 0,16 W/(M²K)



Amount of heat that escapes through one square meter of this component during the heating period. Please note: Due to internal and solar gains, the heating demand is lower than the heat loss.

Non-renewable primary energy (= energy from fossil fuels and nuclear energy) that was used to produce the new building materials ("cradle to gate").

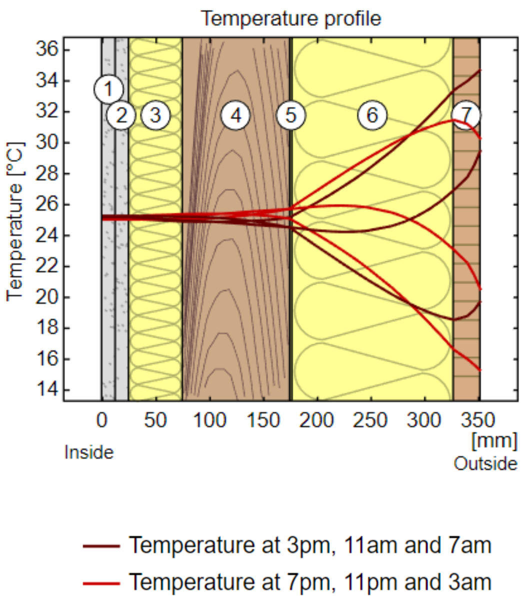
For the production of the building materials used, more greenhouse gases were withdrawn from the atmosphere than emitted.

Fig. 212. Exterior wall- 3D panel finishing stratigraphy behavior, U value calculations.

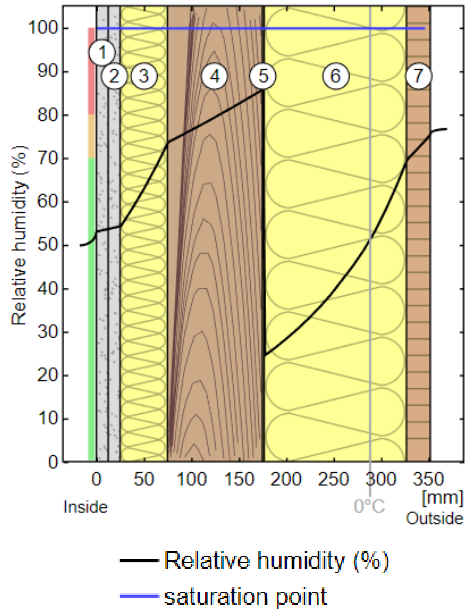
Heat storage capacity (whole component): 130 kJ/m^{2}K
Thermal capacity of inner layers: 79 kJ/m^{2}K

The following figure shows the relative humidity inside the component, 100% = condensate.

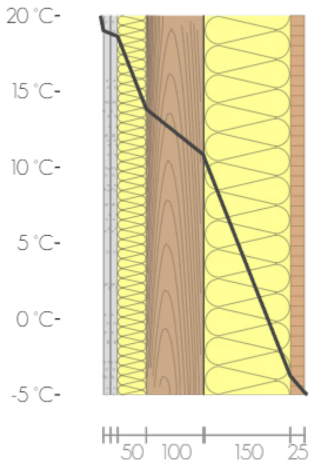
Internal heat behaviour

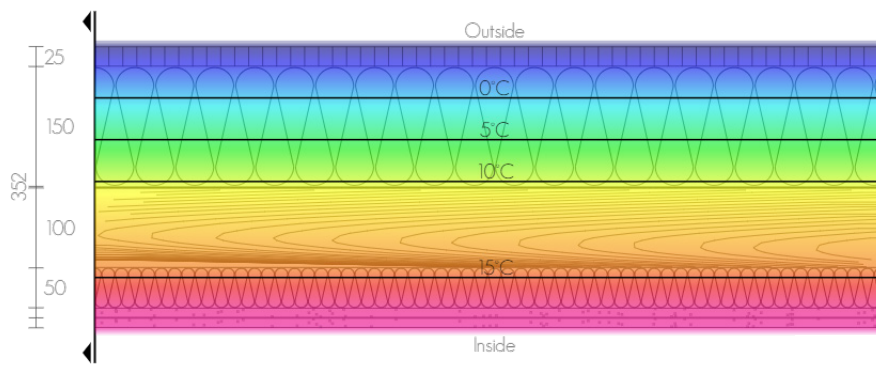


Moisture behaviour

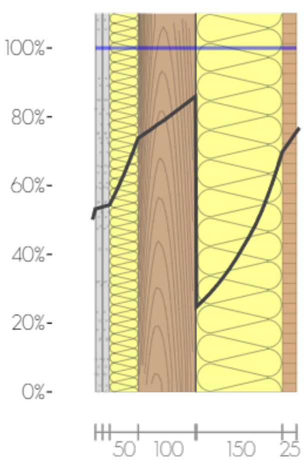


The drawings below shows the cross-section of the temperature behavior in the stratigraphy.





The drawings below show the cross-section of the humidity behavior in the stratigraphy.



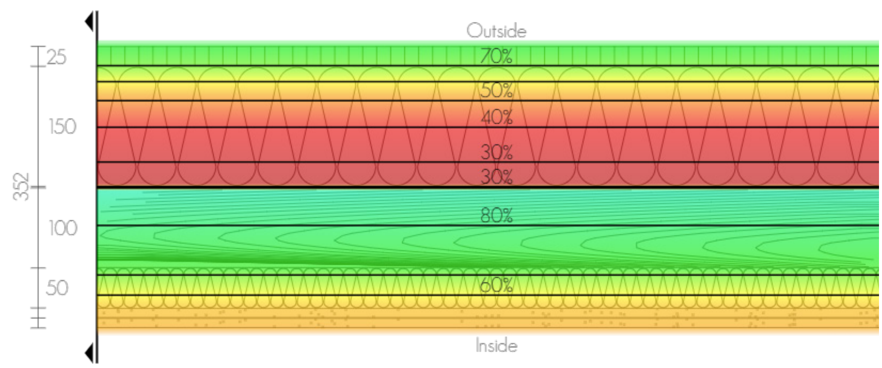
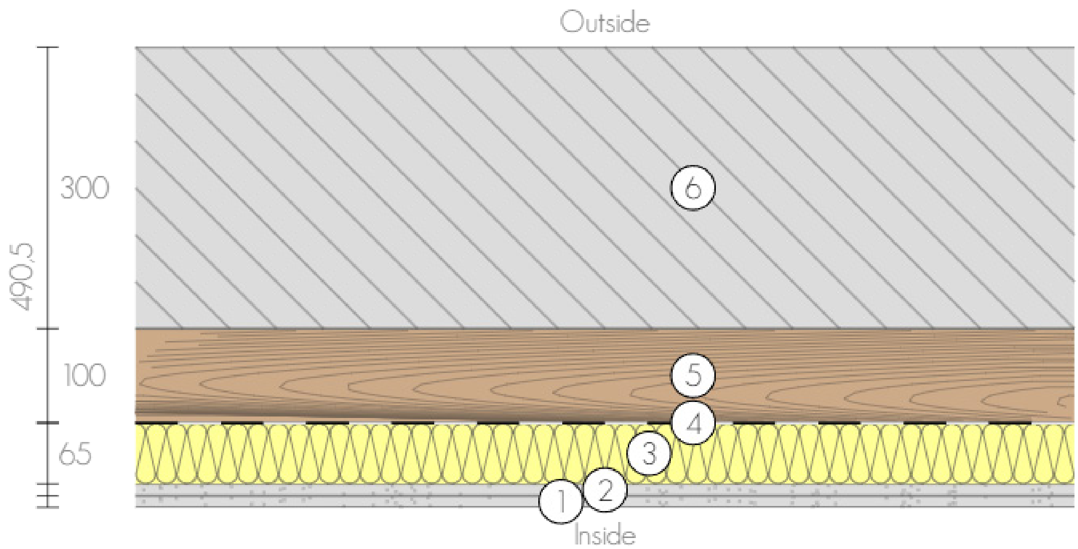


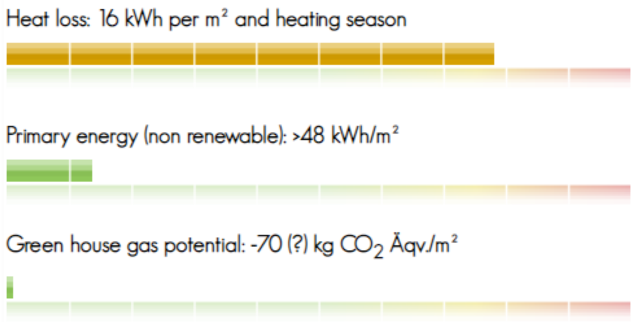
Fig. 213. External wall- 3d panel finishing, stratigraphy thermal and humidity behavior.

5.1.7. EXTERIOR WALL-ADJOINING



#		Material	λ [W/mK]	R [m²K/W]	Temp. [°C] min	max	sd-value [m]	Condensate [kg/m²] [%]	Weight [kg/m²]	Heat capacity [J/(kg*K)]
		Thermal contact resistance		0,130 (0,250)	18,8	20,0				
1	1,25 cm	Gypsum board	0,250	0,050	18,5	18,8	0,05	-	8,5	960
2	1,25 cm	Gypsum board	0,250	0,050	18,3	18,5	0,05	-	8,5	960
3	6,5 cm	Independent studs held 15mm clear from CLT with 50	0,040	1,625	10,3	18,3	0,07	-	1,3	830
4	0,05 cm	Vapor barrier sd=100m	0,220	0,002	10,3	10,3	100,00	-	0,1	1700
5	10 cm	Cross Laminated Timber	0,130	0,769	6,5	10,3	20,00	-	50,0	1600
6	30 cm	Precast lighwight concrete wall panel.	0,130	2,308	-4,8	6,5	3,00	-	150,0	1000
		Thermal contact resistance		0,040	-5,0	-4,8				
	49,05 cm	Whole component		4,974			123,17	-	218,4	

Table. 19. Exterior wall-adjoining- U value calculation



Amount of heat that escapes through one square meter of this component during the heating period. Please note: Due to internal and solar gains, the heating demand is lower than the heat loss.

Non-renewable primary energy (= energy from fossil fuels and nuclear energy) that was used to produce the new building materials ("cradle to gate").

For the production of the building materials used, more greenhouse gases were withdrawn from the atmosphere than emitted.

U-VALUE: 0,201 W/(M²K)

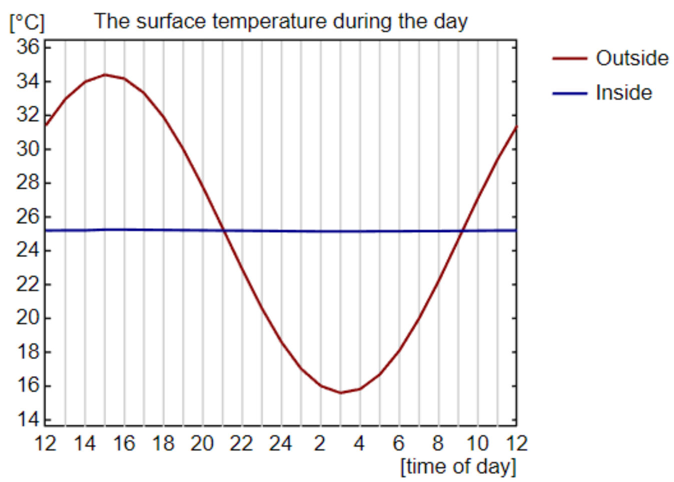
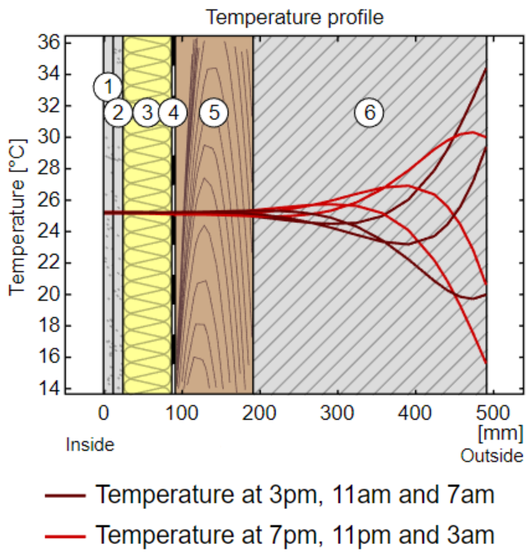


Fig. 214. Exterior wall-adjoinind, stratigraphy behavior, U value calculations.

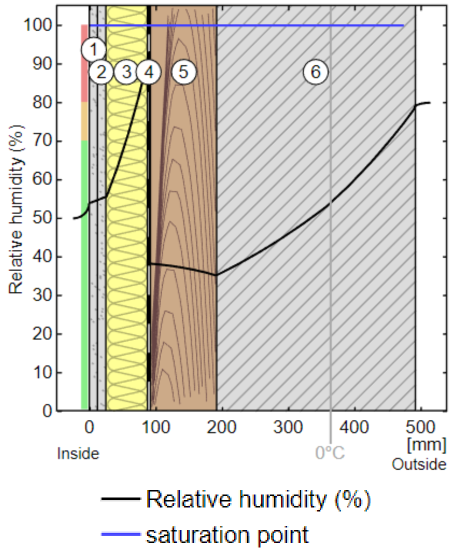
Heat storage capacity (whole component): 248 kJ/m²K
Thermal capacity of inner layers: 98 kJ/m²K

Internal heat behaviour

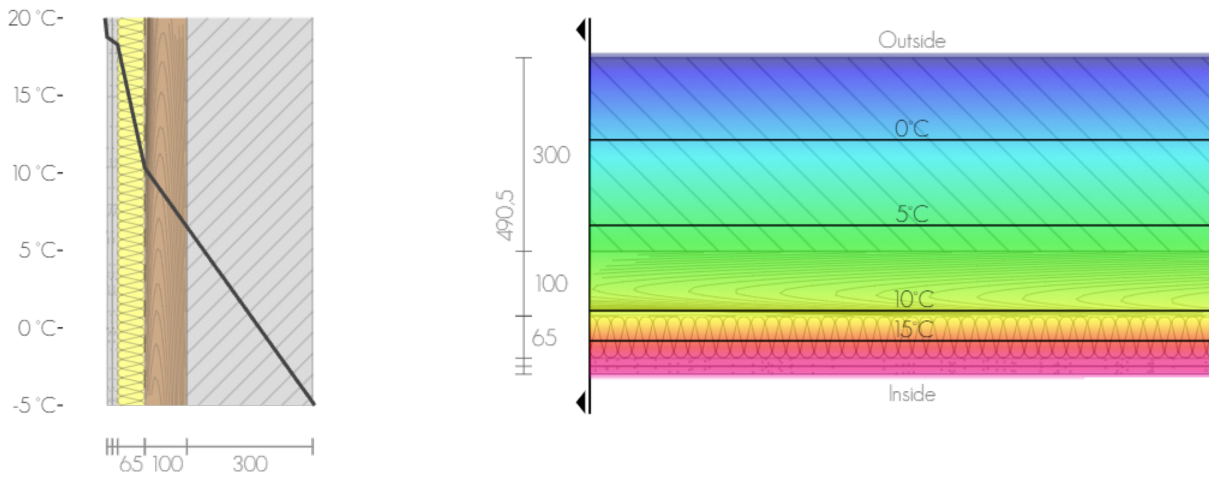


The following figure shows the relative humidity inside the component, 100% = condensate.

Moisture behaviour



The drawings below show the cross-section of the temperature behavior in the stratigraphy.



The drawings below show the cross-section of the humidity behavior in the stratigraphy.

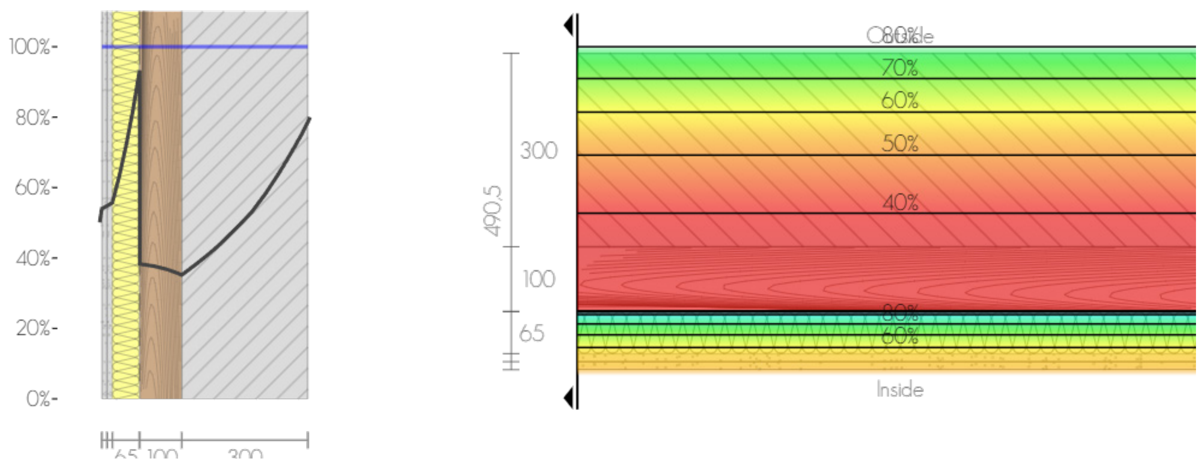
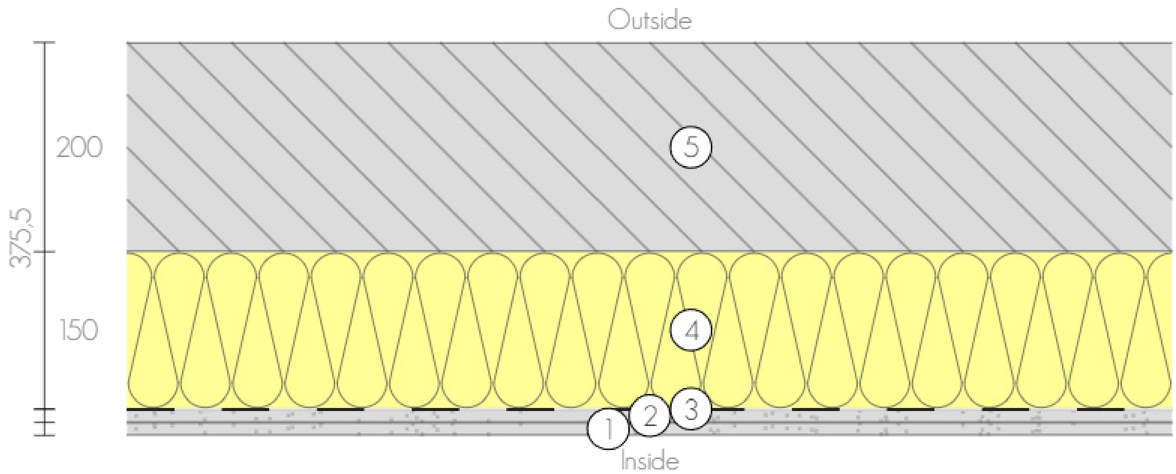


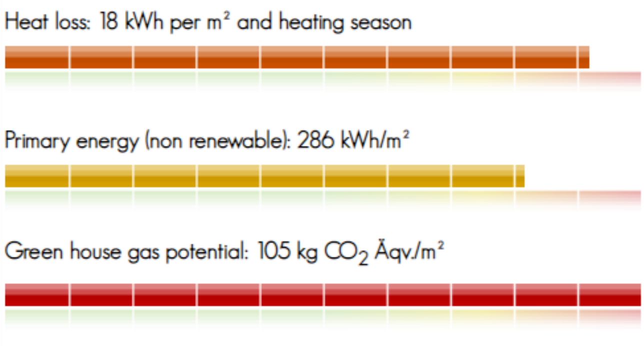
Fig. 215. Exterior wall adjoining, stratigraphy thermal and humidity behavior.

5.1.8. EXTERIOR WALL-CORE



#		Material	λ [W/mK]	R [m²K/W]	Temp. [°C] min	max	sd-value [m]	Condensate [kg/m²] [%]	Weight [kg/m²]	Heat capacity [J/(kg*K)]
		Thermal contact resistance		0,130 (0,250)	18,6	20,0				
1	1,25 cm	Gypsum board	0,250	0,050	18,3	18,6	0,05	-	8,5	960
2	1,25 cm	Gypsum board	0,250	0,050	18,0	18,3	0,05	-	8,5	960
3	0,05 cm	Vapor barrier sd=100m	0,220	0,002	18,0	18,0	100,00	-	0,1	1700
4	15 cm	Independent studs held 15mm clear from CLT with 50	0,040	3,750	-3,6	18,0	0,15	-	3,0	830
5	20 cm	Precast Concrete wall 2000 kg/m3, DIN 105	0,960	0,208	-4,8	-3,6	2,00	-	400,0	1000
		Thermal contact resistance		0,040	-5,0	-4,8				
	37,55 cm	Whole component		4,231			102,25	-	420,1	

Table. 20. Exterior wall-core- U value calculation



U-VALUE: 0,236W/(M²K)

Amount of heat that escapes through one square meter of this component during the heating period. Please note: Due to internal and solar gains, the heating demand is lower than the heat loss.

Non-renewable primary energy (= energy from fossil fuels and nuclear energy) that was used to produce the new building materials ("cradle to gate").

For the production of the building materials used, more greenhouse gases were withdrawn from the atmosphere than emitted.

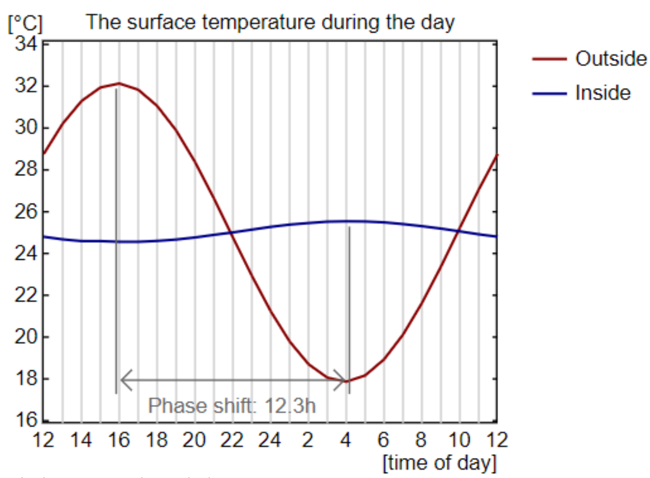
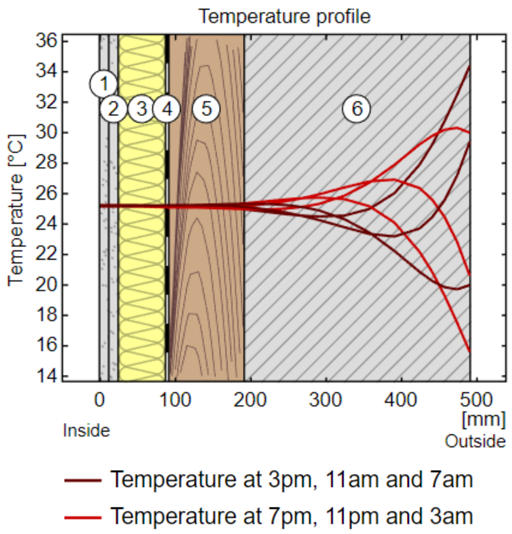


Fig. 216. Exterior wall-core stratigraphy behavior, U value calculations.

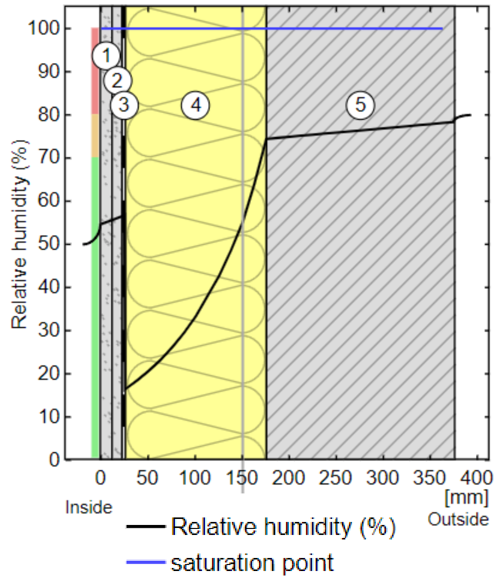
Heat storage capacity (whole component): 419 kJ/m²K
Thermal capacity of inner layers: 32 kJ/m²K

Internal heat behaviour

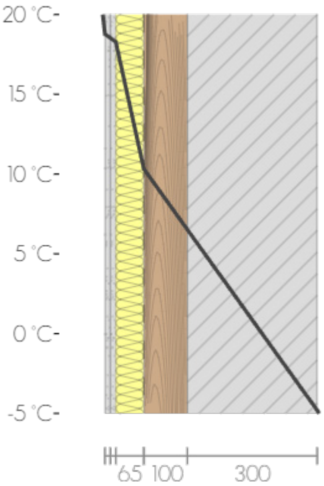


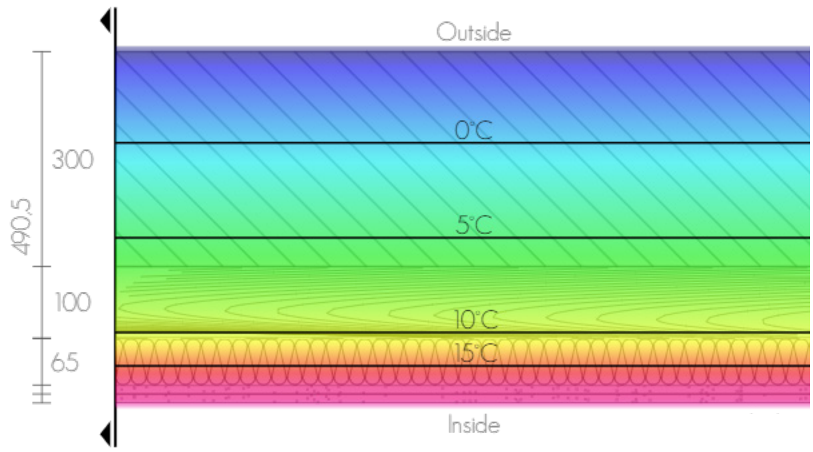
The following figure shows the relative humidity inside the component, 100% = condensate.

Moisture behaviour

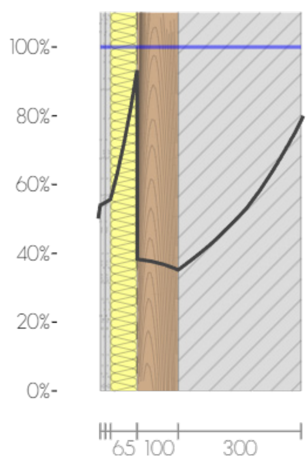


The drawings below illustrate the cross-section of the temperature behavior in the stratigraphy.





The drawings below show the cross-section of the humidity behavior in the stratigraphy.



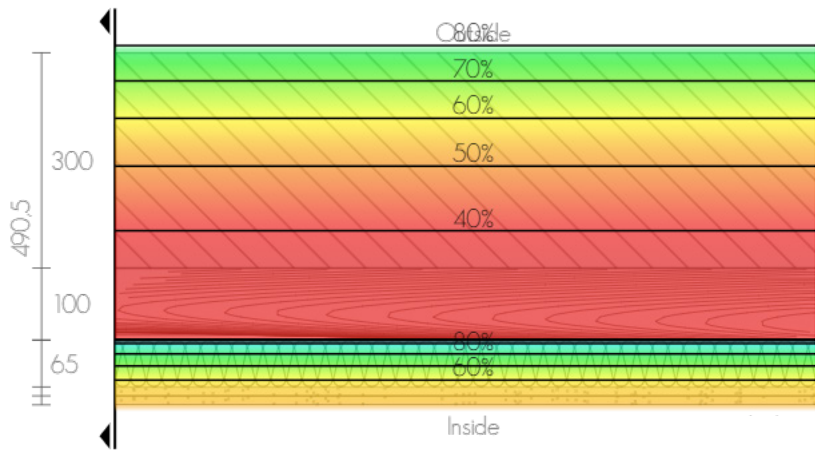
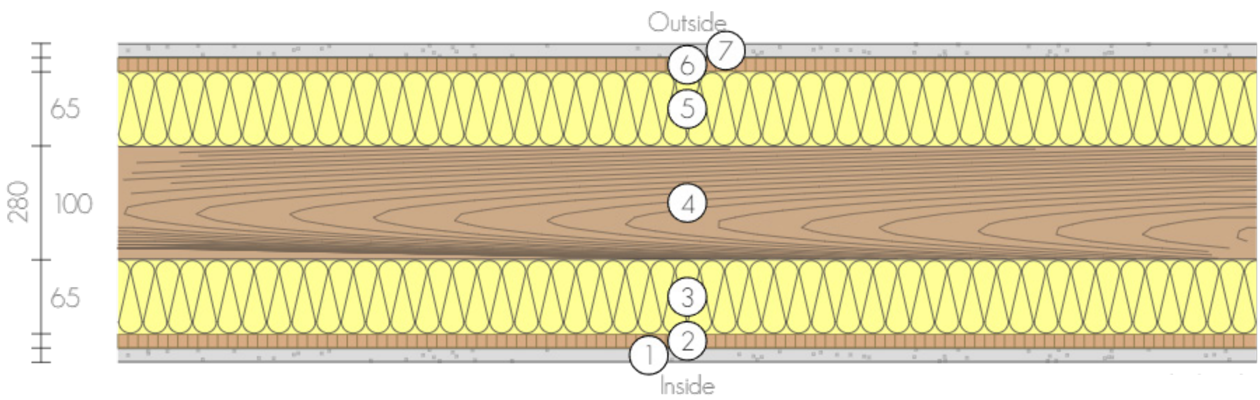


Fig. 217. Exterior wall -core, stratigraphy thermal and humidity behavior.

5.1.9. PARTITION WALL BETWEEN MODULES



#		Material	λ [W/mK]	R [m²K/W]	Temp. [°C] min	max	sd-value [m]	Condensate [kg/m²] [%]	Weight [kg/m²]	Heat capacity [J/(kg*K)]
		Thermal contact resistance		0,130 (0,250)	20,0	20,0				
1	1,25 cm	Gypsum board	0,250	0,050	20,0	20,0	0,05	-	8,5	960
2	1,25 cm	OSB	0,130	0,096	20,0	20,0	0,38	-	8,1	1700
3	6,5 cm	Independent studs with 65mm mineral wool in stud c	0,041	1,585	20,0	20,0	0,07	-	3,6	1130
4	10 cm	Cross Laminated Timber	0,130	0,769	20,0	20,0	4,00	-	50,0	1600
5	6,5 cm	Independent studs with 65mm mineral wool in stud c	0,041	1,585	20,0	20,0	0,13	-	3,6	1130
6	1,25 cm	OSB	0,130	0,096	20,0	20,0	3,75	-	8,1	1700
7	1,25 cm	Gypsum board	0,250	0,050	20,0	20,0	0,13	-	8,5	960
		Thermal contact resistance		0,130 (0,040)	20,0	20,0				
	28 cm	Whole component		4,498			8,50	-	90,4	

Table. 21. Partition wall- U value calculation

Heat loss: 17 kWh per m² and heating season

Primary energy (non renewable): 138 kWh/m²

Green house gas potential: -77 kg CO_2 Äqv./m²

Amount of heat that escapes through one square meter of this component during the heating period. Please note: Due to internal and solar gains, the heating demand is lower than the heat loss.

Non-renewable primary energy (= energy from fossil fuels and nuclear energy) that was used to produce the new building materials ("cradle to gate").

For the production of the building materials used, more greenhouse gases were withdrawn from the atmosphere than emitted.

U-VALUE: 0,223 W/(M²K)

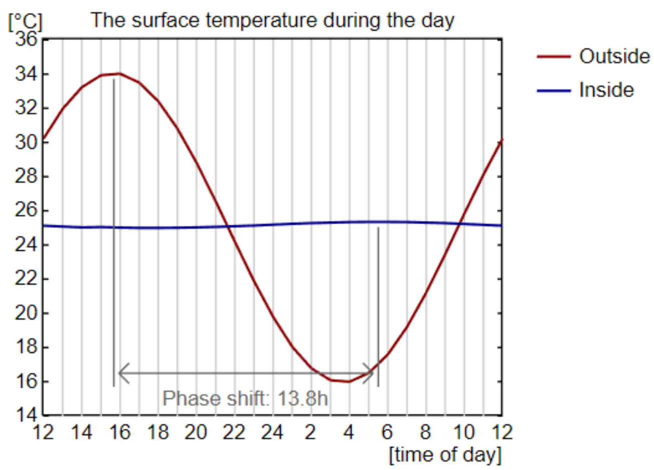
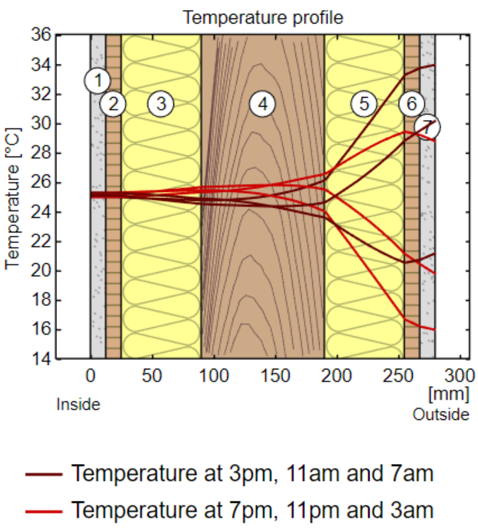


Fig. 218. Partition walls, stratigraphy behavior, U value calculations.

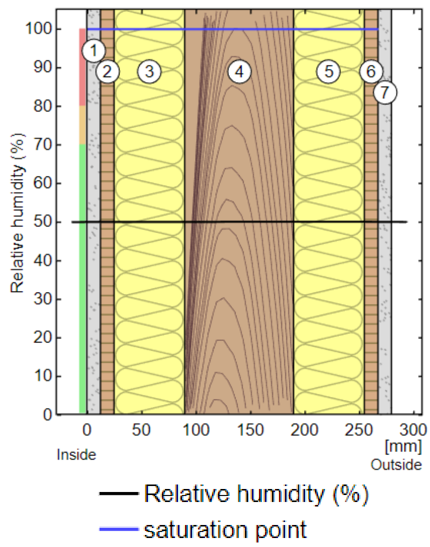
Heat storage capacity (whole component): 132 kJ/m²K
Thermal capacity of inner layers: 64 kJ/m²K

Internal heat behaviour

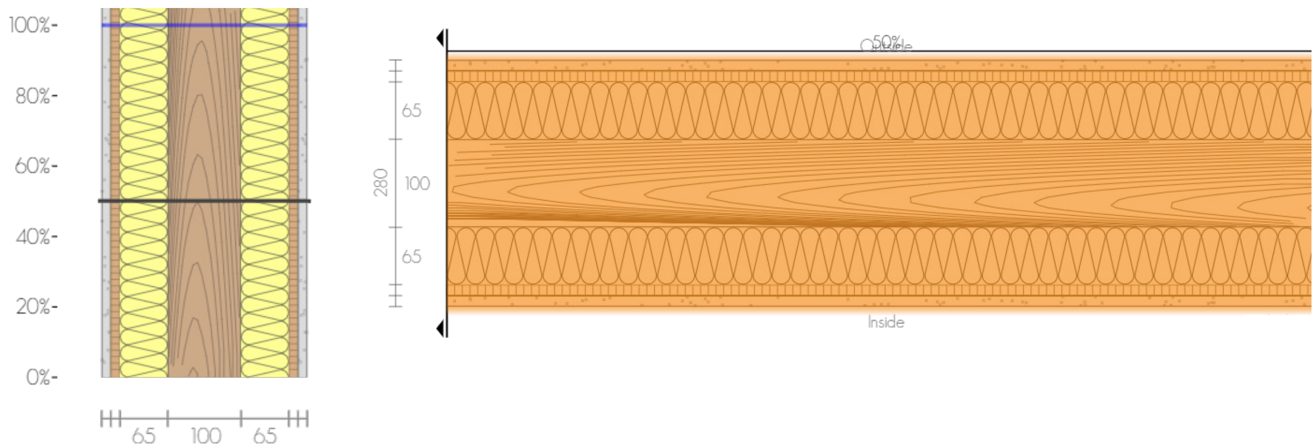


The following figure shows the relative humidity inside the component, 100% = condensate.

Moisture behaviour



The drawings below show the cross-section of the temperature behavior in the stratigraphy.



The drawing below show the cross-section of the humidity behavior in the stratigraphy.

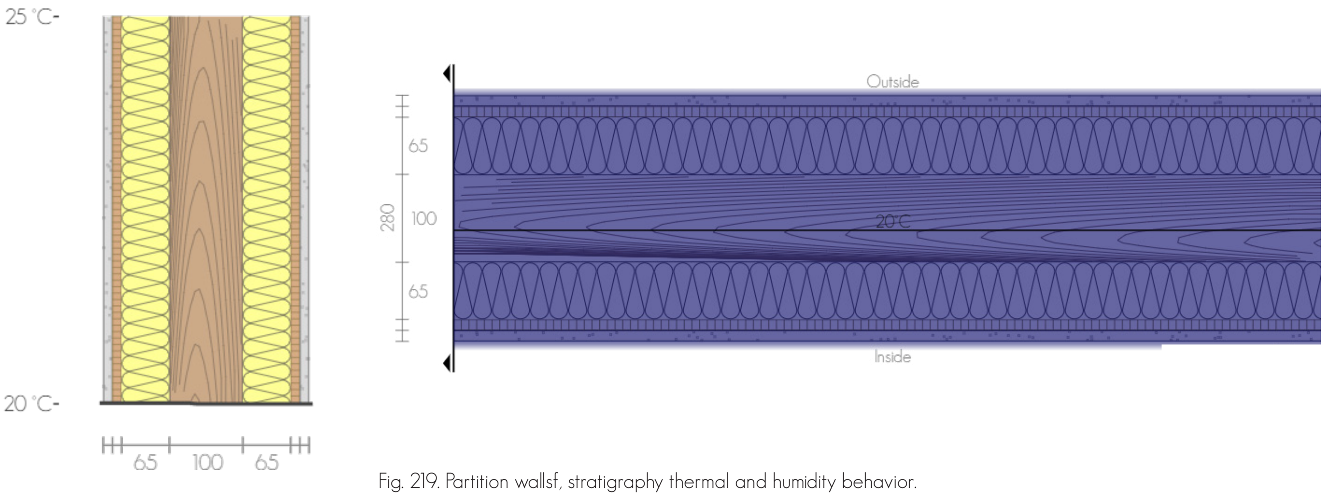
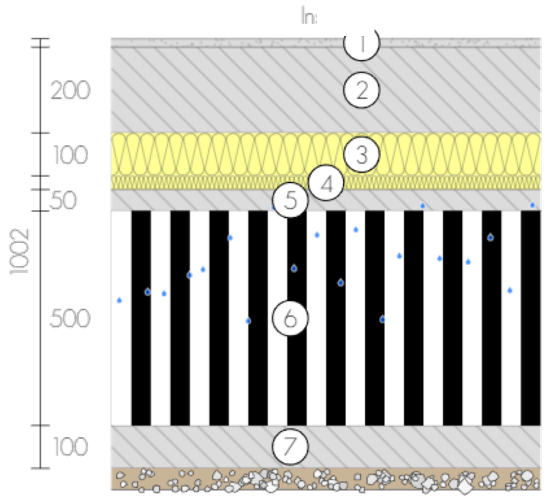
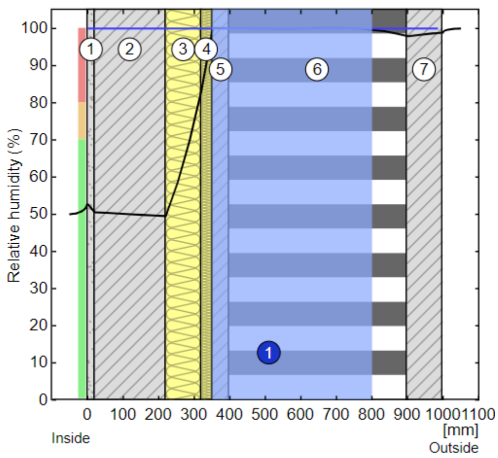


Fig. 219. Partition wallsf, stratigraphy thermal and humidity behavior.

5.1.10. FLOOR TO SOIL



Moisture behaviour



The following figure shows the relative humidity inside the component, 100% = condensate.
During the winter season of 90 days, a total of 0,028 kg of condensation water per square meter is generated.This quantity dries in summer in 27 days (Drying season according to DIN 4108-3:2014-11). In accordance with DIN 4108-3, the maximum allowable amount of condensate is 1,0 kg/m² if all affected layers are capillary water absorbable, else 0.5 kg/m².
Condensate amount: 0,028 kg/m²; Affected layers: Concrete, PAVAPOR, Ventilation system Recycled plastic igloo

#		Material	λ [W/mK]	R [m²K/W]	Temp. [°C] min	max	sd-value [m]	Condensate [kg/m²]	[%]	Weight [kg/m²]	Heat capacity [J/(kg*K)]
		Thermal contact resistance		0,170 (0,250)	19,1	20,0					
1	2 cm	Tiles (ceramic)	1,200	0,017	19,1	19,1	3,00	-		40,0	840
2	20 cm	Cement screed	1,400	0,143	18,6	19,1	3,00	-		400,0	1000
3	10 cm	Insulation/Polystyrene (EPS 040)	0,040	2,500	10,0	18,6	2,00	-		3,0	1500
4	3,2 cm	PAVAPOR	0,040	0,800	7,3	10,0	0,16	0,027	0,6	4,3	2100
5	5 cm	Concrete	2,000	0,025	7,2	7,3	6,50	0,028	0,0	120,0	950
6	50 cm	Ventilation system Recycled plastic igloo	0,250	2,000	0,3	7,2	5.000,00	-		600,0	1800
7	10 cm	Concrete	2,000	0,050	0,1	0,3	13,00	-		240,0	950
		Thermal contact resistance		0,000 (0,040)	0,0	0,1					
8		Soil			0,0						
	100,2 cm	Whole component		5,706			5.027,66	0,028		1.407,3	

Table. 22. Floor to soil- U value calculation

Heat storage capacity (whole component): 1869 kJ/m²K
Thermal capacity of inner layers: 680 kJ/m²K

U-VALUE: 0,175 W/(M²K)

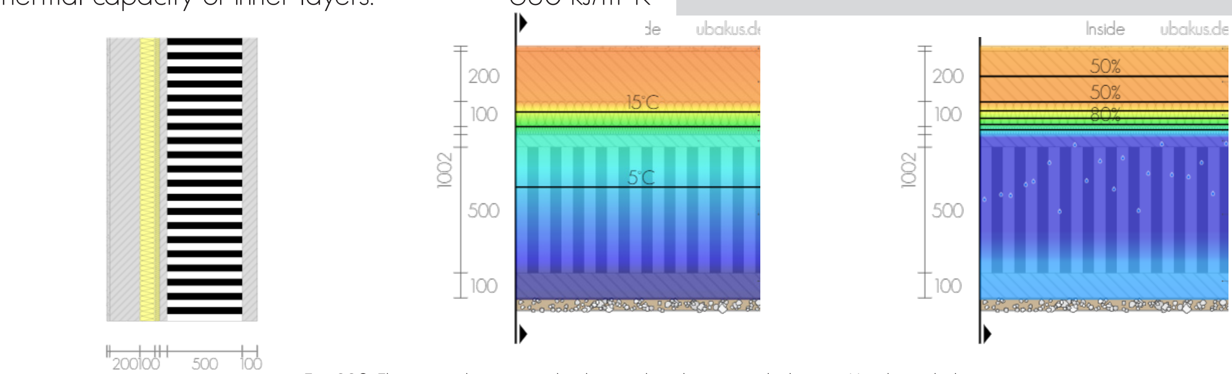


Fig. 220. Floor to soil, stratigraphy thermanl and moirsture behavior, U value calculations.

5.2 DETAILS

5.2.1. FINAL ROOF DETAIL

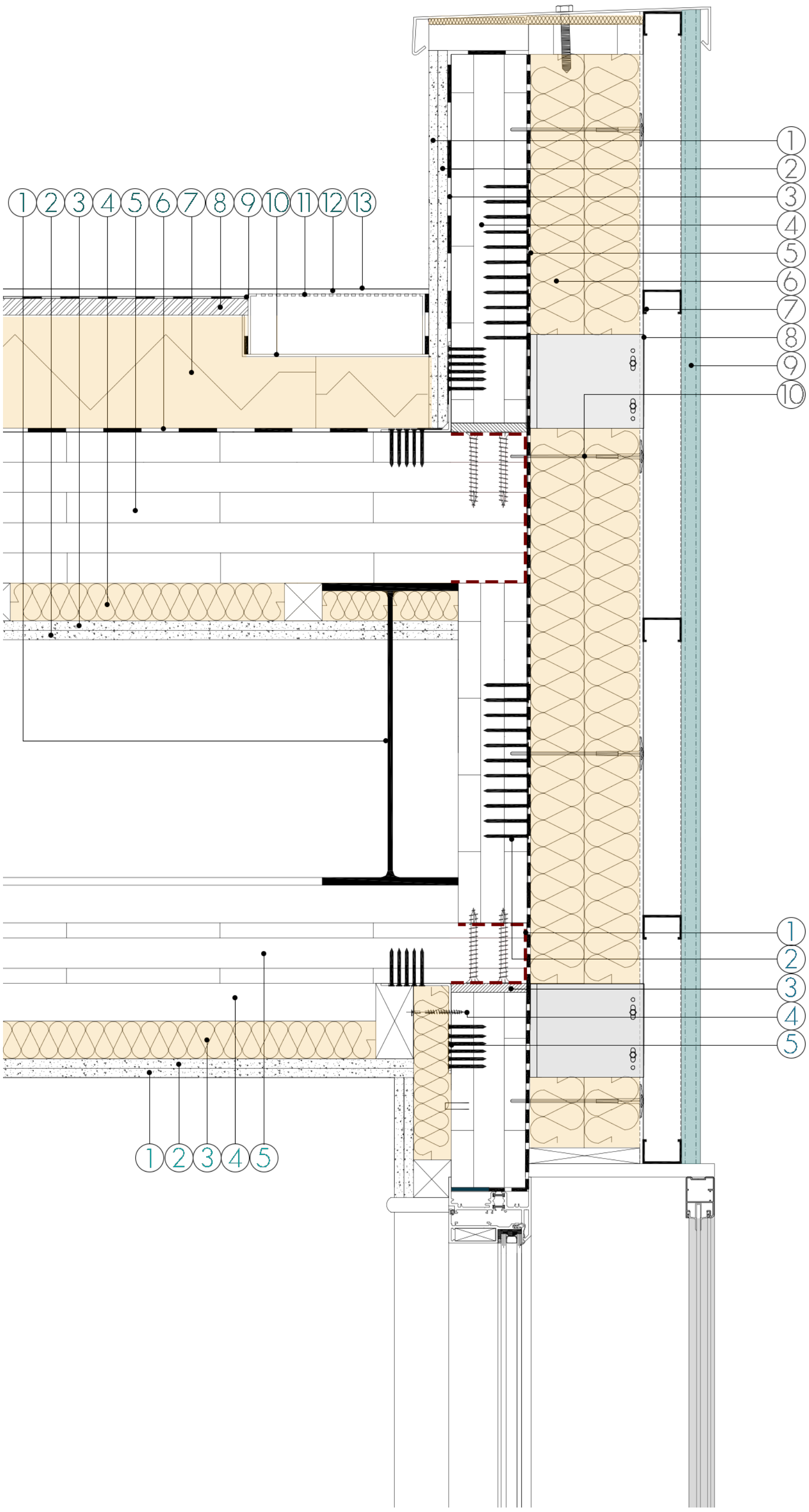


Fig. 221. Final roof blow-up detail.

Roof
1. Steel Beam HD 400X237
2. Fire protection gypsum board type F- Thickness 12.5 mm
3. Gypsum board type A-Thickness 12.5 mm
4. Independent studs with 50 mm thermal and acoustic insulation layer in mineral wool panel, density 20 kg/m3 inside stud cavity.
5. CLT slab, type L5s, Strength class: C24 according to EN 338 -Thickness 200mm
6. Vapor Barrier -Thickness 0.5mm
7. Thermal Insulation Layer -Thickness 150mm
8. Homatherm EnergiePlus comfort-Thickness 150mm
9. Breather membrane sd=0,1m-Thickness 0.5mm
10. Shaped aluminum flashing for rain water drainage
11. Iron grate to avoid the blocking in the drainage channel
12. Asphaltic surface- Sandasphalt- Thickness 0.5mm
13. Roof finishing DuPont Air Guard Reflective thermal contact resistance-Thickness 0.43mm

Module Ceiling
1. Fire protection gypsum board type F- Thickness. 12.5 mm
2. Gypsum board type A-Thickness. 12.5 mm
3. Independent studs held 15mm clear from CLT with 50 mm thermal and acoustic insulation layer in mineral wool panel, density 20 kg/m3 inside stud cavity.
4. Air gap space for services
5. CLT slab, type L3s, Strength class: C24 according to EN 338 -Thickness 100mm

Wall
1. Fire protection gypsum board type F- Thickness. 12.5 mm
2. Gypsum board type A-Thickness. 12.5 mm
3. Vapor Barrier -Thickness 0.5mm
4. CLT wall panels 100 CS3 -Thickness. 100 mm
5. Vapor barrier, Thickness. 2 mm
6. Thermal and acoustic insulation layer in mineral wool panel density 20 kg/m3 inside stud cavity. Thickness. 150 mm
7. Substructure made of aluminum sheet profiles with C-section, 50mm every 500mm, fixed with aluminum clips
8. Double L-shaped bracket for anchoring the ventilated facade system to the wall through 15 cm long anchors dim. 80x40mm
9. 3D TWIX siding boards, WPC (Wood Polymer Composit) Vertical orientation. 197x3000mm,
10. Plastic mechanical anchor

Connection
1. Sealing tape for air tightness
2. Perforated belt connection
3. Full thread connector with countersunk head
4. Special screws for fixing wood battens/ studs with the CLT panel.
5. Metal angle bracket

5.2.2. CANTILEVER.

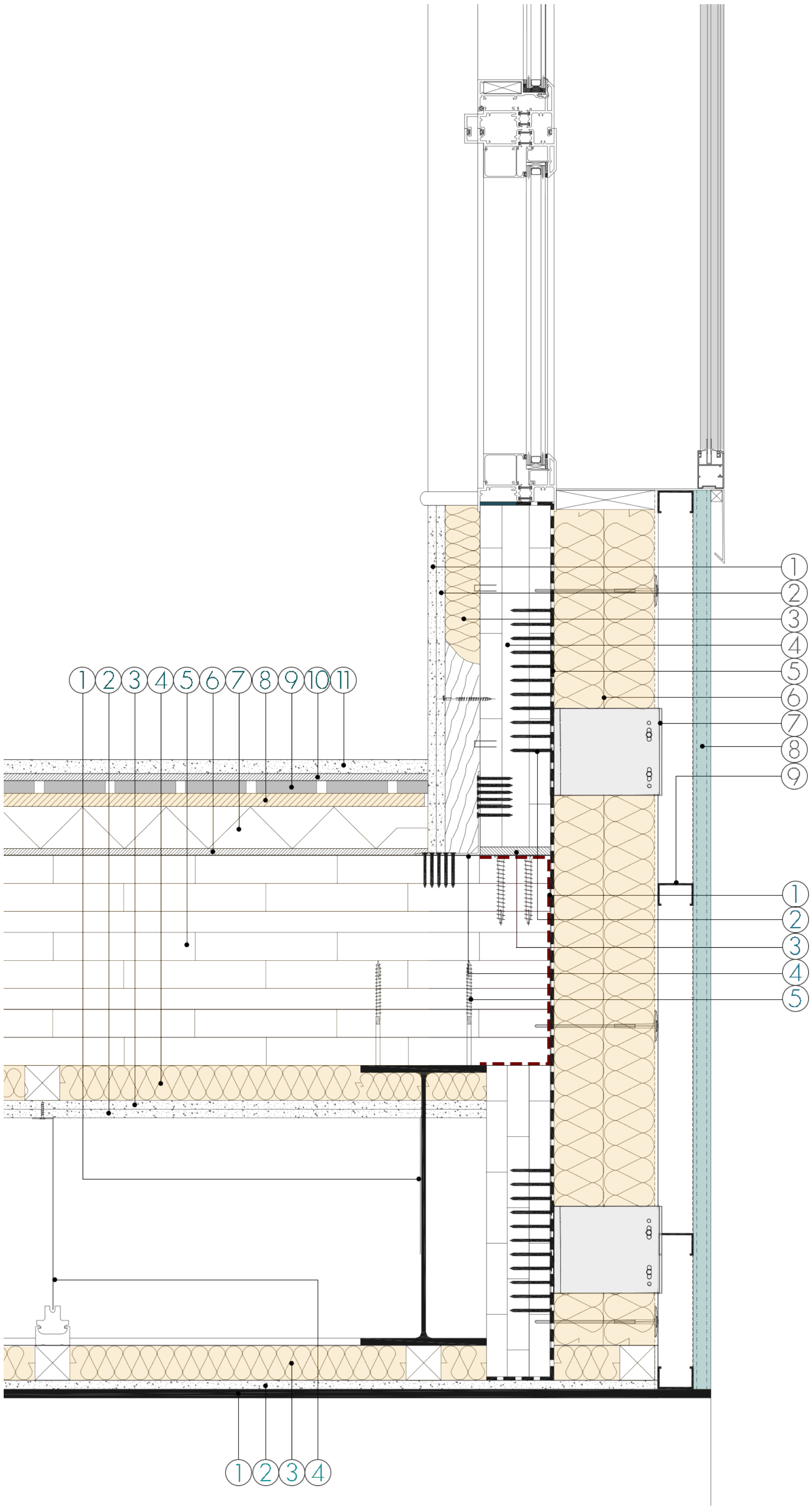


Fig. 222. Cantilever blow-up.

Floor
1. Steel Beam HD 400X237
2. Fire protection gypsum board type F- Thickness 12.5 mm
3. Gypsum board type A-Thickness 12.5 mm
4. Independent studs with 50 mm thermal and acoustic insulation layer in mineral wool panel, density 20 kg/m3 inside stud cavity.
5. CLT slab panel, type L8s, cover layers and inner layer (40mm each) consisting of two lengthwise layers, Strength class:C24 according to EN 338 -Thickness 300mm
6. Self-leveling Beton Ultraplan-Thickness. 10 mm
7. Wood fiber Fibertherm Base. Thickness . 60mm
8. Thermal Insulation Layer -Thickness 150mm
9. Radiant heating panels Betonradiant-Thickness. 40mm
10. Self-leveling Beton Ultraplan-Thickness. 10 mm
11. IFinishing: Porcelain stoneware tiles - Sp. 2 cm dim. 120x60

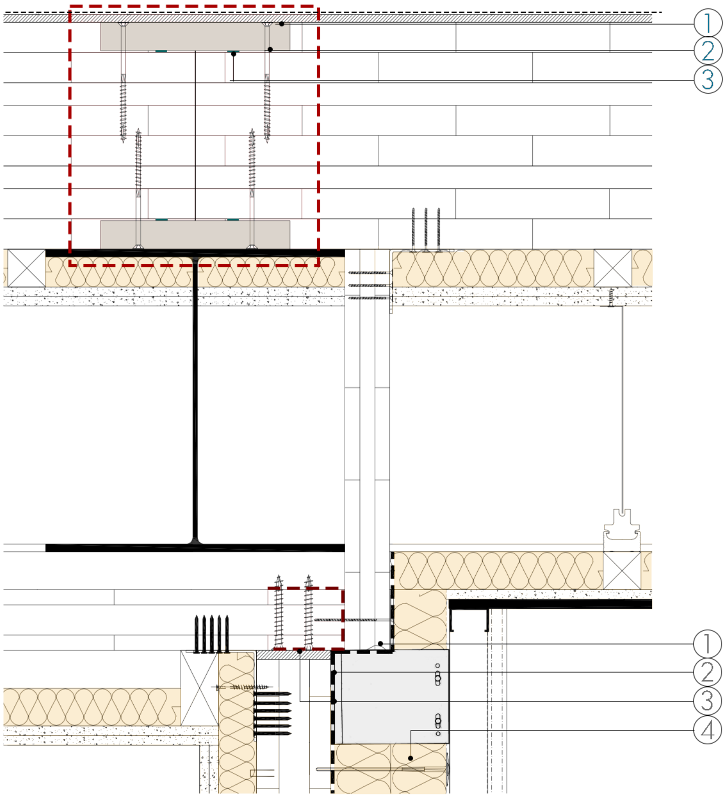
Cantilever
1. Fire protection gypsum board type F- Thickness. 12.5 mm
2. Gypsum board type A-Thickness. 12.5 mm
3. Independent studs held 15mm clear from CLT with 50 mm thermal and acous tic insulation layer in mineral wool panel, density 20 kg/m3 inside stud cavity.
4. Hanger for fixing false ceiling

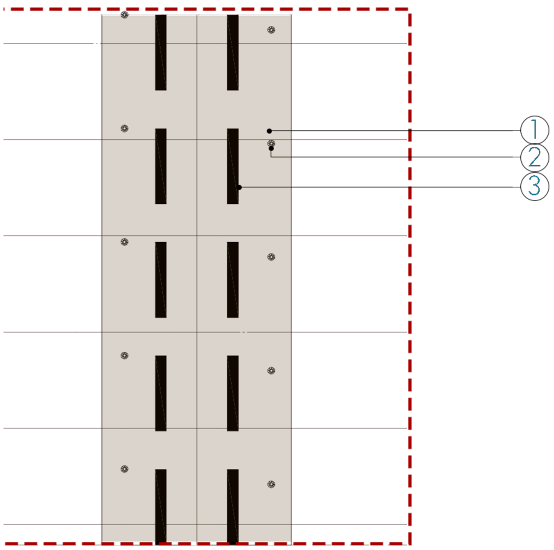
Wall
1. Fire protection gypsum board type F- Thickness. 12.5 mm
2. Gypsum board type A-Thickness. 12.5 mm
3. Independent with 50 mm thermal and acoustic insulation layer in mineral wool panel density 20 kg/m3 inside stud cavity
4. CLT wall panels 100 CS3 -Thickness. 100 mm
5. Vapor barrier, Thickness. 2 mm
6. Thermal and acoustic insulation layer in mineral wool panel density 20 kg/m3 inside stud cavity. Thickness. 150 mm
7. Double L-shaped bracket for anchor -ing the ventilated facade system to the wall through 15 cm long anchors dim. 80x40mm
8. 3D TWIX siding boards, WPC (Wood Polymer Composit) Vertical orientation. 197x3000mm,
9. Substructure made of aluminum sheet profiles with C-section, 50mm every 500mm, fixed with aluminum clips
10. Plastic mechanical anchor

Connection
1. Sealing tape for air tightness
2. Perforated belt connection
3. Full thread connector with countersunk head
4. Metal angle bracket
5. Countersunk screw HBS

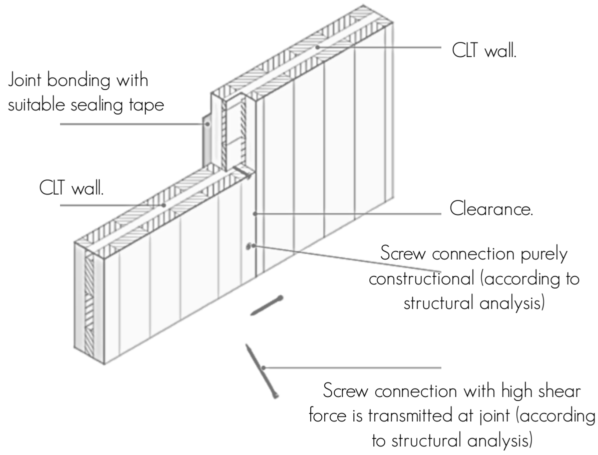
5.2.3. GENERAL JOINTS

INTERNAL SLAB

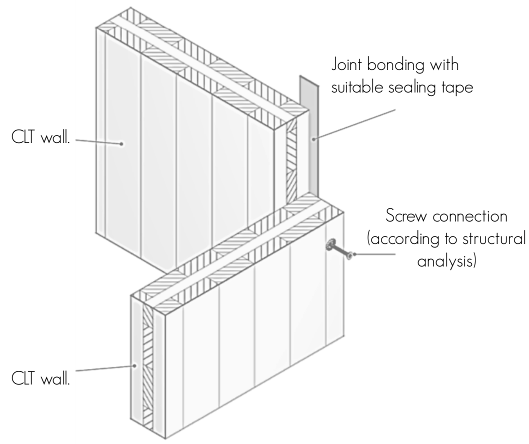




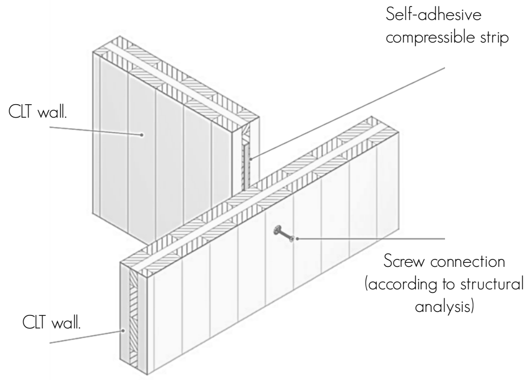
VERTICAL WALL JOIN (LAP)- BETWEEN MODULES.



CORNER JOINT.



T JOINT.



Connection
1. Connection joint
2. Countersunk screw HBS
3. Bi-adhesive butyl tape BUTYL BAND

Fig. 223. Internal slab joints detail

Wall
1. CLT Panel C3S -Thickness. 60 mm
2. Vapor barrier, Thickness. 2 mm
3. Sealing tape for air tightness
4. Thermal and acoustic insulation layer in mineral wool panel density 20 kg/m3 inside stud cavity. Thickness. 150 mm

Fig. 224. CLT walls joints details

5.2.4. INTERNAL SLAB TERRACE

Wall

1. Fire protection gypsum board type F- Thickness. 12.5 mm
2. Gypsum board type A-Thickness. 12.5 mm
3. Independent with 50 mm thermal and acoustic insulation la
4. CLT wall panels 100 CS3 -Thickness. 100 mm
5. Vapor barrier, Thickness. 2 mm
6. Thermal and acoustic insulation layer in mineral wool panel
7. Double L-shaped bracket for anchoring the ventilated faca
8. 3D TWIX siding boards, WPC (Wood Polymer Composit) W
10. Plastic mechanical anchor
9. Substructure made of aluminum sheet profiles with C-sectio
10. EQUITONE White Fibrocement Panel (moisture proof and l

Floor

1. Steel Beam HD 400X237
2. Fire protection gypsum board type F- Thickness 12.5 mm
3. Gypsum board type A-Thickness 12.5 mm
4. Independent studs with 50 mm thermal and acoustic insulation layer in mineral wool panel, density 20 kg/m3 inside stud cavity.
5. CLT slab panel, type L8s, cover layers and inner layer (40mm each) consisting of two lengthwise layers, Strength class:C24 according to EN 338 -Thickness 300mm
6. Self-leveling Beton Ultraplan- Thickness. 10 mm
7. Wood fiber Fibertherm Base. Thickness. 60mm
8. Thermal Insulation Layer -Thickness. 150mm
9. Radiant heating panels Betonradiant-Thickness. 40mm
10. Self-leveling Beton Ultraplan-Thickness. 10 mm
11. IFinishing: Porcelain stoneware tiles - Sp. 2 cm dim. 120x60

Module Ceiling

1. Fire protection gypsum board type F- Thickness. 12.5 mm
2. Gypsum board type A-Thickness. 12.5 mm
3. Independent studs held 15mm clear from CLT with 50 mm thermal and acoustic insulation layer in mineral wool panel, density 20 kg/m3 inside stud cavity.
4. Air gap space for services
5. CLT slab, type L3s, Strength class: C24 according to EN 338 -Thickness 100mm
6. Full thread connector with cylinrical head VGZ

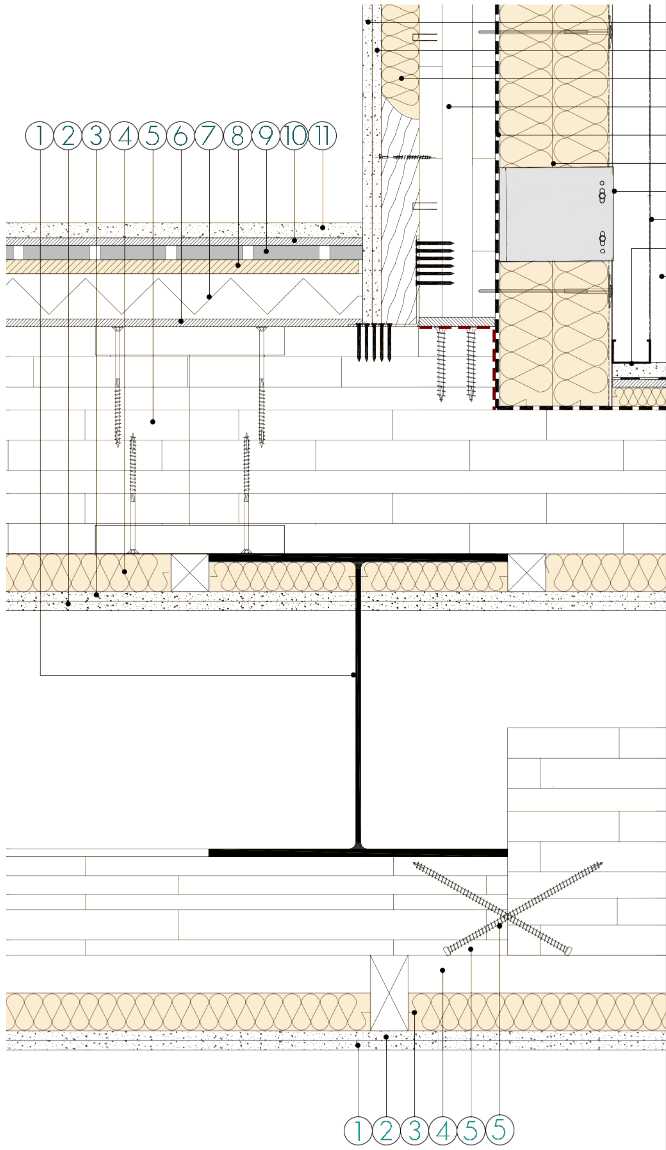
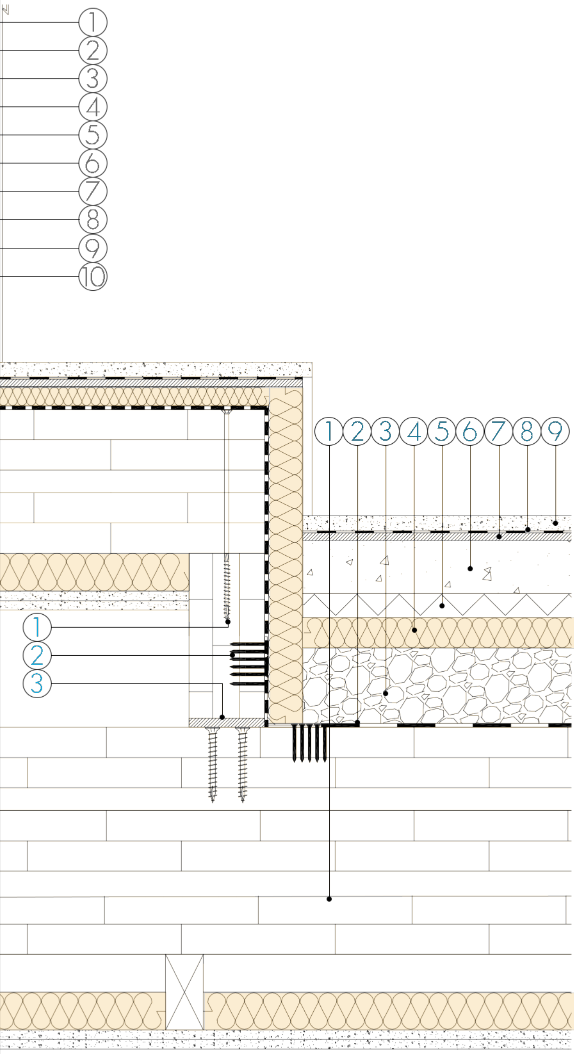


Fig. 225. Internal slab and terrace detail.

yer in mineral wool panel density 20 kg/m3 inside stud cavity

density 20 kg/m3 inside stud cavity. Thickness. 150 mm
de system to the wall through 15 cm long anchors dim. 80x40mm
ertical orientation. 197x3000mm,

n, 50mm every 500mm, fixed with aluminum clips
JV stable.) Thickness12 mm



Floor

1. Steel Beam HD 400X237
2. Fire protection gypsum board type F- Thickness 12.5 mm
3. Gypsum board type A-Thickness 12.5 mm
4. Independent studs with 50 mm thermal and acoustic insulation layer in mineral wool panel, density 20 kg/m3 inside stud cavity.
5. CLT slab panel, type L8s, cover layers and inner layer (40mm each) consisting of two lengthwise layers, Strength class:C24 according to EN 338 -Thickness 300mm
6. Self-leveling Beton Ultraplan-Thickness. 10 mm
7. Wood fiber Fibertherm Base. Thickness. 60mm
8. Thermal Insulation Layer -Thickness 150mm
9. Radiant heating panels Betonradiant-Thickness. 40mm
10. Self-leveling Beton Ultraplan-Thickness. 10 mm
11. IFinishing: Porcelain stoneware tiles - Sp. 2 cm dim. 120x60

Connection

1. Perforated belt connection
2. Metal angle bracket
3. Countersunk Screw HBS

5.2.5. TERRACE DETAIL.

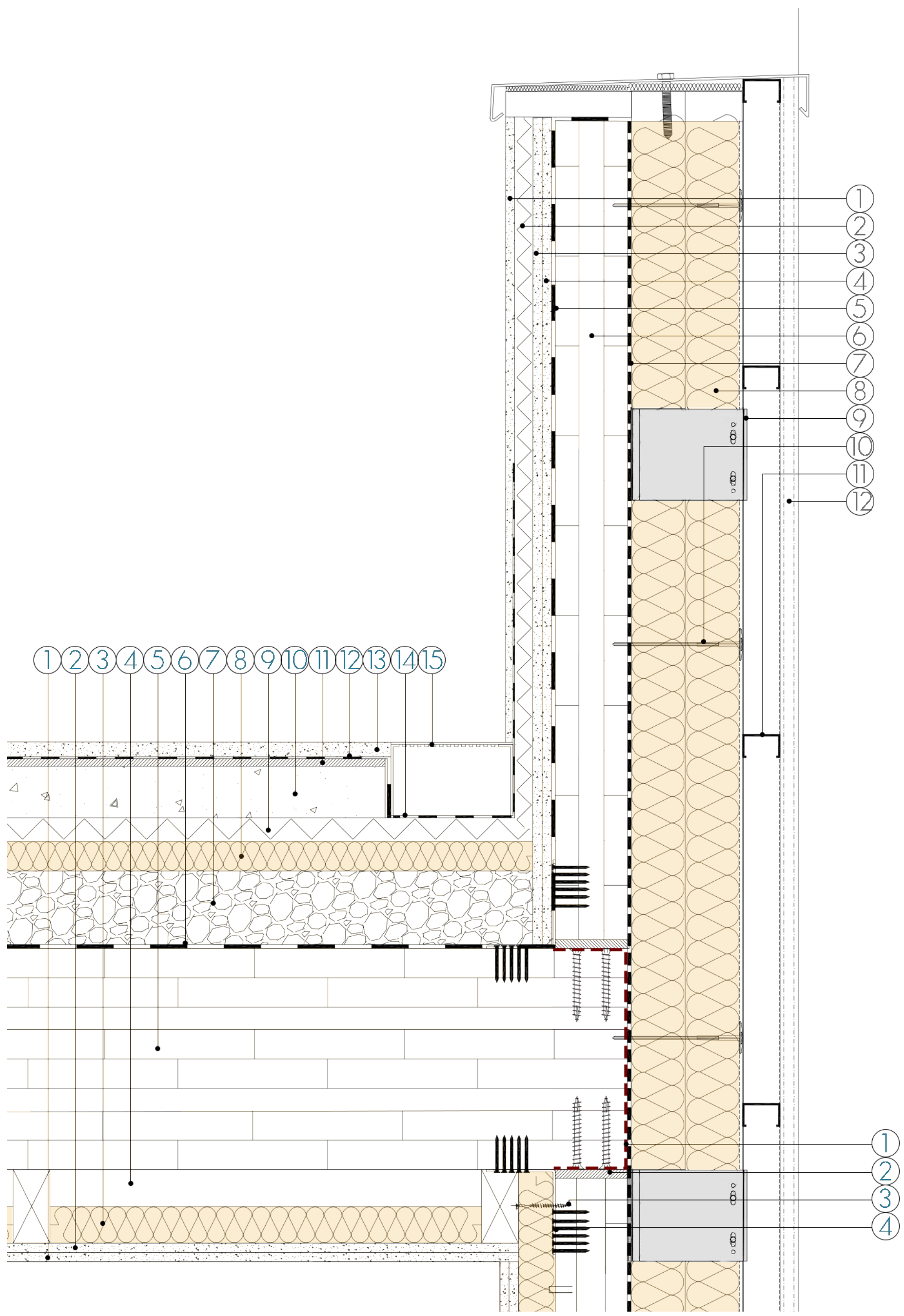


Fig. 226. Terrace slab blow-up.

Floor
1. Fire protection gypsum board type F- Thickness. 12.5 mm
2. Gypsum board type A-Thickness. 12.5 mm
3. Independent studs held 15mm clear from CLT with 50 mm thermal and acoustic insulation layer in mineral wool panel, density 20 kg/m3 inside stud cavity.
4. Air gap space for services
5.CLT slab panel, type L8s, cover lay ers and inner layer (40mm cm each) consisting of two lengthwise layers, Strength class: C24 according to EN 338 -Thickness 300mm
6. Vapor retarder sd=2,3m-Thickness. 10 mm
7. Gravel layer, thickness 8 cm
8. Impact sound insulation, thickness. 40mm
9. Vapour barrier PAVAPOR, thickness. 32mm
10. Cement screed, thickness 40mm
11. Rigid foam EPS thickness, 10mm
12. EPDM waterproofing membrane, thickness. 10 mm
13. Outdoor flooring in treated wood dim 2.35x14x280 mm, thickness 20 mm
14. Shaped aluminum flashing for rain water drainage
15. Iron grate to avoid the blocking in the drainage channel

Wall
1. Gypsum board type A-Thickness. 12.5 mm
2. Vapour barrier PAVAPOR, thickness. 32mm
3. Fire protection gypsum board type F- Thickness 12.5 mm
4. Gypsum board type A-Thickness 12.5 mm
5. Vapor Barrier -Thickness 0.5mm
6. CLT wall panels 100 CS3 -Thickness. 100 mm
7. Vapor barrier, Thickness. 2 mm
8. Thermal and acoustic insulation layer in mineral wool panel den sity 20 kg/m3 inside stud cavity. Thickness. 150 mm
9. Double L-shaped bracket for anchoring the ventilated facade system to the wall through 15 cm long anchors dim. 80x40mm
10. Plastic mechanical anchor
11. Substructure made of aluminum sheet profiles with C-section, 50mm every 500mm, fixed with aluminum clips
12. 3D TWIX siding boards, WPC (Wood Polymer Composit) Vertical orientation. 197x3000mm.

Connection
1. Sealing tape for air tightness
2. Perforated belt connection
3. Full thread connector with counter sunk head
4. Special screws for fixing wood battens/studs

5.2.6. GROUNDFLOOR SLAB

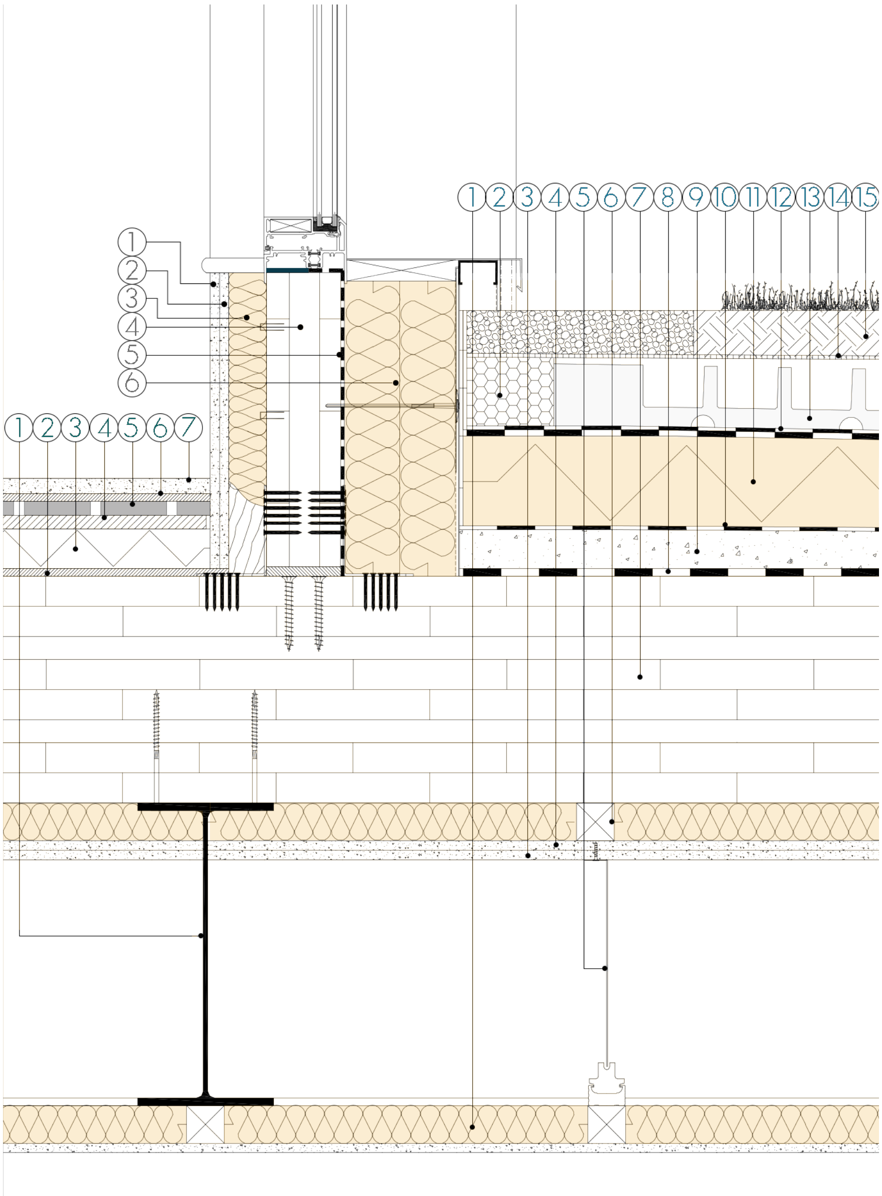


Fig. 227. Groundfloor slab blow-up.

Floor
1. Steel Beam HD 400X237
2. Self-leveling Beton Ultraplan-Thickness. 10 mm
3. Wood fiber Fibertherm Base. Thickness. 60mm
4. Thermal Insulation Layer -Thickness 150mm
5. Radiant heating panels etonradi ant-Thickness. 40mm
6. Self-leveling Beton Ultraplan-Thickness. 10 mm
7. IFinishing: Porcelain stoneware tiles - Sp. 2 cm dim. 120x60

Green Slab
1. Independent studs held 15mm clear from CLT with 50 mm thermal and acoustic insulation layer in min eral wool panel, density 20 kg/ 3 inside stud cavity with Gypsum board type A finishing layer-Thick ness. 12.5 mm
2. Aerated concrete block, Gasbeton h.8cm
3. Fire protection gypsum board type F- Thickness. 12.5 mm
4. Gypsum board type A-Thickness. 12.5 mm
5. Hanger for fixing false ceiling
6. Independent studs held 15mm clear from CLT with 50 mm thermal and acoustic insulation layer in mineral wool panel, density 20 kg/m3 inside stud cavity
7. CLT slab panel, type L8s, cover lay ers and inner layer (40mm each) consisting of two lengthwise layers, Strength class:C24 according to EN 338 -Thickness 300mm
8. Vapor barrier h. 6 mm
9. Lightened sloping substrate layer maximum th. 10 cm, slope 2%
10. Vapor barrier h. 6 mm
11. Thermal insulation layer h. 12cm ; = 0.036 W/m°K
12. Anti-root sheath th. 0.5cm coupled with cold laid self-adhesive water proofing membrane
13. Water storage,drainage and ther mal insulation h.8 cm
14. Anti-root membrane h.1.3 cm
15. Fertile soil from h. 13 to 18 cm

Wall
1. Fire protection gypsum board type F- Thickness. 12.5 mm
2. Gypsum board type A-Thickness. 12.5 mm
3. Independent with 50 mm thermal and acoustic insulation layer in min eral wool panel density 20 kg/m3 inside stud cavity
4. CLT wall panels 100 CS3 -Thickness. 100 mm
5. Vapor barrier, Thickness. 2 mm
6. Thermal and acoustic insulation layer in mineral wool panel den sity 20 kg/m3 inside stud cavity. Thickness. 150 mm

5.2.7. GREEN ROOF.

Green Slab

1. Independent studs held 15mm clear from CLT with 50 mm thermal and acoustic insulation layer in min eral wool panel, density 20 kg/ m3 inside stud cavity with Gypsum board type A finishing layer-Thick ness. 12.5 mm
2. Hanger for fixing false ceiling
3. Fire protection gypsum board type F- Thickness. 12.5 mm
4. Gypsum board type A-Thickness. 12.5 mm
5. Independent studs held 15mm clear from CLT with 50 mm thermal and acoustic insulation layer in mineral wool panel, density 20 kg/m3 inside stud cavity
6. CLT slab panel, type L8s, cover lay ers and inner layer (40mm each) consisting of two lengthwise layers, Strength class:C24 according to EN 338 -Thickness 300mm
7. Vapor barrier h. 6 mm
8. Lightened sloping substrate layer maximum th. 10 cm, slope 2%
9. Vapor barrier h. 6 mm
10. Thermal insulation layer h. 12cm ; = 0.036 W/m°K
11. Anti-root sheath th. 0.5cm coupled with cold laid self-adhesive water proofing membrane
12. Water storage, drainage and ther mal insulation h.8 cm
13. Anti-root membrane h.1.3 cm
14. Fertile soil from h. 13 to 18 cm
15. Shaped aluminum flashing for rain water drainage
16. Iron grate to avoid the passage of gravel in the drainage channel

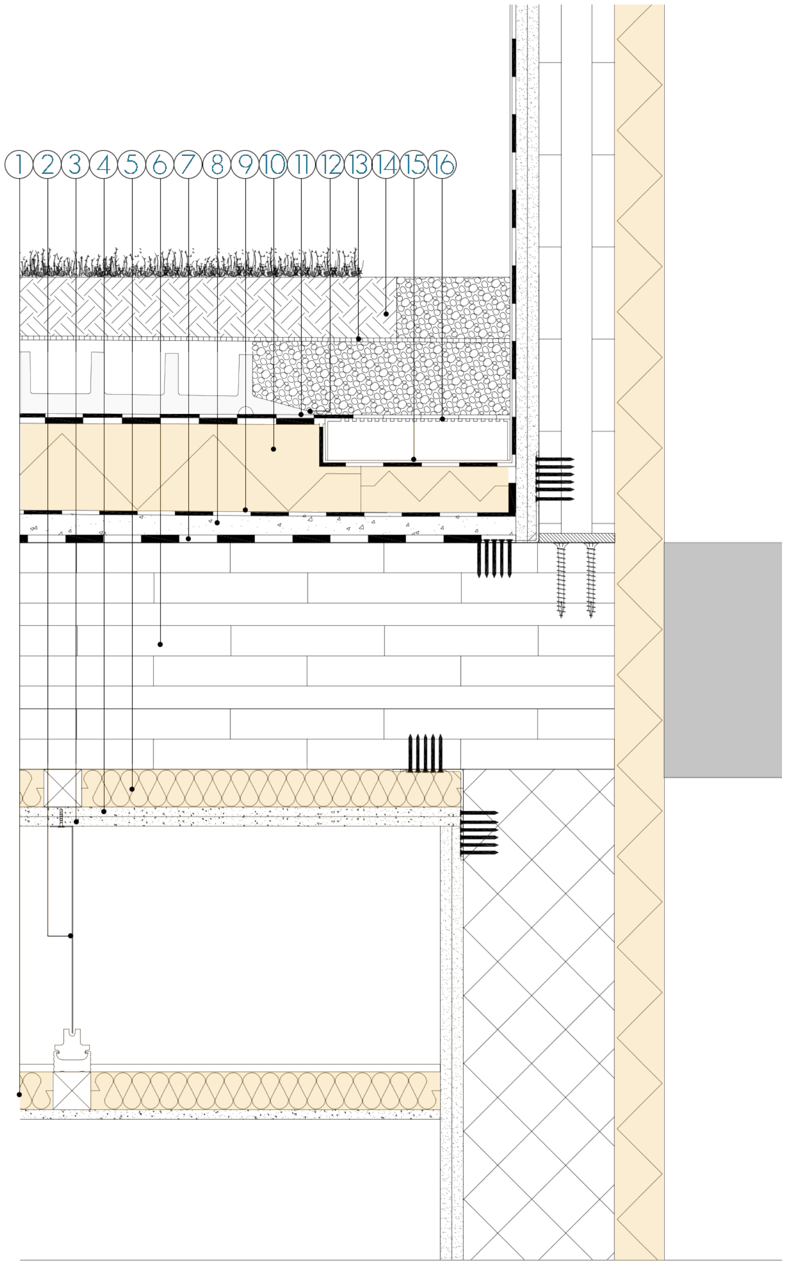


Fig. 228. Green roof detail.

5.2.8. UNDER GROUND SLAB.

Floor

1. Soil
2. Oversite concrete -Thickness. 10 cm
3. Ventilation system for floor in con tact with the ground with regen erated plastic igloo; dimensions 50x50x50cm
4. Reinforced concrete layer with elec tro-welded mesh - Thickness. 5 cm
5. Vapor barrier. Thickness. 32 mm
6. Discontinuous EPS insulation layer - Thickness. 10 cm - =0,034 W/mK
7. Layer of screed for the plant pas sage . Thickness. 200 mm
8. Reinforced concrete foundation

Wall

1. Fire protection gypsum board type F- Thickness. 12.5 mm
2. Gypsum board type A-Thickness. 12.5 mm
3. Reinforced concrete wall
4. Insulating layer in "Stiferite - Class SK" in rigid EXP with saturated min eral fiber coverings 12 cm thick d = 0.025 w /m2k
5. Waterproofing membrane h. 0.5 cm

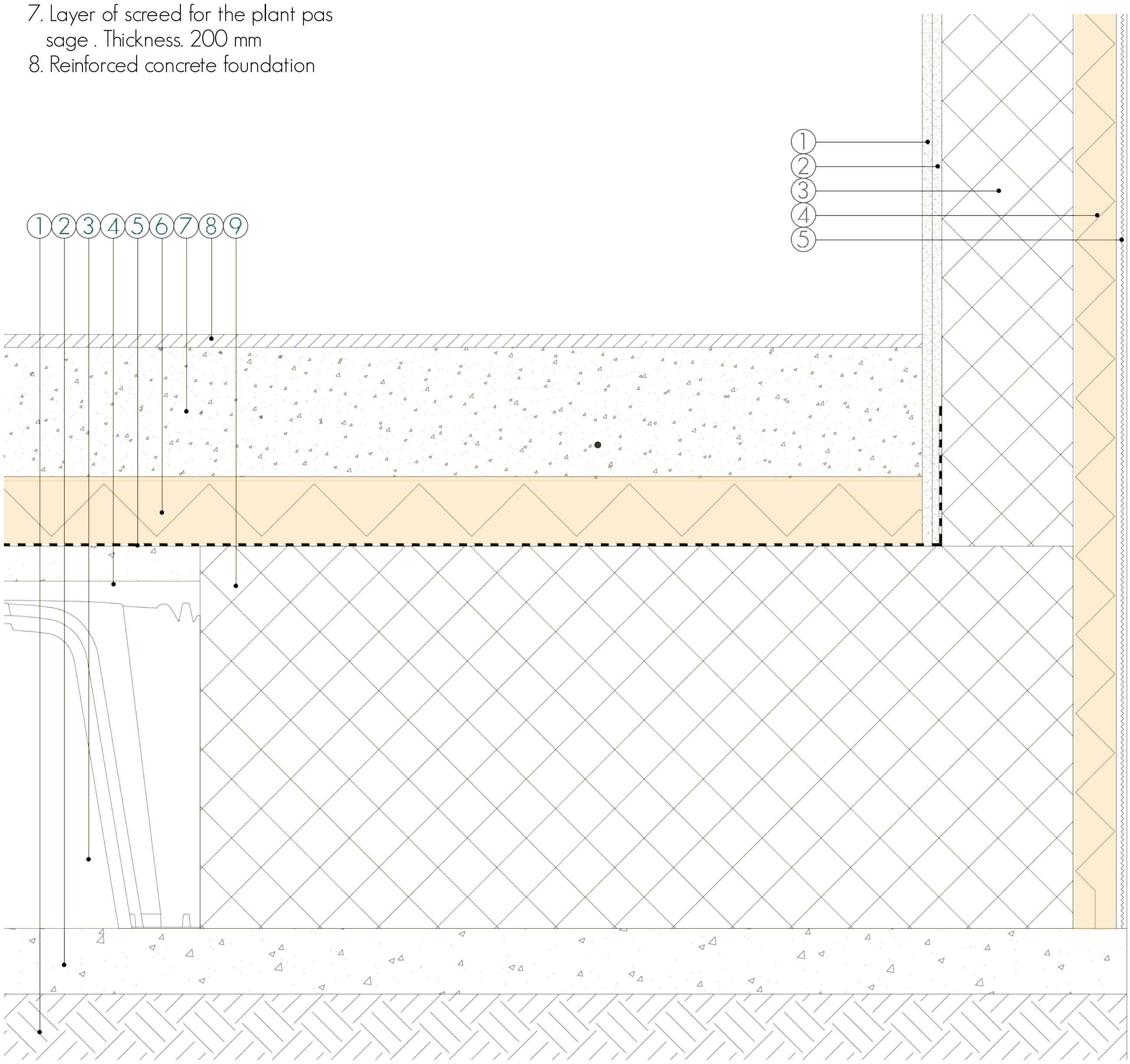
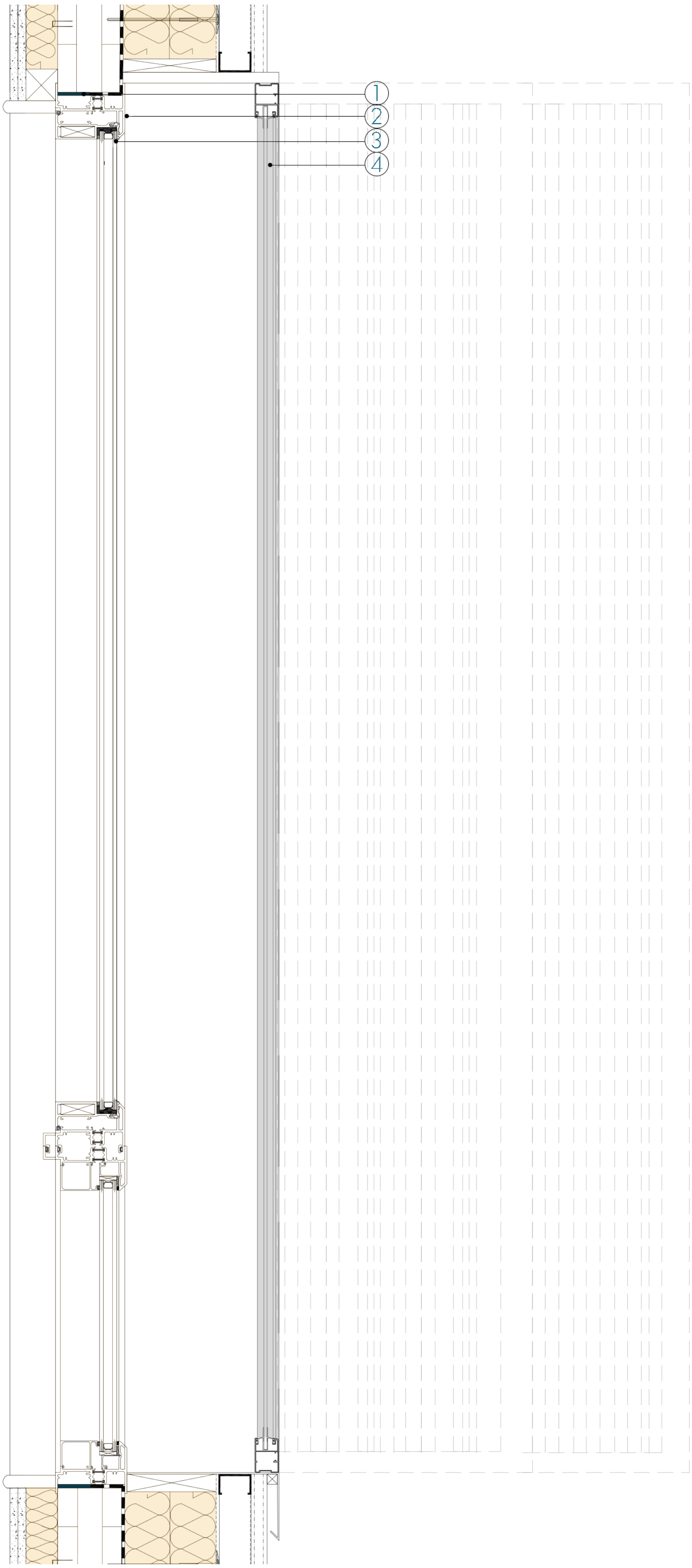
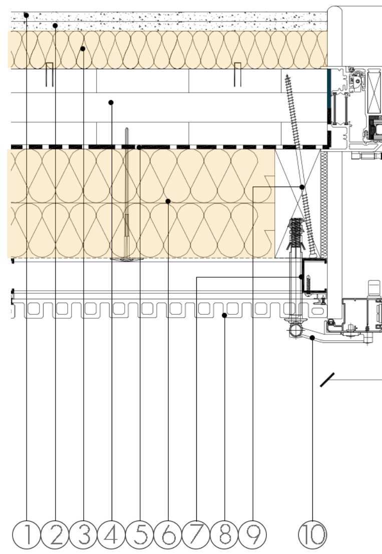
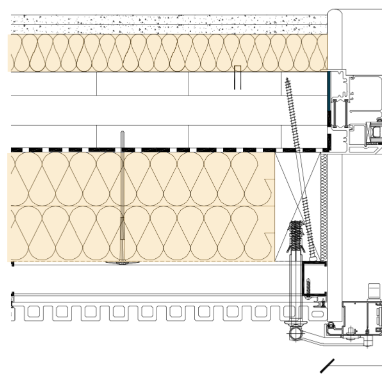


Fig. 229. Under ground slab detail.



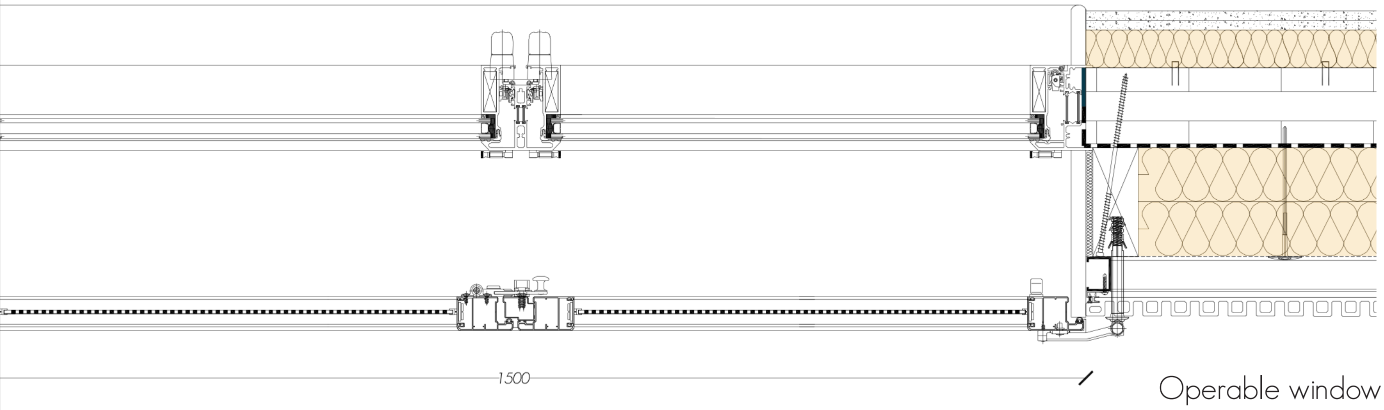




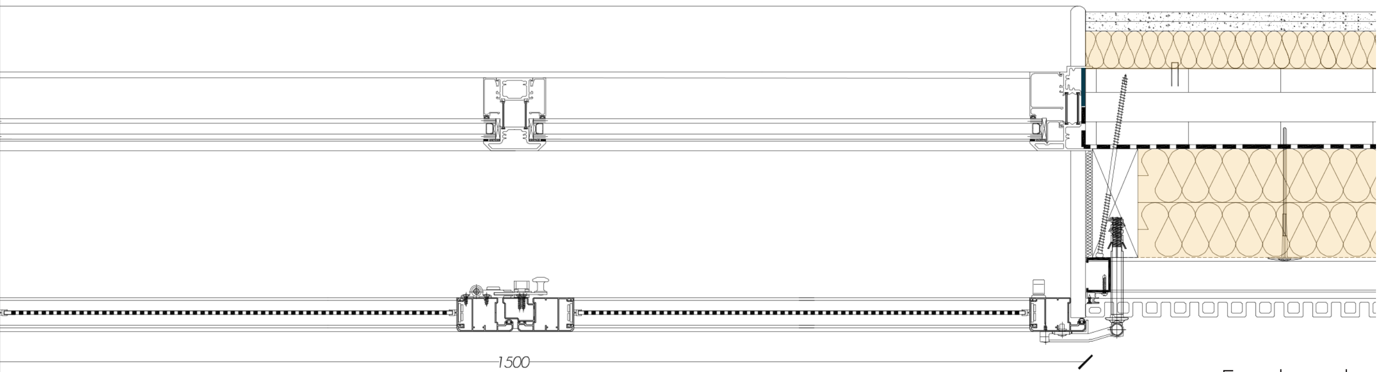
Window Detail

1. Sealing tape for windows and doors FRAME BAND
2. External windows with Aluminum profiles U=1.9 W/m2K
3. Double clear glazing with argon, U=2.53 W/m2K
4. External aluminum vertical louvers

5.2.9. TRANSPARANT DETAIL



Operable window



Fixed window

Wall

1. Soil
2. Oversite concrete -Thickness. 10 cm
3. Ventilation system for floor in con tact with the ground with regen erated plastic igloo; dimensions 50x50x50cm
4. Reinforced concrete layer with elec tro-welded mesh - Thickness. 5 cm
5. Vapor barrier. Thickness. 32 mm
6. Discontinuous EPS insulation layer - Thickness. 10 cm - =0,034 W/mK
7. Layer of screed for the plant pas sage . Thickness. 200 mm
8. Reinforced concrete foundation

Fig. 230. Transparant elementes general detail.

5.3.10. OPAQUE DETAIL.

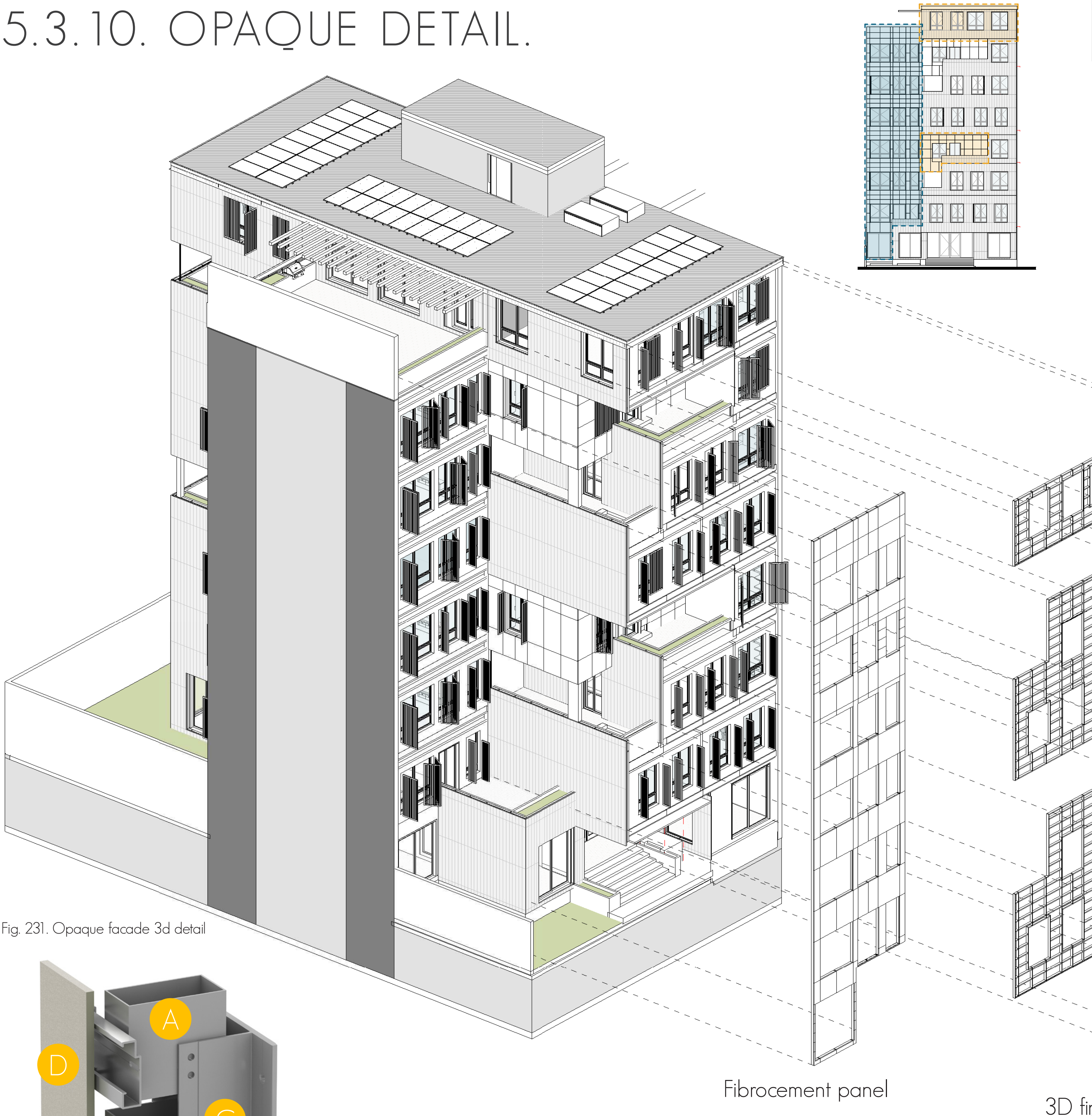


Fig. 231. Opaque facade 3d detail

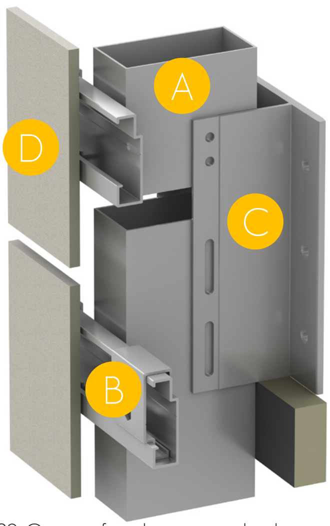


Fig. 232. Opaque facade structure detail

A. Double L-shaped bracket for anchoring the ventilated facade system to the wall through 15 cm long anchors dim. 80x40mm

B. Substructure made of aluminum sheet profiles with C-section, 50mm every 500mm, fixed with aluminum clips

C. Plastic mechanical anchor

D. 3D TWIX siding boards, or fibercement panel

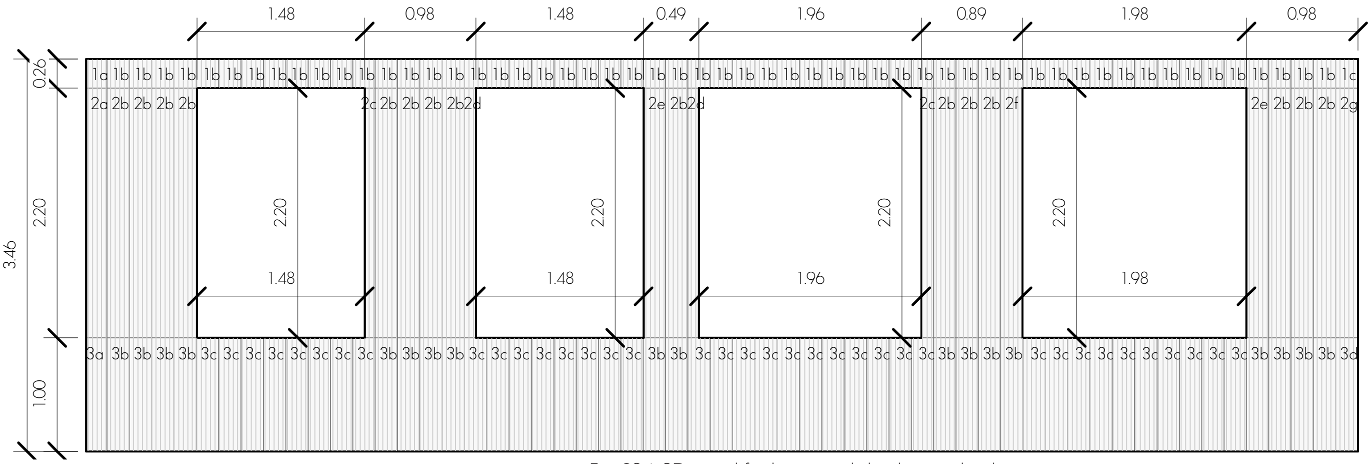
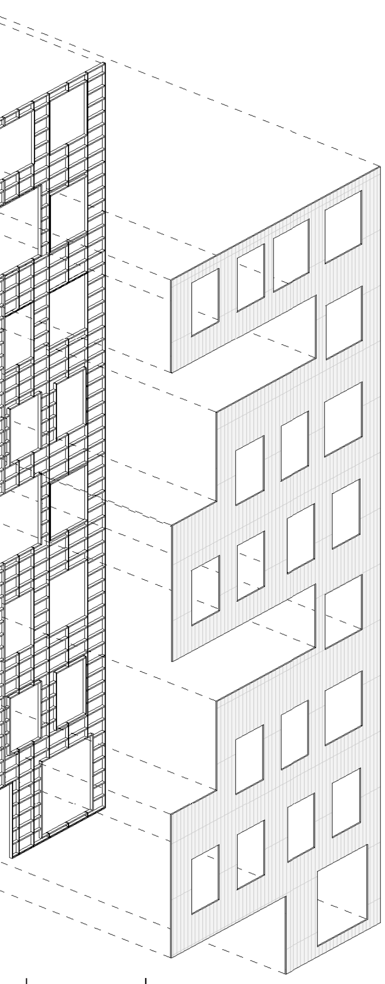
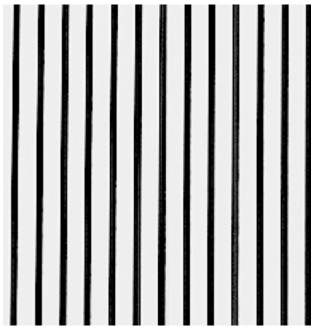


Fig. 234. 3D panel finishing panel distribution detail,



nishing panel



FINISHING TYPE 01

3D TWIX siding boards are a type of cladding material made from a Wood Polymer Composite (WPC) that gives the boards the appearance of natural wood but with added durability and resistance to weathering and insects. The boards are designed to be installed vertically and have a three-dimensional texture, adding visual interest and depth to the wall surface. With dimensions of 197mm wide and 3000mm long, the 3D TWIX siding boards offer a stylish and low-maintenance option for exterior wall cladding.

FINISHING TYPE 02

The EQUITONE White Fibrocement Panel is a premium cladding material made of a blend of cement, cellulose fibers, and other additives that provide high strength and durability. The panel has a smooth white finish that is moisture proof and UV stable, making it an ideal option for use in a variety of climates. The panel is highly resistant to fire, impact, and insects, providing excellent protection to the building's exterior. Its easy installation, low maintenance, and modern appearance make it a popular choice for architects and designers looking for a long-lasting and aesthetically pleasing cladding system.

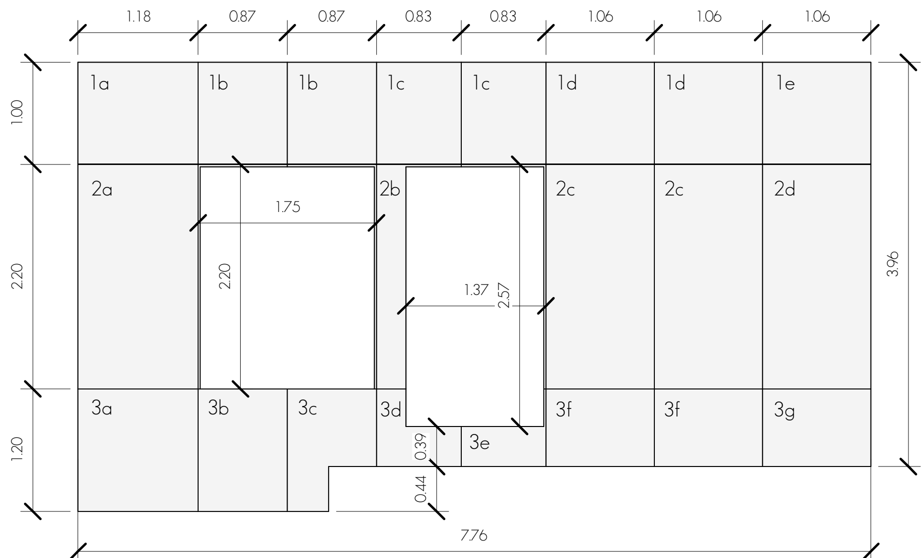


Fig. 233. Fibercement general facade detail.

6

SUSTAINABLE BUILDING TECHNOLOGIES

In recent years, sustainable building technologies have gained increasing attention due to their significant potential to reduce energy consumption, minimize environmental impact, and improve occupant comfort and well-being. This chapter, includes passive and active strategies, daylight analysis, and energy analysis.

Passive strategies involve designing buildings to take advantage of natural resources such as sunlight, and air movement, to minimize the need for mechanical systems. The passive strategies include building orientation, window placement and sizing, insulation, and shading devices.
On the other hand, active strategies use mechanical systems to reduce energy consumption and improve indoor environmental quality. Such as energy-efficient lighting, heating and cooling systems, and renewable energy technologies such as solar panels.

Daylight analysis is an essential aspect of sustainable building design, as it can significantly reduce the need for artificial lighting while improving occupant comfort and productivity. This analysis involves studying the amount and quality of natural light that enters a building and designing the space accordingly. Energy analysis is another critical aspect of sustainable building design, as it can help identify opportunities to reduce energy consumption and improve building performance. This analysis involves evaluating the energy use of the building systems and identifying areas where energy efficiency improvements can be made.

6.1

SUSTAINABLE STRATEGIES

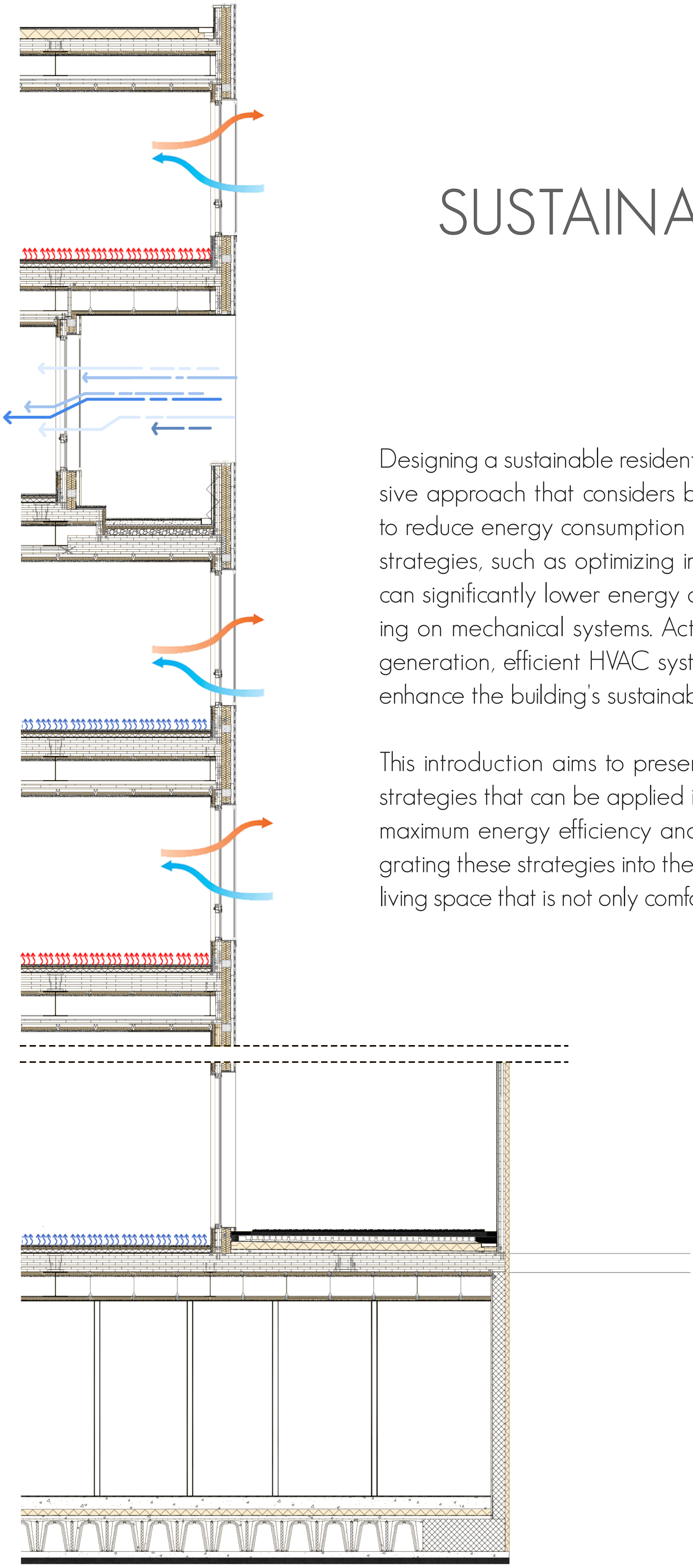


Fig. 235. Schematic design detail

Designing a sustainable residential modular building requires a comprehensive approach that considers both passive and active design strategies to reduce energy consumption and minimize environmental impact. Passive strategies, such as optimizing insulation, shading, and natural ventilation, can significantly lower energy demand and improve comfort without relying on mechanical systems. Active strategies, such as renewable energy generation, efficient HVAC systems, and lighting optimization, can further enhance the building's sustainability performance.

This introduction aims to present the various passive and active design strategies that can be applied in a residential modular building to achieve maximum energy efficiency and sustainability. By understanding and integrating these strategies into the building's design process, we can create a living space that is not only comfortable but also environmentally responsible.

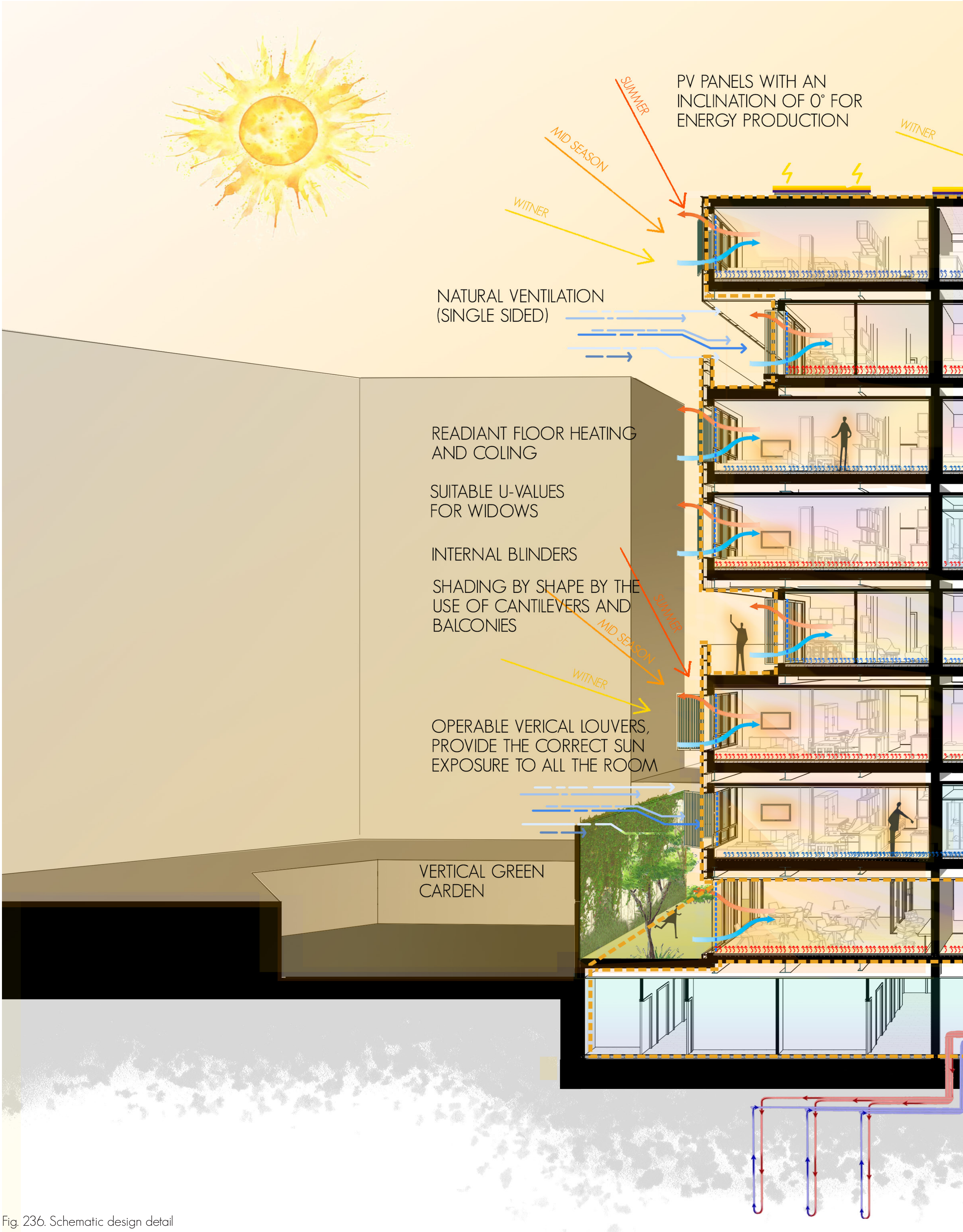


Fig. 236. Schematic design detail

6.1.1. SCHEMATIC DESIGN

One of the primary passive design strategies for a residential modular building is optimizing the U-value. The U-value is a measure of how well a building material insulates against heat transfer. A lower U-value indicates better insulation, which can help reduce heating and cooling loads.

By using high-performance insulation materials and careful detailing, the U-value can be optimized to reduce the building's energy consumption.

Another important strategy is the use of photovoltaic (PV) panels to generate renewable electricity. By installing PV panels on the roof or façade of the modular building, it is possible to offset a significant portion of the building's energy requirements. This not only reduces the building's carbon footprint but also lowers energy costs over the building's lifetime.

Vertical louvers are another passive strategy that can be used to reduce solar incidence and control daylighting. These louvers can be adjusted to let in the desired amount of natural light while minimizing heat gain. By shading the building's façade, the cooling load can be reduced, leading to a more comfortable indoor environment.

Active strategies such as radiant floor heating and cooling can be employed to provide comfortable indoor temperatures year-round. This system circulates heated or chilled water through pipes embedded in the floor, providing a comfortable and efficient heating and cooling solution.

Natural ventilation, such as single-sided ventilation, can also be used to improve indoor air quality and reduce cooling loads, resulting in lower energy consumption.

Optimizing lighting is another important consideration when designing a residential modular building. By using energy-efficient lighting fixtures and controls, it is possible to reduce the building's energy consumption while providing a comfortable and well-lit environment for occupants.

Finally, using a water-to-water heat pump can provide efficient heating and cooling, utilizing the building's water supply to transfer heat between the interior and exterior of the building.

In summary, the passive and active design strategies discussed above can be employed to improve the energy efficiency and sustainability of a residential modular building. By considering these strategies during the schematic design phase, it is possible to create a comfortable and environmentally friendly living space for occupants.

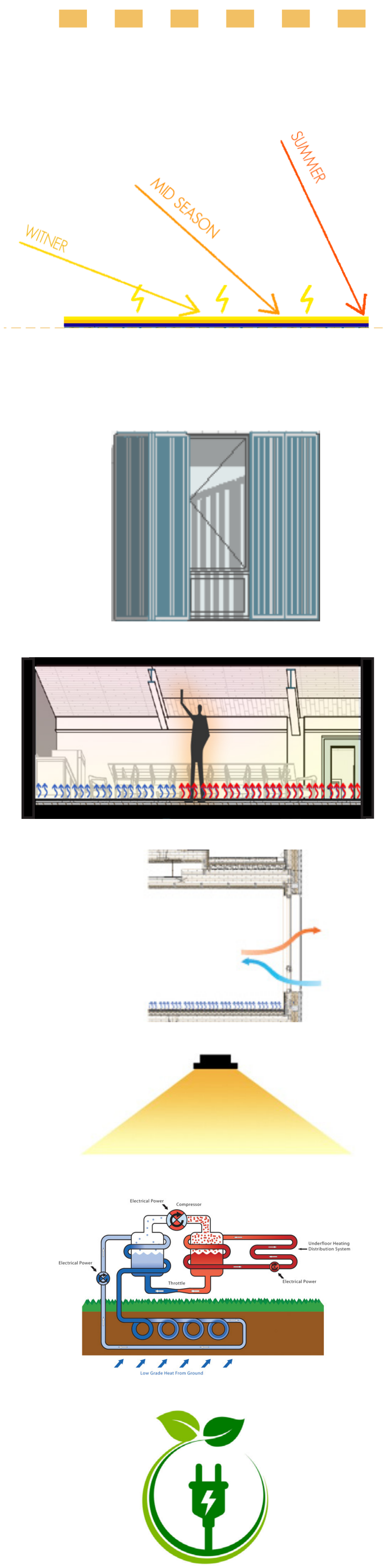


Fig. 237. Schematic design legend.

6.2
DAYLIGHT AND SHADING OPTIMIZATION

6.2.1 DAYLIGHT ANALYSIS

Daylight analysis involves the study of the amount and quality of natural light entering a building to determine the appropriate design strategies to optimize the use of daylight, reduce energy consumption, and enhance the visual comfort of occupants. This may involve adjusting the placement and size of windows, adding shading devices

A 3D model of the building is created using specialized software. This model can be used to simulate the behavior of natural light inside the building under different conditions

Then various analyses can be carried out to assess the quality and quantity of natural light inside the building. These analyses may include measuring the illuminance (amount of light) at different points in the building, analyzing the distribution of light throughout the space, and evaluating the potential for glare.

Finally, the daylight analysis process may involve iterating and refining the design based on feedback from the analysis. This may involve making further adjustments to the building layout or fenestration, or fine-tuning the placement and configuration of shading devices.

Rhinoceros

AUTODESK® INSIGHT™

AUTODESK® REVIT®

Fig. 238. Sofwares logo. Source. Rhinoceros, Climate studio, Autodesk Revit, Autodesk Insight..

6.2.2 PROCESS OF DAYLIGHT ANALYSIS

The studyi of different window heights, it involves evaluating the ideal height of windows and their location to maximize the benefits of daylight and minimize the negative effects of solar radiation. This requires consideration of the building's orientation, surrounding environment, and the desired level of natural light.

Glazing optioneering is the process of selecting the most appropriate type of glazing for a building based on factors such as energy efficiency, thermal performance, visual comfort, and acoustic performance After specifying the appropriate window height an evaluation of the various options for glass and other materials used in windows, such as low-e coatings, insulated glazing, and double glazing was conducted.

After specifying the appropriate window height and glazing type for the building, a final analysis is conducted. Taking into account the building's orientation towards the North and South, vertical shadings have been strategically incorporated onto the South facade to effectively minimize the amount of solar heat gain that enters the building while still allowing for adequate natural light. This addition has been made with the aim of ensuring that the desired level of visual comfort is achieved, providing a more pleasant and conducive environment for the occupants.

01 Window Height Analysis for Preliminary Design

- Window Height: 2.75
  Window Sill: 0.0m
- Window Height: 2.50m
  Window Sill: 0.0m
- Window Height: 2.20m
  Window Sill: 0.5m

02 Window Glazing Analysis or the Chosen Proposal

- Single Clear Glazing
- Double Clear Glazing (Air)
- Double Clear Glazing (Argon)
- Double Clear Solarban 90 (Krypton)

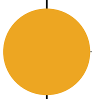
03 Final Daylight Analysis for the Chosen Proposal with Shading

- Window Height: 2.20m
- Window Sill: 0.5m
- Glazing Type: Double Clear (Argon)
- Vertical Shading on the South Facade

The examination is centered on three crucial stories: the first, fourth, and sixth. Each module on these floors is thoroughly analyzed, with values for sDA and ASE reported for individual spaces.

Fig. 239. Process of daylight analysis

6.2.3.
WINDOW HEIGHT ANALYSIS FOR PRELIMINARY DESIGN



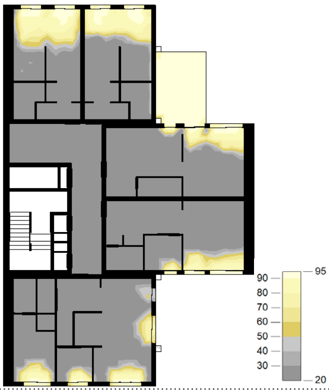
Window Height Analysis for the Preliminary Design

01

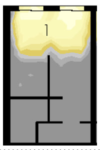
- Window Height: 2.75
  Window Sill: 0.0m
- Window Height: 2.50m
  Window Sill: 0.0m
- Window Height: 2.20m
  Window Sill: 0.5m

WINDOW HEIGHT 2.50 m
WINDOW SILL 0.0 m

First Level

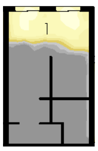


D1



1. sDA 44% ASE 0%

D1

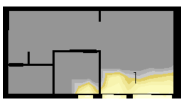


1. sDA 42% ASE 0%

B

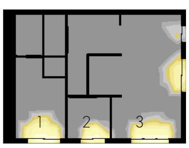
1. sDA 30% ASE 0%

C



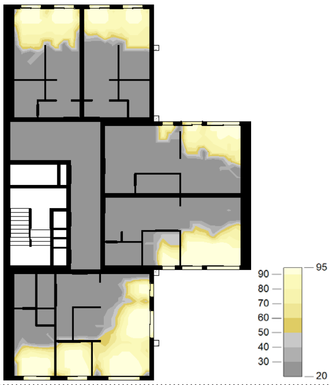
1. sDA 21% ASE 7%

F

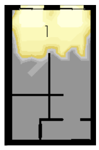


1. sDA 26% ASE 21%
2. sDA 21% ASE 32%
3. sDA 24% ASE 17%

Fourth Level

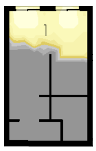


D1



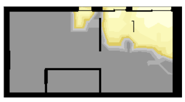
1. sDA 54% ASE 100%

D1



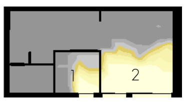
1. sDA 52% ASE 0%

B



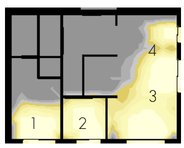
1. sDA 52% ASE 0%

C



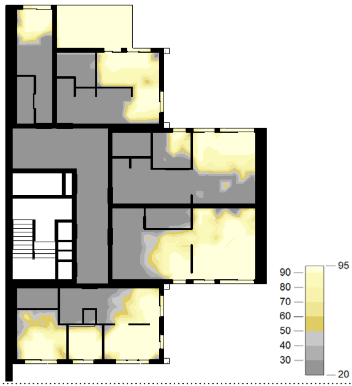
1. sDA 54% ASE 45%
2. sDA 35% ASE 30%

F

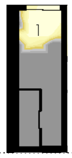


1. sDA 44% ASE 56%
2. sDA 100% ASE 95%
3. sDA 86% ASE 68%
4. sDA 29% ASE 12%

Sixth Level



A



1. sDA 42% ASE 0%

D2

1. sDA 100% ASE 0%
2. sDA 96% ASE 10%

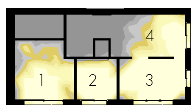
C

1. sDA 59% ASE 0%
2. sDA 40% ASE 0%

B

1. sDA 39% ASE 10%
2. sDA 96% ASE 64%

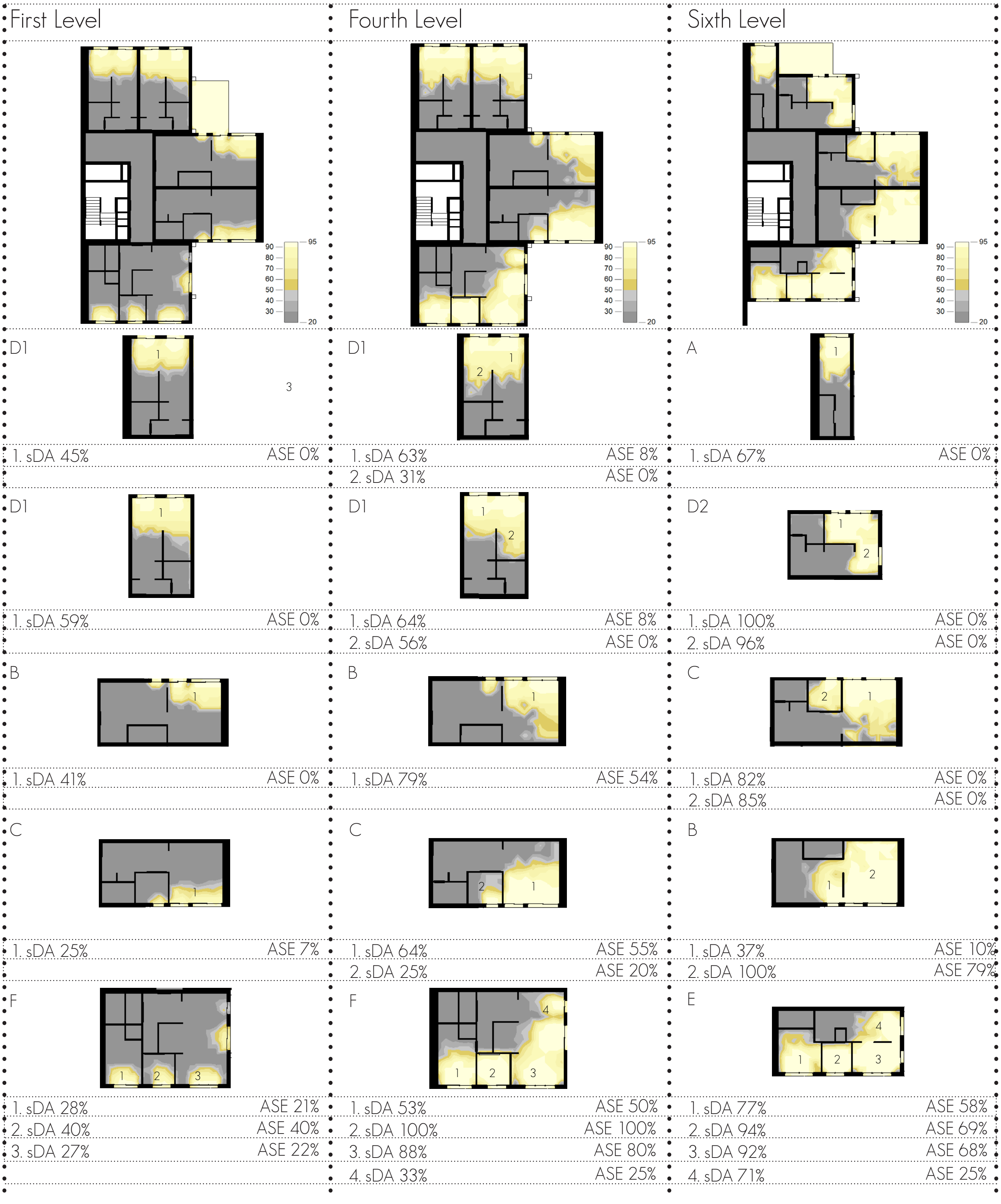
E



1. sDA 76% ASE 53%
2. sDA 100% ASE 71%
3. sDA 92% ASE 72%
4. sDA 57% ASE 25%

Fig. 240. Floor plan of daylight results, windows height analysis. Height 2.50 Sill: 0.00

WINDOW HEIGHT 2.75 m
WINDOW SILL 0.0 m



First Level		Fourth Level		Sixth Level	
D1		**D1**		**A**	
1. sDA 45%	ASE 0%	1. sDA 63%	ASE 8%	1. sDA 67%	ASE 0%
		2. sDA 31%	ASE 0%		
D1		**D1**		**D2**	
1. sDA 59%	ASE 0%	1. sDA 64%	ASE 8%	1. sDA 100%	ASE 0%
		2. sDA 56%	ASE 0%	2. sDA 96%	ASE 0%
B		**B**		**C**	
1. sDA 41%	ASE 0%	1. sDA 79%	ASE 54%	1. sDA 82%	ASE 0%
				2. sDA 85%	ASE 0%
C		**C**		**B**	
1. sDA 25%	ASE 7%	1. sDA 64%	ASE 55%	1. sDA 37%	ASE 10%
		2. sDA 25%	ASE 20%	2. sDA 100%	ASE 79%
F		**F**		**E**	
1. sDA 28%	ASE 21%	1. sDA 53%	ASE 50%	1. sDA 77%	ASE 58%
2. sDA 40%	ASE 40%	2. sDA 100%	ASE 100%	2. sDA 94%	ASE 69%
3. sDA 27%	ASE 22%	3. sDA 88%	ASE 80%	3. sDA 92%	ASE 68%
		4. sDA 33%	ASE 25%	4. sDA 71%	ASE 25%

Fig. 241. Floor plan of daylight results, windows height analysis. Height 2.75 Sill: 0.00

WINDOW HEIGHT 2.20 m
WINDOW SILL 0.5 m

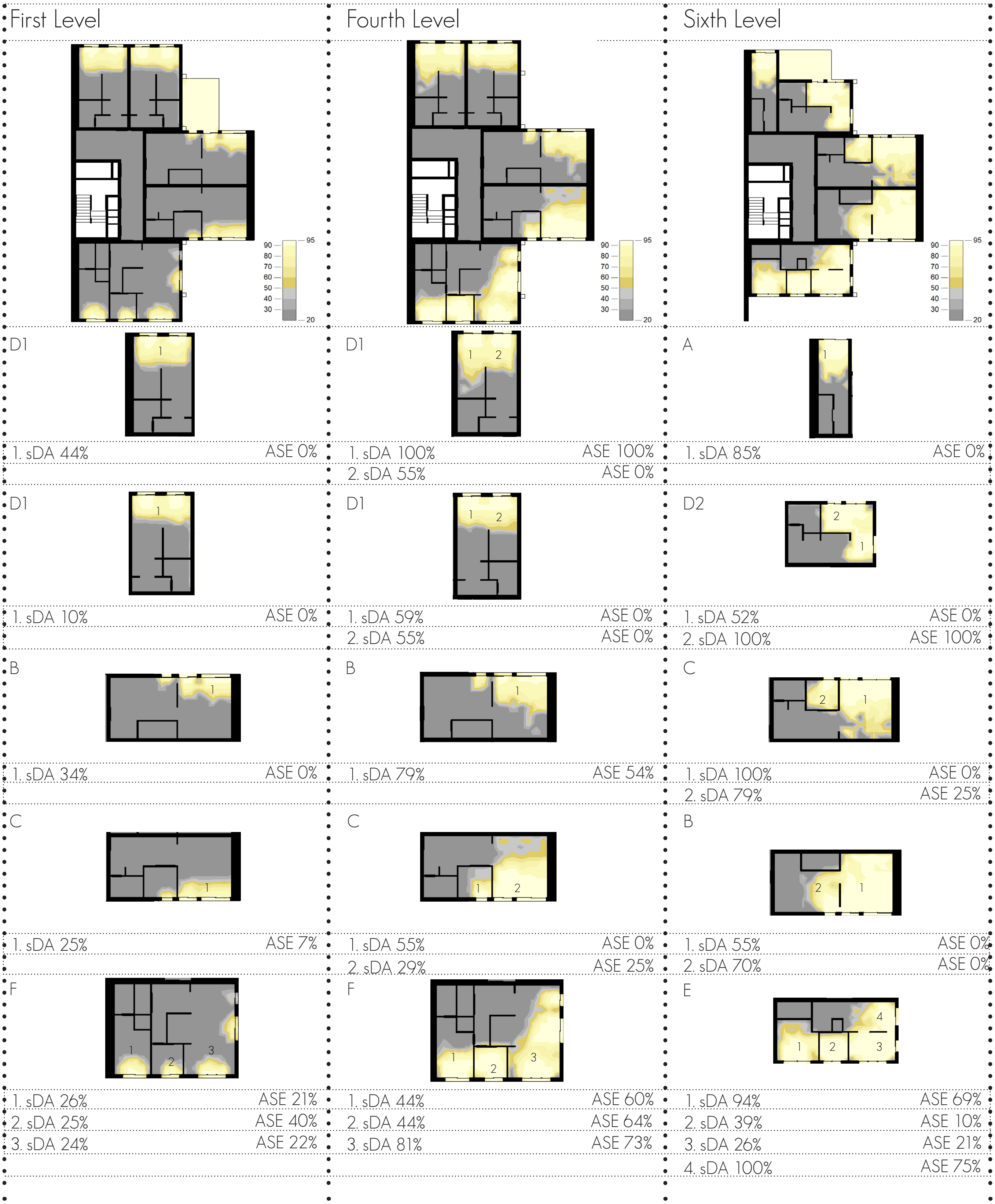


Fig. 242. Floor plan of daylight results, windows height analysis. Height 2.20 Sill: 0.50

6.2.4. WINDOW GLAZING ANALYSIS FOR THE CHOSEN PROPOSAL

Window Glazing Analysis

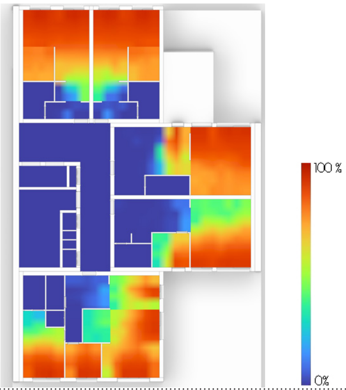
- Single Clear Glazing
- Double Clear Glazing (Air)
- Double Clear Glazing (Argon)
- Double Clear Solarban 90 (Krypton)

02

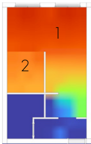
After conducting a daylight analysis on various window heights, modifications were implemented to ensure that the rooms received sufficient natural light. Specifically, the North facade on the sixth level underwent a change, with module D2 being rotated to optimize daylight exposure. This alteration was made with the goal of improving the overall quality of light within the space.

SINGLE CLEAR GLAZING

First Level

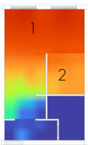


D1



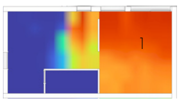
1. sDA 86.21% ASE 0%
2. sDA 100% ASE 0%

D1



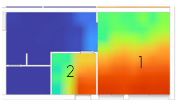
1. sDA 10% ASE 0%
2. sDA 100% ASE 0%

B



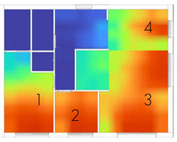
1. sDA 100% ASE 0%

C



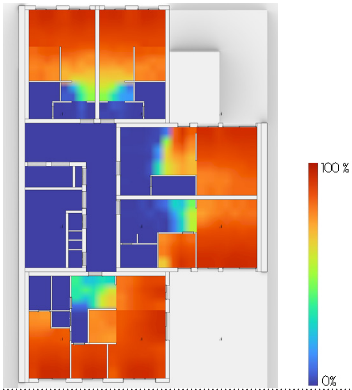
1. sDA 71.43% ASE 10.71%
2. sDA 62.50% ASE 6.25%

F

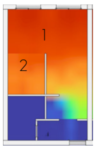


1. sDA 76.47% ASE 11.76%
2. sDA 100% ASE 18.75%
3. sDA 100% ASE 7.84%
4. sDA 75% ASE 0%

Fourth Level



D1

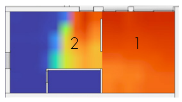


1. sDA 87.93% ASE 100%
2. sDA 100% ASE 0%

D1

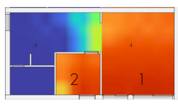
1. sDA 88.14% ASE 0%
2. sDA 88.14% ASE 0%

B



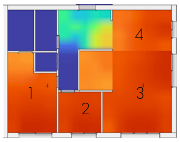
1. sDA 100% ASE 0%
2. sDA 33.33% ASE 0%

C



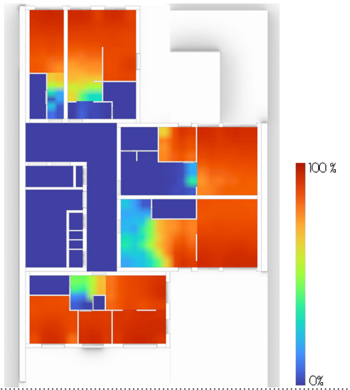
1. sDA 100% ASE 39.29%
2. sDA 100% ASE 18.75%

F



1. sDA 100% ASE 52.94%
2. sDA 100% ASE 56.25%
3. sDA 100% ASE 66.67%
4. sDA 100% ASE 20.83%

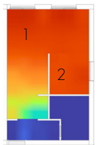
Sixth Level



A

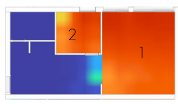
1. sDA 100% ASE 0%

D2



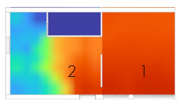
1. sDA 96.15% ASE 0%
2. sDA 100% ASE 0%

C



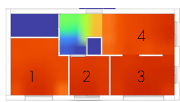
1. sDA 100% ASE 0%
2. sDA 100% ASE 0%

B



1. sDA 100% ASE 53.57%
2. sDA 46.30% ASE 9.26%

E

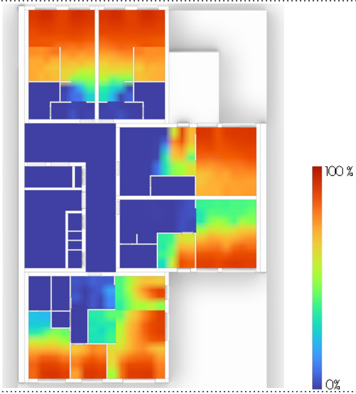


1. sDA 100% ASE 41.18%
2. sDA 100% ASE 75%
3. sDA 100% ASE 100%
4. sDA 100% ASE 42.86%

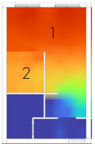
Fig. 243. Floor plan of daylight results, single clear glazing.

DOUBLE CLEAR GLAZING WITH ARGON

First Level

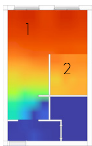


D1



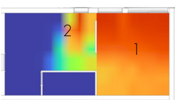
1. sDA 82.76% ASE 0%
2. sDA 100% ASE 0%

D1



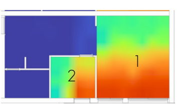
1. sDA 83.05% ASE 0%
2. sDA 100% ASE 0%

B



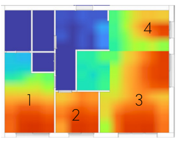
1. sDA 100% ASE 0%
2. sDA 24.07% ASE 0%

C



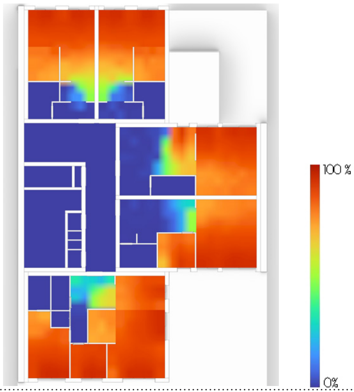
1. sDA 66.07% ASE 10.71%
2. sDA 56.25% ASE 6.25%

F

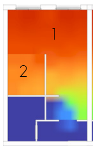


1. sDA 70.59% ASE 11.76%
2. sDA 100% ASE 18.75%
3. sDA 98.04% ASE 7.84%
4. sDA 62.50% ASE 20.83%

Fourth Level

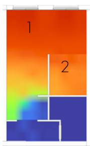


D1



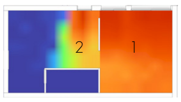
1. sDA 87.93% ASE 0%
2. sDA 100% ASE 0%

D1



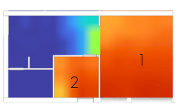
1. sDA 88.14% ASE 0%
1. sDA 100% ASE 0%

B



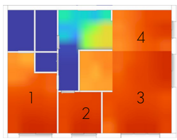
1. sDA 100% ASE 0%
2. sDA 29.63% ASE 0%

C



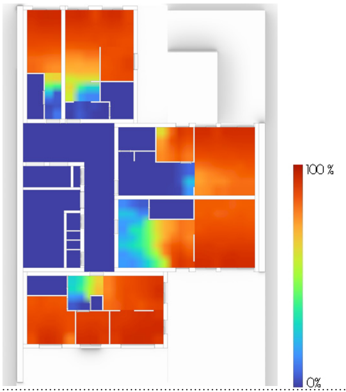
1. sDA 100% ASE 39.29%
2. sDA 100% ASE 18.75%

F



1. sDA 100% ASE 52.94%
2. sDA 100% ASE 56.25%
3. sDA 100% ASE 66.67`%
4. sDA 100% ASE 20.83%

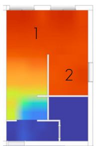
Sixth Level



A

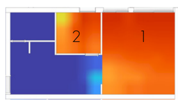
1. sDA 100% ASE 0%

D2



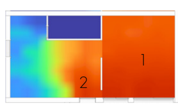
1. sDA 92.31% ASE 0%
2. sDA 100% ASE 0%

C



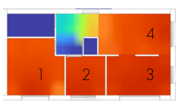
1. sDA 100% ASE 0%
2. sDA 100% ASE 25%

B



1. sDA 100% ASE 53.57%
2. sDA 44.44% ASE 9.26%

E

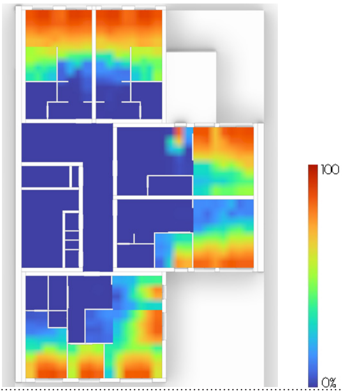


1. sDA 100% ASE 41.18%
2. sDA 100% ASE 75%
3. sDA 100% ASE 100%
4. sDA 100% ASE 42.86%

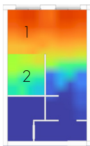
Fig. 244. Floor plan of daylight results, Double clear glazing with argon.

DOUBLE CLEAR SOLARBAN 90 WITH KRYPTON

First Level

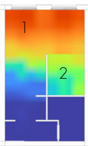


D1



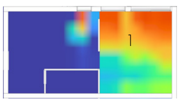
1. sDA 62.07% ASE 0%
2. sDA 31.25% ASE 0%

D1



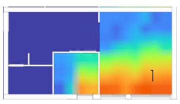
1. sDA 62.71% ASE 0%
2. sDA 25% ASE 0%

B



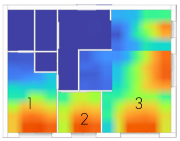
1. sDA 57.14% ASE 0%

C



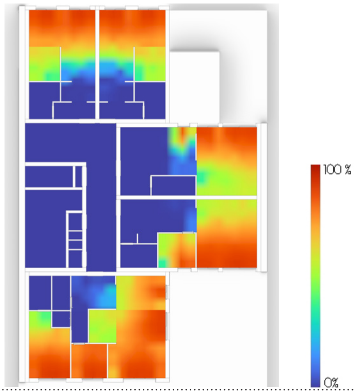
1. sDA 42.88% ASE 10.71%
2. sDA 25% ASE 6.25%

F

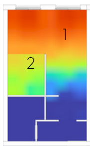


1. sDA 44.12% ASE 11.76%
2. sDA 25% ASE 40%
3. sDA 58.82% ASE 7.84%

Fourth Level

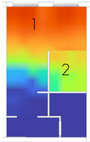


D1



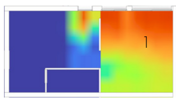
1. sDA 68.97% ASE 100%
2. sDA 68.75% ASE 0%

D1



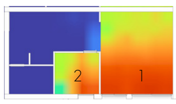
1. sDA 66.10% ASE 0%
2. sDA 81.25% ASE 0%

B



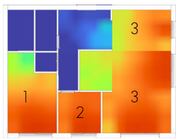
1. sDA 89.29% ASE 54%

C



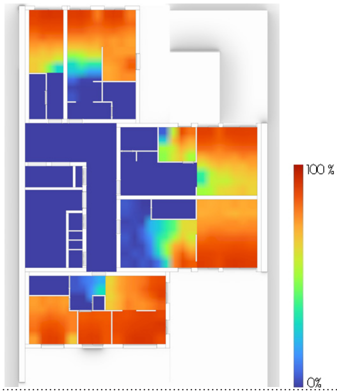
1. sDA 98.21% ASE 39.26%
2. sDA 93.75% ASE 18.75%

F



1. sDA 94.14% ASE 50%
2. sDA 100% ASE 56.25%
3. sDA 81% ASE 73%
4. sDA 29% ASE 25%

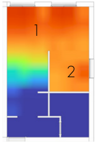
Sixth Level



A

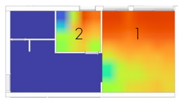
1. sDA 93.75% ASE 0%

D2



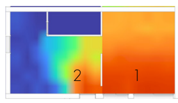
1. sDA 71.15% ASE 0%
2. sDA 100% ASE 0%

C



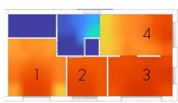
1. sDA 94.64% ASE 0%
2. sDA 81.25% ASE 0%

B



1. sDA 100% ASE 48.21%
2. sDA 25.93% ASE 9.26%

E



1. sDA 100% ASE 38.24%
2. sDA 100% ASE 75%
3. sDA 26% ASE 21%
4. sDA 100% ASE 100%

Fig. 245. Floor plan of daylight results, Double clear solarban 90 with krypton

6.2.5. FINAL DAYLIGHT ANALYSIS FOR THE CHOSEN PROPOSAL WITH SHADING

After conducting a thorough analysis, it is clear that the Double Clear Solarban 90 with Krypton glazing is the most effective option for reducing glare. However, it has been observed that the use of this glazing type resulted in a reduction of up to 20% in sDA levels in some rooms. Therefore, a more balanced approach would be to opt for Double Clear Glazing in combination with Vertical Louvers on the South facade, and windows height set to 2.20m with a sill of 0.5m. This careful selection of materials ensures that the chosen glazing and shading systems effectively reduce glare while maintaining good levels of sDA in all rooms.

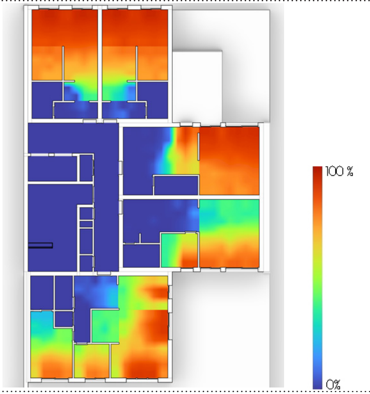
Final Daylight Analysis with Shading

03

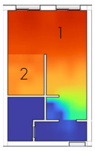
- Window Height: 2.20m
- Window Sill: 0.5m
- Glazing Type: Double Clear (Argon)
- Vertical Louvers on the South

WINDOW HEIGHT: 2.20m SILL HEIGHT: 0.5m
DOUBLE CLEAR GLAZING WITH ARGON
VERTICAL SHADING LOUVERS ON THE SOUTH FACADE

First Level

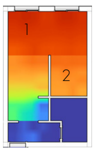


D1



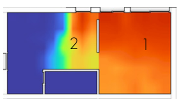
1. sDA 87.93% ASE 0%
2. sDA 100% ASE 0%

D1



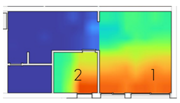
1. sDA 100% ASE 0%
2. sDA 100% ASE 0%

B



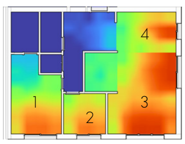
1. sDA 100% ASE 0%
2. sDA 29.63% ASE 0%

C



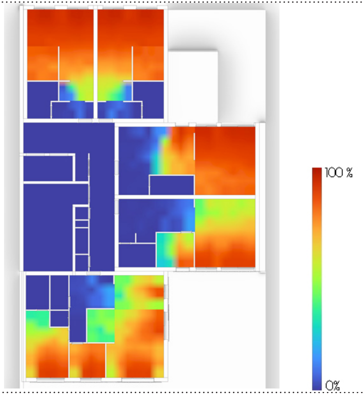
1. sDA 25% ASE 7%
2. sDA 58.93% ASE10.71%

F

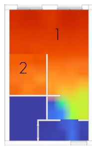


1. sDA 55.88% ASE 8.82%
2. sDA 93.75% ASE 18.75%
3. sDA 98.04% ASE 7.84%
4. sDA 70.83% ASE 0%

Fourth Level

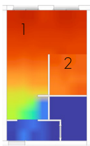


D1



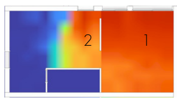
1. sDA 91.38% ASE 0%
2. sDA 100% ASE 0%

D1



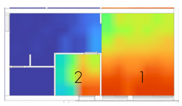
1. sDA 91.53% ASE 0%
2. sDA 100% ASE 0%

B



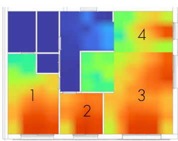
1. sDA 100% ASE 0%
2. sDA 33.33% ASE 0%

C



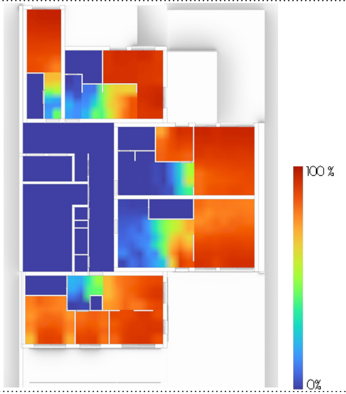
1. sDA 94.64% ASE 8.93%
2. sDA 50% ASE 0%

F

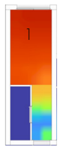


1. sDA 88.24% ASE 8.82%
2. sDA 100% ASE 6.25%
3. sDA 100% ASE 7.84%
4. sDA 70.83% ASE 0%

Sixth Level

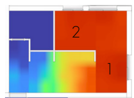


A



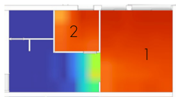
1. sDA 100% ASE 0%

D2



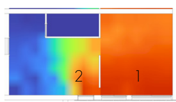
1. sDA 100% ASE 12.50%
2. sDA 59.26% ASE 0%

C



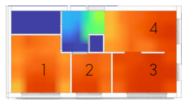
1. sDA 100% ASE 0%
2. sDA 100% ASE 0%

B



1. sDA 100% ASE 14.29%
2. sDA 27.78% ASE 1.85%

E



1. sDA 94% ASE 69%
2. sDA 100% ASE 0%
3. sDA 100% ASE 12.50%
4. sDA 100% ASE 0%

Fig. 246. Floor plan of daylight results with shading system. SDA and ASE Final results.

WINDOW HEIGHT: 2.50m SILL HEIGHT: 0.5m
DOUBLE CLEAR GLAZING WITH ARGON
VERTICAL SHADING LOUVERS ON THE SOUTH FACADE

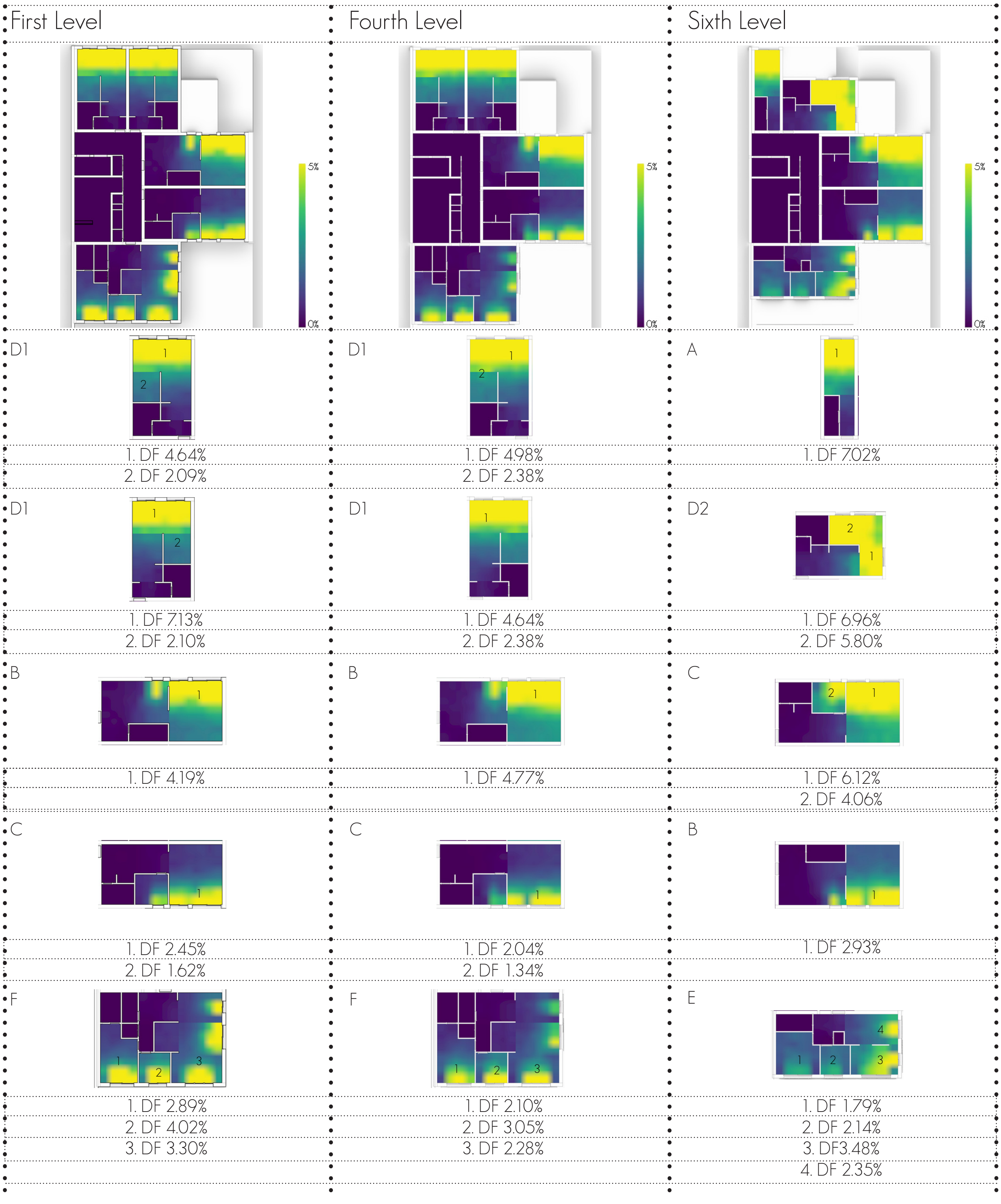


Fig. 247. Floor plan of daylight results with shading system. Daylight factor Final results.

6.2.6. DAYLIGHT RESULTS

The presented images depict the conclusive outcomes of the daylight analysis, showcasing the use of louvers and balconies for shading. The first image displays a studio apartment oriented towards the north, receiving ample natural light. The subsequent two images exhibit the daylight in two distinct time frames on the south facade with the implementation of louvers. Finally, the last images portray the efficacy of the balcony in the south facade.

Fig. 248. Inteternal view studio thrid floor.

Fig. 249. Inteternal view room module F, 5th floor. afternoon.

Fig. 250. Inteternal view room module F, 5th floor. morning.

Fig. 251. Inteternal view room module E,3rd floor. Use of the balconies.


Fig. 252. Inteternal view room module D,4th floor. Use of the balconies.


Fig. 253. Inteternal view living-dining room module F,4th floor. South facade.

6.3
ENERGY ANALYSIS AND BUILDING PERFORMANCE

Conducting an energy building analysis is a critical step towards designing and constructing sustainable, energy-efficient buildings. With the increasing demand for energy-efficient buildings, the analysis helps to evaluate the energy performance of a building and identify potential areas for improvement.

The analysis involves a comprehensive evaluation of various factors that affect the energy consumption, such as the building's orientation, shading, insulation, ventilation, heating and cooling systems, lighting, and the use of renewable energy sources.

Rhino and Climate Studio software were used to conduct the energy analysis. The process begins with creating a 3D model of the building using Rhino. The model includes information such as the building's shape, orientation, and materials, as well as details about the location, climate, and local energy costs.

Once the Rhino model is complete, it is imported into Climate Studio, where energy simulations are run to assess the building's energy performance. Climate Studio uses a range of advanced analysis tools to simulate factors such as heating, cooling, lighting, and ventilation, and to evaluate the impact of different energy-saving strategies, such as insulation, shading, and renewable energy systems.

The project analysis employed the energy costs specific to Italy, and utilized an EnergyPlus EPW weather file to simulate conditions in Milan.

The resulting data was used to compare the building's energy use intensity (EUI), taking into account factors such as operational costs, CO_2 emissions, and architectural design elements.

Rhinoceros

6.3.1. ENERGY ANALYSIS AND OPTIMIZATION PR

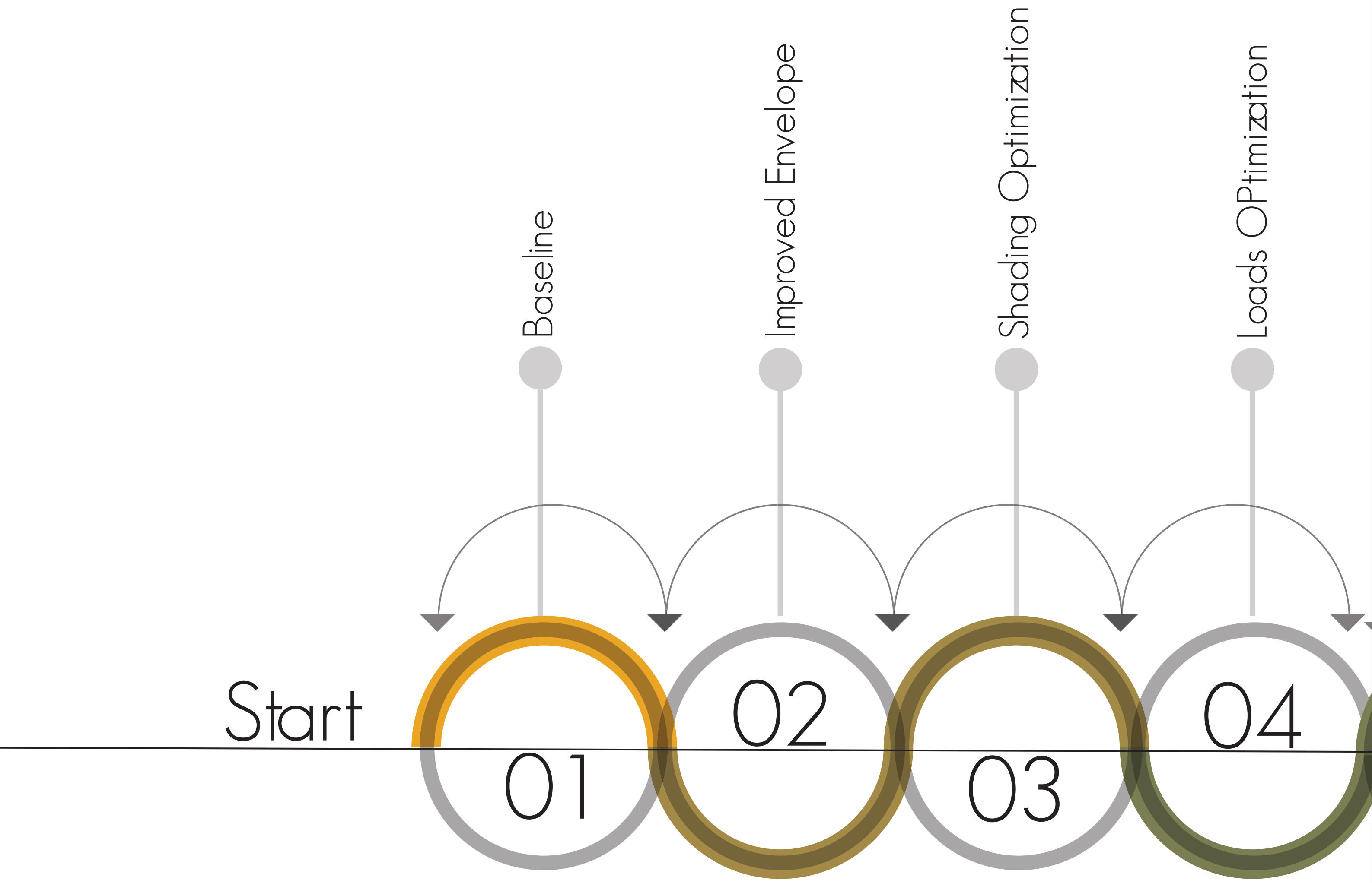


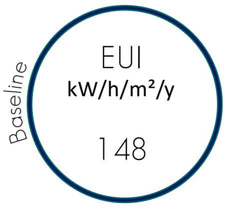
Fig. 254. Energy analysis and optimization process

ROCESS


HVAC & Natural Ventilation
Artifical Light Optimization
PV Panels Production
Optimized System
05
06
07
08
Result

6.3.2. BASELINE

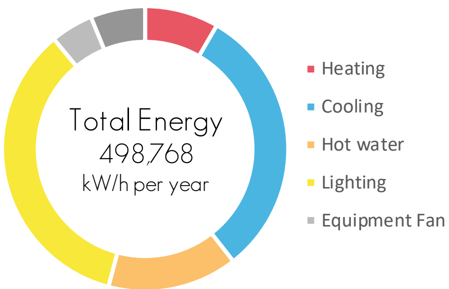
To initiate the simulations and establish a baseline for the project, the building specifications were selected from the Climate Studio library, based on the general materials used in the construction. Parameters such as crack infiltration, occupant density, and equipment power density were defined according to the ASHRAE 90.1 standards for residential buildings. Other simulation parameters were left at their default values for residential buildings in Climate Studio. Notably, no shading strategies were employed at this point in the simulations.



Building Information

U-Roof	0.215 W/m²K	Lighting Power Density	9.5 W/m²	Schedule CS Default
U-Wall	0.0.264 W/m²K	Outside Air Rate/Person	0.2 L/s/m²	Schedule CS Default
U-Floor	0.416 W/m²K	Hot Water COP	1	Schedule CS Default
U-Glazing Single	5.89 W/m²K	Heating COP	1	Schedule CS Default
SHGC	0.913 W/m²K	Cooling COP	1	Schedule CS Default
Crack Infiltration	0.3 ACH	Shading	----------	----------
Occupant Density	0.025 P/m²	Natural Ventilation	----------	----------
Equipment Power Density	2 W/m²	Mechanical Ventilation	Available	Schedule ALL ON

Annual Energy Use



Segment	kWh per year	% of total use
Heating	37,192	7%
Cooling	158,411	32%
Hot water	71,399	14%
Lighting	174,902	35%
Equipment Fan	25,686	5%
Equipment	31,175	6%

Table. 23. Anual energy use per trype. Baseline

Monthly Energy Use

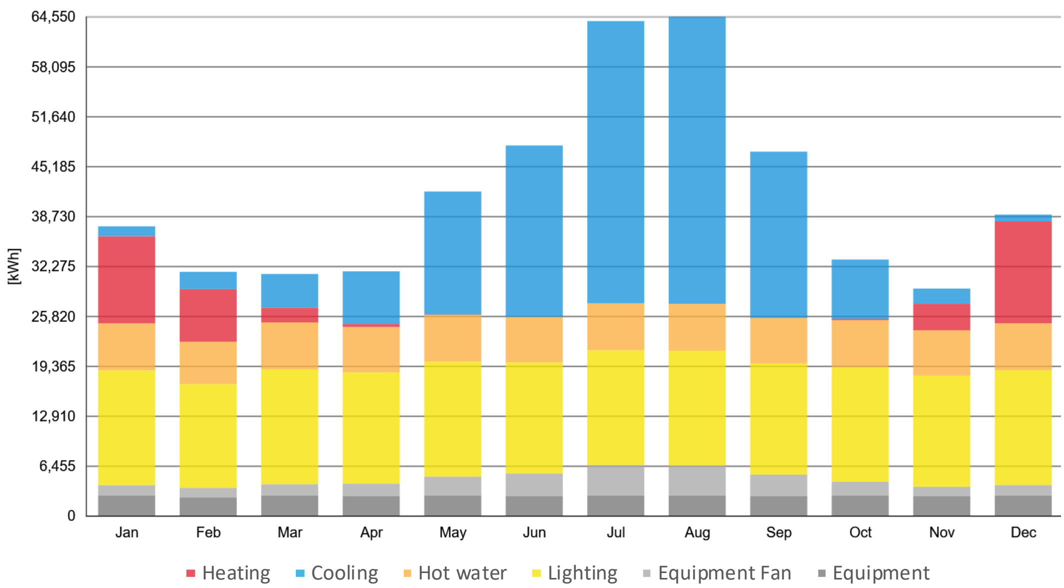


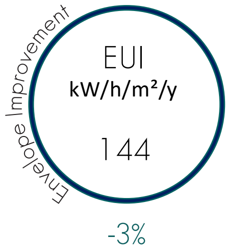
Fig. 255. Monthly Energy Use for Baseline Simulation

6.3.3. ENVELOPE IMPROVEMENT

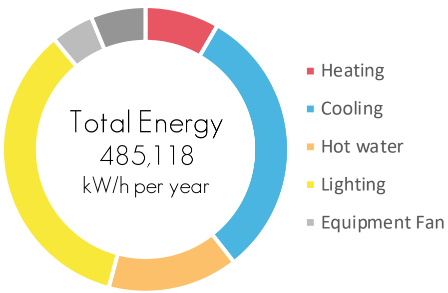
To improve the building's energy efficiency, changes were made to the materials used in the construction, as well as to their thickness. This resulted in improved envelope U-values for both the opaque and transparent sections of the building. The assigned materials were demonstrated previously with the associated thermal behaviour. Additionally, through the daylight analysis, a double clear glazing with Argon was selected, while the remaining parameters were kept at their default values. The improved U-values contributed to a reduction in the building's energy consumption, resulting in a lower (EUI) value.

Building information

U-Roof	0.138 W/m²K	Lighting Power Density	9.5 W/m²	Schedule CS Default
U-Wall	0.163 W/m²K	Outside Air Rate/Person	0.2 L/s/m²	Schedule CS Default
U-Floor	0.14 W/m²K	Hot Water COP	1	Schedule CS Default
U-Glazing Double Clear (Argon)	2.53 W/m²K	Heating COP	1	Schedule CS Default
SHGC	0.704 W/m²K	Cooling COP	1	Schedule CS Default
Crack Infiltration	0.3 ACH	Shading	---------	---------
Occupant Density	0.025 P/m²	Natural Ventilation	---------	---------
Equipment Power Density	2 W/m²	Mechancial Ventilation	Available	Schedule ALL ON



Annual Energy Use



Segment	kWh per year	% of total use
Heating	40,555	8%
Cooling	150,786	31%
Hot water	71,399	15%
Lighting	169,134	35%
Equipment Fan	23,397	5%
Equipment	30,044	6%

Table. 24. Anual energy use per trype. Envelope improvement.

Monthly Energy Use

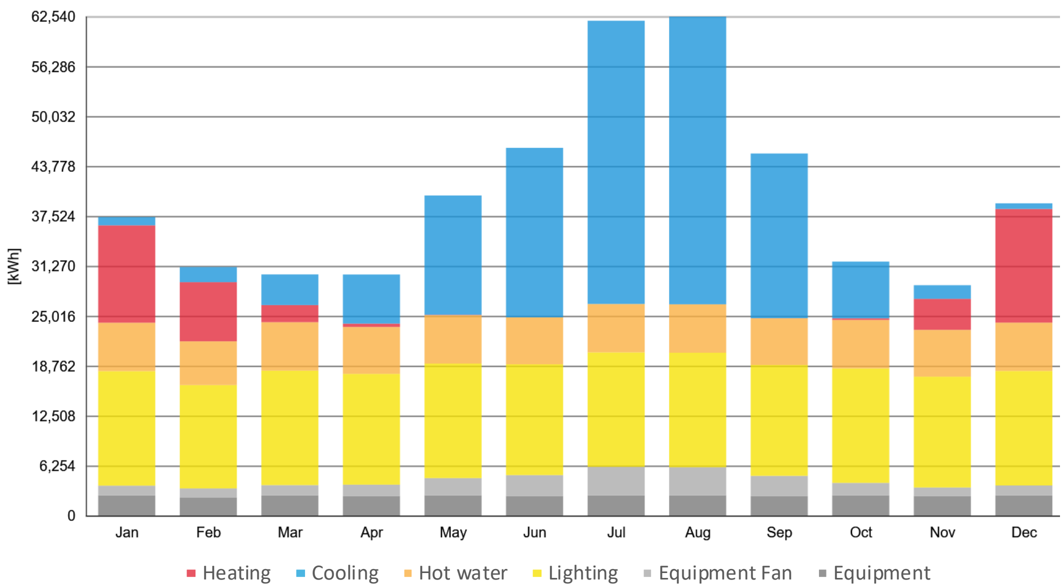
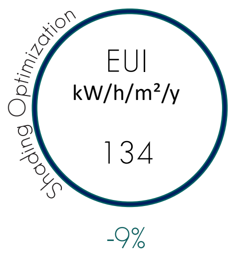


Fig. 256. Monthly Energy Use for Improved Envelope Simulation

6.3.4. SHADING OPTIMIZATION

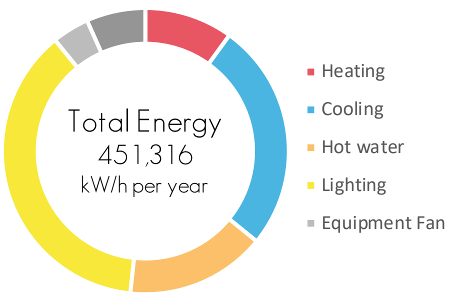
The daylight analysis revealed that shading was required for the south-facing facade of the building. To address this, an exterior vertical shading was added to the south side. The next energy analysis was conducted, building on the previous step, with the schedule for the shading set to activate during times of high solar radiation. This resulted in a decrease in cooling consumption and a further reduction in the overall energy use intensity (EUI) value.



Building information

U-Roof	0.138 W/m²K	Lighting Power Density	9.5 W/m²	Schedule CS Default
U-Wall	0.163 W/m²K	Outside Air Rate/Person	0.2 L/s/m²	Schedule CS Default
U-Floor	0.14 W/m²K	Hot Water COP	1	Schedule CS Default
U-Glazing Double Clear (Argon)	2.53 W/m²K	Heating COP	1	Schedule CS Default
SHGC	0.704 W/m²K	Cooling COP	1	Schedule CS Default
Crack Infiltration	0.3 ACH	Shading (Exterior)	On the South Window	ON If High Solar On
Occupant Density	0.025 P/m²	Natural Ventilation	----------	----------
Equipment Power Density	2 W/m²	Mechanical Ventilation	Available	Schedule ALL ON

Annual Energy Use



Segment	kWh per year	% of total use
Heating	44,995	10%
Cooling	116,849	26%
Hot water	71,399	16%
Lighting	169,133	37%
Equipment Fan	18,856	4%
Equipment	30,082	7%

Table. 25. Anual energy use per trype. Shading optimization

Monthly Energy Use

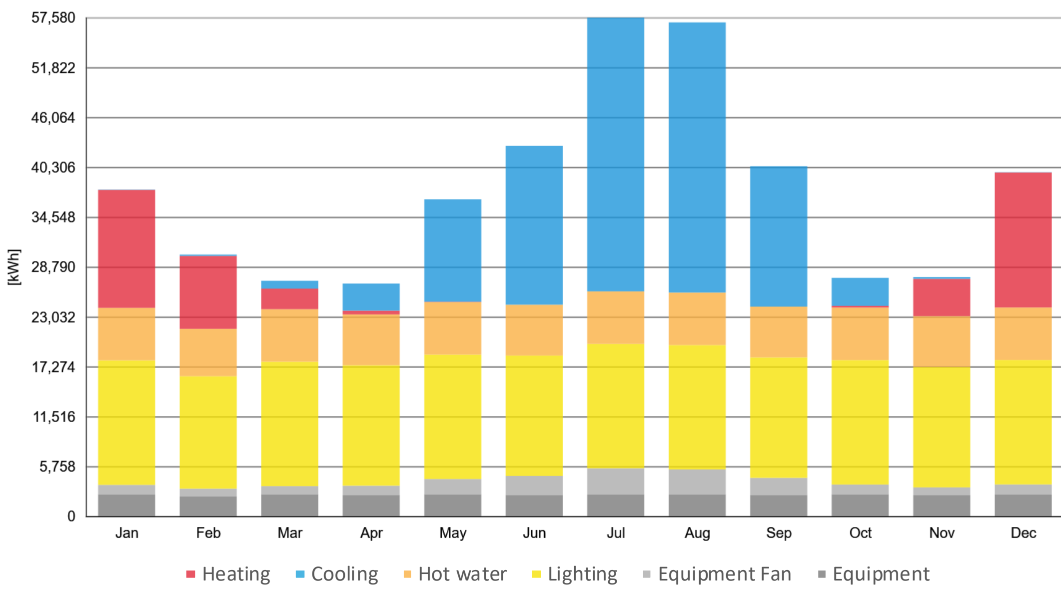


Fig. 257. Monthly Energy Use for Shading Optimization Simulation

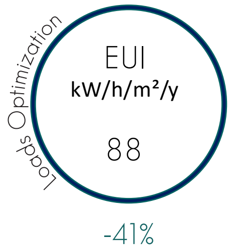
6.3.5. LOADS OPTIMIZATION

In this stage, the lighting power density was optimized in accordance with ASHRAE 90.1 standards Table 9.4.5. The power density was reduced from 9.5 W/m^2 to 7.5 W/m^2 and dimming was set to continous. Additionally, the hot water coefficient of performance (COP) was updated to 2.5. The inlet water temperature was set to 15°C, and the water supply temperature was set to 40°C.

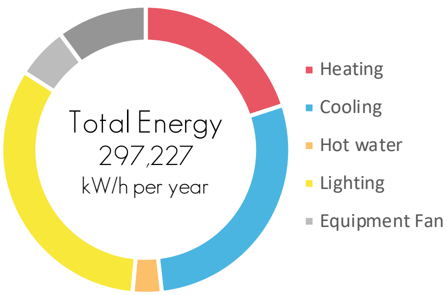
The changes made to the load parameters resulted in a substantial decrease in the building's overall energy use intensity (EUI) value in addition to the lighting and hot water annual energy use..

Building information

U-Roof	0.138 W/m^{2}K	Lighting Power Density	7.5 W/m^2	Schedule CS Default
U-Wall	0.163 W/m^{2}K	Outside Air Rate/Person	0.2 L/s/m^2	Schedule CS Default
U-Floor	0.14 W/m^{2}K	Hot Water COP	2.5	Schedule CS Default
U-Glazing Double Clear (Argon)	2.53 W/m^{2}K	Heating COP	1	Schedule CS Default
SHGC	0.704 W/m^{2}K	Cooling COP	1	Schedule CS Default
Crack Infiltration	0.3 ACH	Shading (Exterior)	On the South	On If High Solar On Window
Occupant Density	0.025 P/m^2	Natural Ventilation	---------	---------
Equipment Power Density	2 W/m^2	Mechanical Ventilation	Available	Schedule ALL ON



Annual Energy Use



Segment	kWh per year	% of total use
Heating	59,412	20%
Cooling	83,884	28%
Hot water	9,712	3%
Lighting	96,869	33%
Equipment Fan	17,303	6%
Equipment	30,044	10%

Table. 26. Anual energy use per trype. Loads optimization

Monthly Energy Use

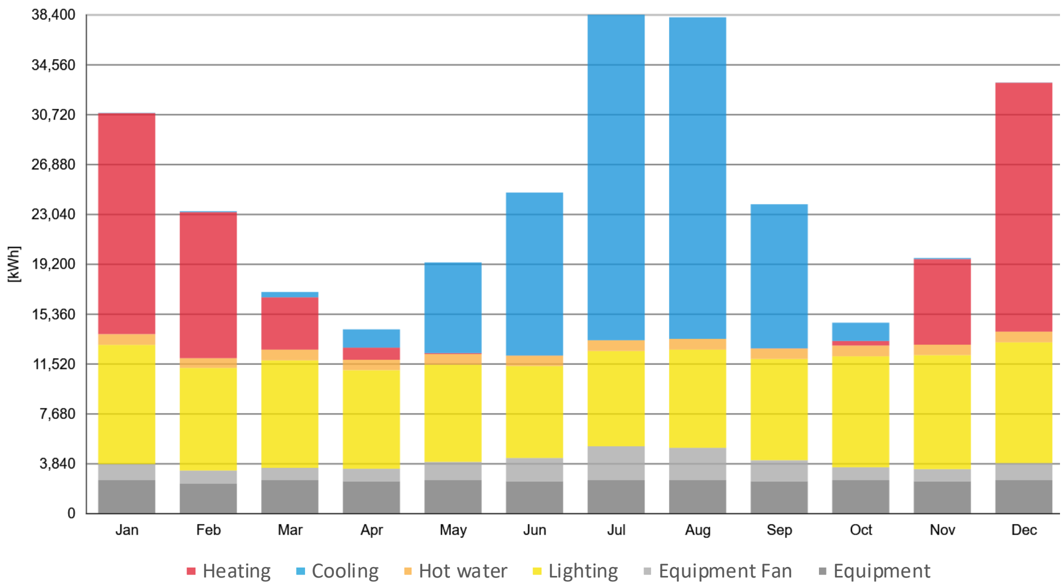


Fig. 258. Monthly Energy Use for Loads Optimization Simulation

6.3.6. HVAC AND NATURAL VENTILATION OPTIMIZATION

Francesco Causone, an assistant professor at Politecnico di Milano, wrote a paper on the Climatic Potential for Natural Ventilation (CPNV). The paper aims to evaluate whether a climate is suitable for natural ventilation by calculating the CPNV, which is determined by the number of hours in a year when natural ventilation is possible divided by the total number of hours in a year. The Belwo figure demonstrates how the years is divided into nine areas based on temperature and humidity ratio thresholds.

However, to prevent overestimation of the system, it is recommended to use humidity control when using natural ventilation. The study shows the climate in Milan and points out the issue of humidity, which significantly reduces the number of hours when natural ventilation is feasible.

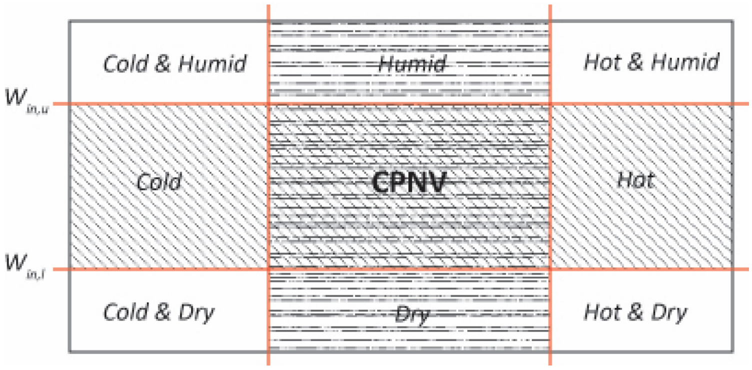


Fig. 259. Time of year subdivided in 9 areas according to temperature and humidity ratio thresholds. Source: Climatic Potential for Natural Ventilation paper`

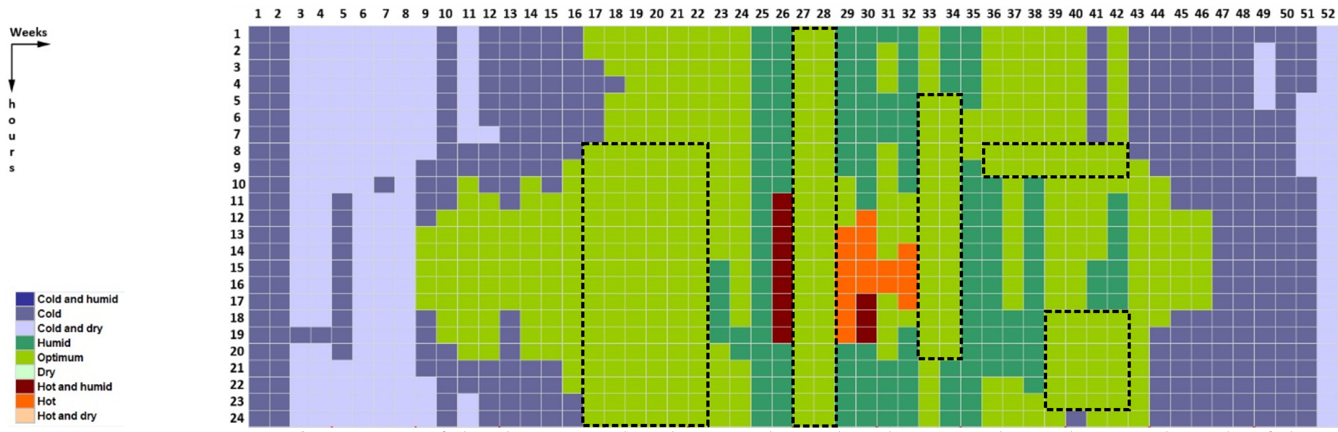


Fig. 260. Heat map of the climate in Milan showing relevant humidity issues during the central months of the year and temperature limitations during winter. Source: Climatic Potential for Natural Ventilation paper

The data from the heat map of Milan shows that natural ventilation may not be suitable during a significant portion of winter due to excessively cold and occasionally dry weather conditions. However, it can be used during the day in spring. In May, June, and September, the weather is generally favorable for natural ventilation both during the day and at night. During the summer months, the weather is typically hot or hot and humid during the day, and excessively humid during the night, making natural ventilation less effective.

Based on this data and using the optimum periods indicated in the map a schedule for natural ventilation was established to reduce the consumption of the HVAC system. The specific schedule is outlined in the following table.

Weeks and hours for natural ventilation schedule	
Week 17 to 22: April 24th to June 4th	Total of 14 hours
Week 27 to 28: July 3rd to July 16th	Total of 24 hours
Week 33 to 34: August 14th to August 27th	Total of 13 hours
Week 36 to 42: September 4th to October 22nd	Total of 2 hours
Week 39 to 42: September 25th to October 22nd	Total of 6 hours

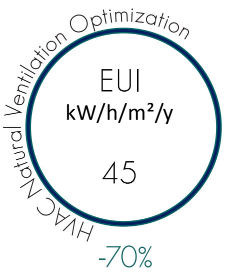
Table. 27. Weeks and hours for natural ventilation schedule

Regarding the HVAC system, it was decided to use a water to water heat pump and a radiant floor for heating and cooling. The efficiency values of the system are indicated in the table below, showing both the Coefficient of Performance (COP) and the Energy Efficiency Ratio (EER). In addition, the system has been scheduled in accordance with the regulations established by Italian law, which specifies that the temperature range for heating should not exceed 21°C, and for cooling, it should not go below 22°C. Moreover, the law also specifies a maximum usage time of 14 hours per day.

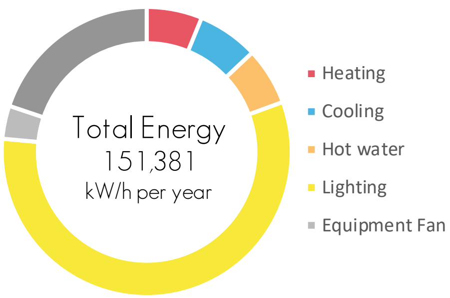
Furthermore, the mechanical ventilation system will be switched off when natural ventilation is in use.

Building information

U-Roof	0.138 W/m²K	Lighting Power Density (W/m²)	7.5 W/m²	From 3pm to 11pm
U-Wall	0.163 W/m²K	Outside Air Rate/Person (L/s/m²)	0 L/s/m²	Schedule CS Default
U-Floor	0.14 W/m²K	Hot Water COP	2.5	Schedule CS Default
U-Glazing Double Clear (Argon)	2.53 W/m²K	Heating (Radiant Floor) COP	5.5	15th of Oct to 15th of April
SHGC	0.704 W/m²K	Cooling (Radiant Floor) COP	7.5	15 of April to 15 of Oct
Crack Infiltration	0.3 ACH	Shading (Exterior)	On the South	On If High Solar On Window
Occupant Density	0.025 P/m²	Natural Ventilation	Available	
Equipment Power Density	2 W/m²	Mechanical Ventilation	Available	Optimized Schedule When Natural Ventilation Off



Annual Energy Use



Segment	kWh per year	% of total use
Heating	9,382	6%
Cooling	10,277	7%
Hot water	9,712	6%
Lighting	86,375	57%
Equipment Fan	5,588	4%
Equipment	30,044	20%

Table. 28. Anual energy use per trype. Natural ventilation

Monthly Energy Use

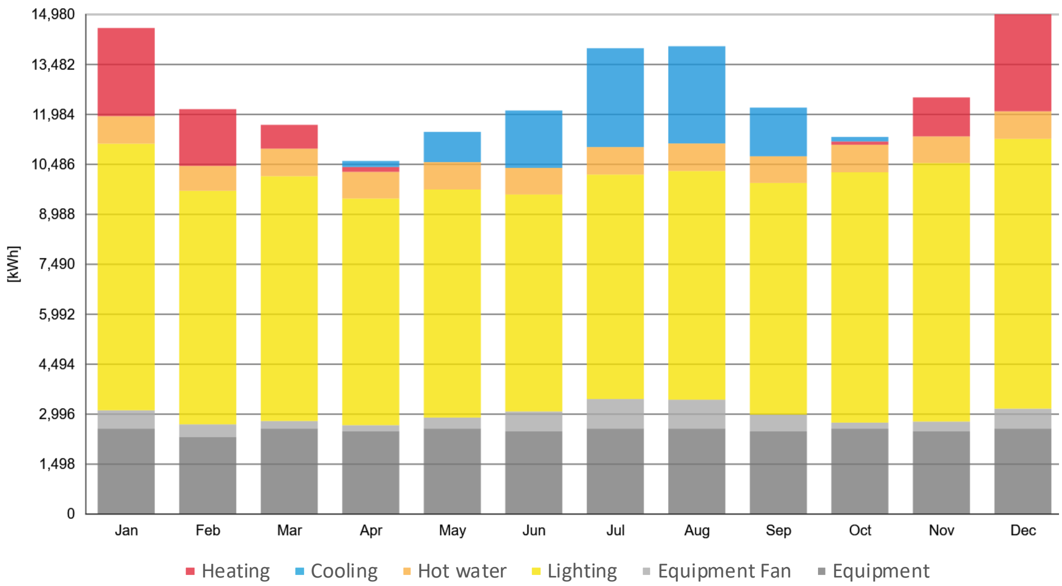
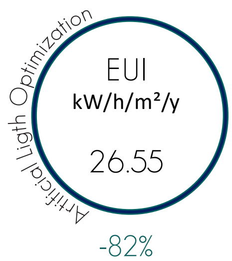


Fig. 261. Monthly Energy Use for HVAC and Natural Ventilation Optimization Simulation

6.3.7. ARTIFICIAL LIGHT OPTIMIZATION

Moving to the next step of the optimization, it was necessary to reduce the light consumption. This process was done in three main stages. First, the study of the result of daylight, calculating the average hours of occupancy, taking into account the spaces with and without daylight. For this step, it was necessary to know how many hours of our awake time we spend at home and the average sleeping time. According to different sources, the average sleeping time in Italy is 8.3 hours per day. Then, the working hours are 8 hours, and the time spent at home will be approximately 1/3 of the entire day. This proportion was also explained by Le Corbusier during the study of the Modulor. With this data, we have a total of 3624 hours per year at home. This does not take into account holidays and assumes the same 1/3 time for weekends. The chart below shows the monthly sunlight hours in Milan, and the second chart shows the comparison between the effective hours of daylight at home and the daylight hours active at home. These effective hours are calculated as 75% of the sunlight hours minus the average waking hours of 7.67 hours.The data was multiplied by SDA to determine the total hours of artificial light required. The table illustrates the study of the second floor, which was applied to all rooms and then to all the levels.



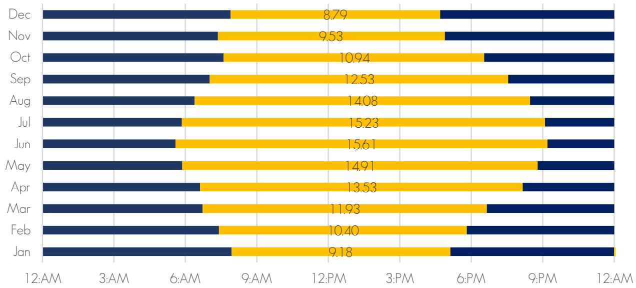


Fig. 262. Sunlight hours

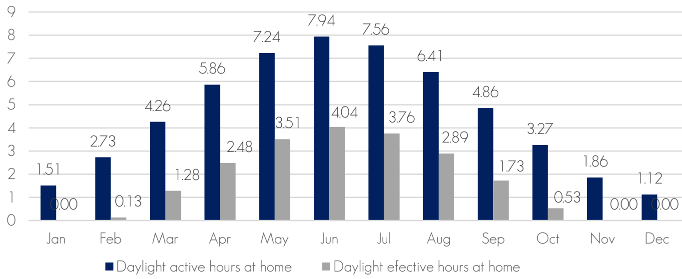


Fig. 263. Efective sun hours at home.

Description	SDA	DF	Mean Lux	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
LEVEL 02														
01-G-LOBBY	0.0%	0.0%	0	3.39	2.64	3.96	2.98	2.14	1.71	1.94	2.65	3.59	4.57	5.43
02-A-BATHROOM	0.0%	0.0%	0	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
02-A-HALL	16.7%	0.7%	228	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44
02-A-LIVING ROOM (BEDROOM) / KITCHEN	100.0%	6.5%	1,395	3.11	2.20	1.05	-0.15	-1.18	-1.71	-1.43	-0.56	0.60	1.80	2.85
02-B-BATHROOM	0.0%	0.0%	0	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
02-B-BEDROOM	18.5%	0.7%	396	8.72	8.56	8.34	8.12	7.93	7.83	7.88	8.04	8.26	8.48	8.68
02-B-LIVING ROOM / KITCHEN	73.2%	3.0%	768	4.96	4.29	3.45	2.57	1.81	1.43	1.63	2.27	3.12	3.99	4.77
02-C-BATHROOM	0.0%	0.0%	0	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
02-C-BEDROOM	93.8%	3.0%	604	3.54	2.69	1.61	0.48	-0.48	-0.98	-0.71	0.10	1.19	2.31	3.30
02-C-HALL	0.0%	0.3%	62	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
02-C-LIVING ROOM / KITCHEN	100.0%	4.3%	885	3.11	2.20	1.05	-0.15	-1.18	-1.71	-1.43	-0.56	0.60	1.80	2.85
02-D1-BATHROOM	0.0%	0.0%	0	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50
02-D1-HALL	0.0%	0.3%	111	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
02-D1-LIVING ROOM / KITCHEN	88.5%	5.1%	1,055	3.91	3.10	2.08	1.02	0.11	-0.36	-0.11	0.66	1.69	2.74	3.68
02-D1-STUDIO / BEDROOM	100.0%	3.7%	955	3.11	2.20	1.05	-0.15	-1.18	-1.71	-1.43	-0.56	0.60	1.80	2.85
02-F-BATHROOM	0.0%	0.0%	0	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
02-F-BATHROOM	0.0%	0.0%	0	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
02-F-BEDROOM	88.2%	3.5%	1,803	3.92	3.12	2.10	1.04	0.13	-0.33	-0.08	0.68	1.71	2.76	3.69
02-F-BEDROOM	100.0%	4.9%	2,731	3.11	2.20	1.05	-0.15	-1.18	-1.71	-1.43	-0.56	0.60	1.80	2.85
02-F-HALL	0.0%	0.3%	109	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
02-F-KITCHEN	95.8%	2.1%	992	3.40	2.53	1.42	0.27	-0.71	-1.22	-0.95	-0.12	1.00	2.14	3.15
02-F-LAUN	0.0%	0.0%	0	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
02-F-LIVING / DINING ROOM	98.0%	2.8%	1,309	3.25	2.35	1.23	0.05	-0.96	-1.48	-1.20	-0.35	0.79	1.96	2.99
02-F-STUDIO	8.3%	0.8%	336	9.43	9.35	9.25	9.15	9.07	9.02	9.05	9.12	9.22	9.32	9.40
G-01-CORE	0.0%	0.0%	0	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73

Table. 29. Efective sun hours per month according to the daylight per room.

To proceed, it was nedded to investigate the required amount of light for the space and compare the average lux levels for each room. The following table displays the data for each room type and the corresponding lamp selection.

Space	Storage	Gym	Bathroom	Living room	Kitchen	Studio	Bedroom	Hall	Coworking
Temp. (K)	6500	6500	4000	3000	4000.00	3000.00	3000.00	4000.00	3000.00
Total power (W)	15	15	12	24	24.00	24.00	24.00	12.00	30.00
Energy class	A+	A+	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1	Class 1
Luminous flux (lm)	890	890	565	1000	1000.00	1000.00	1000.00	565.00	1780.00
Light level	100	250	100	200	300	300	300	100	300

Table. 30. Space light level requirements and chosen light fixture per space

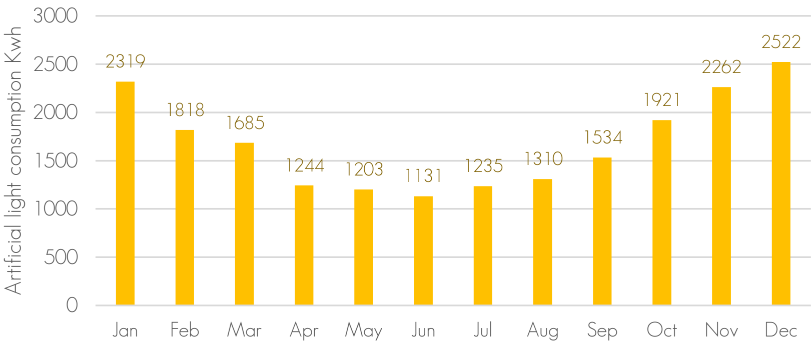


Fig. 264. Monthly artifitial light optimized energy consumption

Description	Areas (m²)	Quatity lamps	Total power	IECC 2021 LIGHTING POWER DENSITY (WATTS PER SF)	IECC 2021 LIGHTING POWER DENSITY (WATTS PER m2)	Total power
BASEMENT	526.96	Total	2156.28		Total	3036.01
		Total (kWh/year)	7814.11	29%	Total (kWh/year)	11002.15
		Total (kWh/year/m2)	14.83	Savings		
		Total Optimize (kWh/year)	4584.53	41%	Total Optimize (kWh/year/m2)	8.700
GROUND FLOOR	301.45	Total	2048.79		Total	2439.99
		Total (kWh/year)	7424.57	16%	Total (kWh/year)	8842.22
		Total (kWh/year/m2)	24.63	Savings		
		Total Optimize (kWh/year)	3524.34	53%	Total Optimize (kWh/year/m2)	11.691
LEVEL 01	316.73	Total	2133.44		Total	2678.82
		Total (kWh/year)	7731.32	20%	Total (kWh/year)	9707.73
		Total (kWh/year/m2)	24.41	Savings		
		Total Optimize (kWh/year)	2487.71	68%	Total Optimize (kWh/year/m2)	7.854
LEVEL 02	296.67	Total	1965.27		Total	2519.68
		Total (kWh/year)	7121.92	22%	Total (kWh/year)	9131.02
		Total (kWh/year/m2)	24.01	Savings		
		Total Optimize (kWh/year)	1974.95	72%	Total Optimize (kWh/year/m2)	6.657
LEVEL 03	271.31	Total	1780.51		Total	2330.93
		Total (kWh/year)	6452.35	24%	Total (kWh/year)	8447.00
		Total (kWh/year/m2)	23.78	Savings		
		Total Optimize (kWh/year)	1521.89	76%	Total Optimize (kWh/year/m2)	5.609
LEVEL 04	316.73	Total	2133.44		Total	2715.98
		Total (kWh/year)	7731.32	21%	Total (kWh/year)	9842.40
		Total (kWh/year/m2)	24.41	Savings		
		Total Optimize (kWh/year)	1870.00	76%	Total Optimize (kWh/year/m2)	5.904
LEVEL 05	296.67	Total	1965.27		Total	2519.68
		Total (kWh/year)	7121.92	22%	Total (kWh/year)	9131.02
		Total (kWh/year/m2)	24.01	Savings		
		Total Optimize (kWh/year)	1552.42	78%	Total Optimize (kWh/year/m2)	5.233
LEVEL 06	114.83	Total	1720.90		Total	2341.74
		Total (kWh/year)	6236.32	27%	Total (kWh/year)	8486.20
		Total (kWh/year/m2)	54.31	Savings		
		Total Optimize (kWh/year)	1544.69	75%	Total Optimize (kWh/year/m2)	13.452
LEVEL 07	249.73	Total	1650.91		Total	1871.77
		Total (kWh/year)	5982.71	12%	Total (kWh/year)	6783.07
		Total (kWh/year/m2)	23.96	Savings		
		Total Optimize (kWh/year)	1126.16	81%	Total Optimize (kWh/year/m2)	4.509
		Total (kWh/year)	63616.52	2276641124		
		Total Optimize (kWh/year)	20186.69	68%		

Table. 31. Artifitial light savings per floor

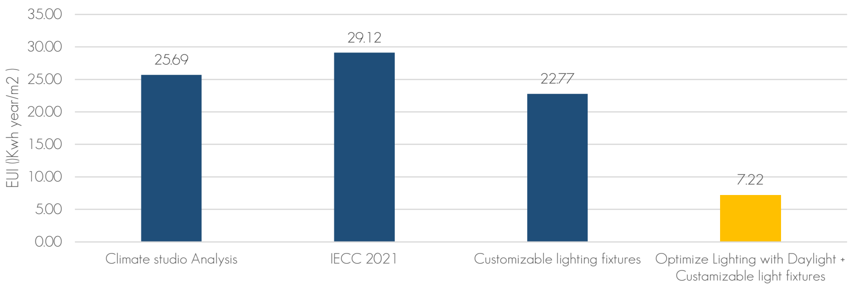


Fig. 265. Anualy artifitial light energy consumption comparison.

This chart shows the monthly consumption for the total building, taking into account the amount of daylight in each room, and in the case of no sunlight, the relationship with occupancy. For example, the bathroom was calculated taking into account that we spend 0.75 hours per person, which was then multiplied by the number of people in the apartment.

Afterward, we calculated the energy consumption of artificial daylight per floor according to the lamps. According to the IECC 2021, this standard provides the reference for the amount of energy needed to be consumed per room. With these calculations, we moved on to calculate the amount of savings in comparison with leaving the lights on for 24 hours. This was only with the artificial light needed and the use of light fixtures. The light optimization was done by multiplying the monthly calculated hours by the total consumption, giving the approximate light consumption per space. It is noticeable that the higher the level, the higher the optimization. This is where we can see the influence of daylight in the building.

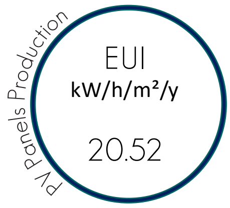
As a result, we obtained the Total Optimized amount of 20,186.69 kWh/year, having a 68% of savings (only in artifitial light), which corresponds to a 7.22 EIU.

The following chart compares the four artificial light calculations: the one for climate studio only with schedules in the kitchen, the IECC 2021 standard, the total consumption only by the use of lighting fixtures and the study of the luxes per space, and finally, the same study with the study of daylight.

6.3.8. PV PANELS

The project places great emphasis on generating renewable energy on-site, and for this purpose, the most suitable option was determined to be photovoltaic collectors. These were preferred due to their adaptability, wide availability in the market, and low upkeep requirements. The PV collectors were installed on the roof of the building, and their potential energy output was calculated using the Photovoltaic Geographical Information System, a tool provided by the European Commission.

The installed capacity of the photovoltaic system resulted to be 71,785 kWh. It is expected to greatly reduce the building's reliance on non-renewable sources of power. Additionally, the use of renewable energy on-site will help to reduce the carbon footprint of the building and contribute to a cleaner, more sustainable environment.



Provided inputs	
Latitude/Longitude	45.486,9.216
Horizon	Calculated
Database used	PVGIS-SARAH2
PV technology	Crystalline silicon
PV installed	54 kWp
System loss	14%

Table. 32. PV-Provided Inputs

Simulation Outputs	
Slope angle	30 °
Azimuth angle	0 °
Yearly PV energy production	71785.95 kWh
Yearly in-plane irradiation	1718.24 kWh/m²
Year-to-year variability	3424.67 kWh

Table. 33. PV-Simulation Outputs

Changes in output due to	
Angle of incidence	-2.74%
Spectral effects	1.11%
Temperature and low irradiance	-8.52%
Total loss	-22.63%

Table. 34. PV-Changes in output due to

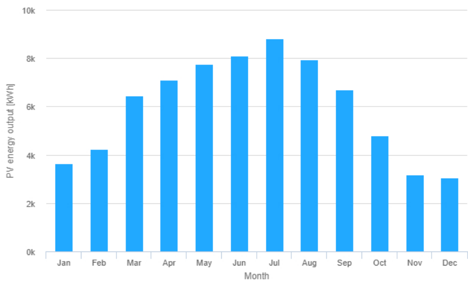


Fig. 268. Monthly Energy Output from Fix-Angle PV System

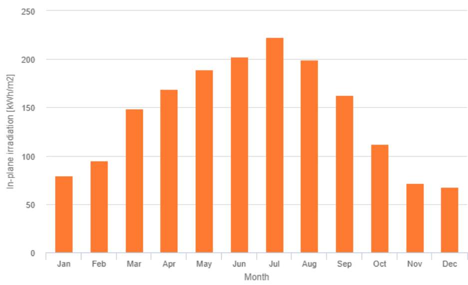


Fig. 269. Monthly In-Plane Irradiation for Fixed-Angle

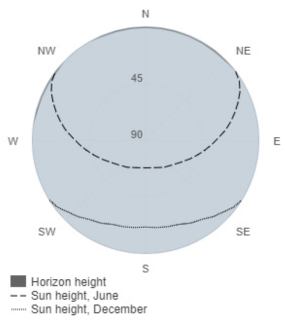


Fig. 267. Outline of horizon at chosen location

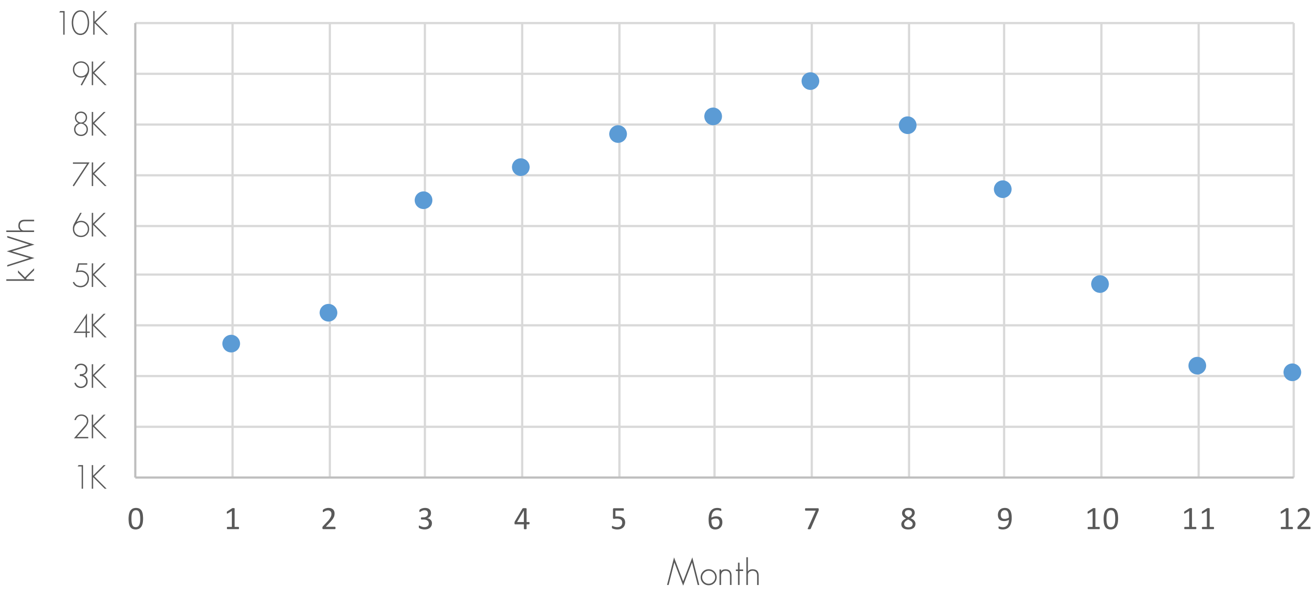


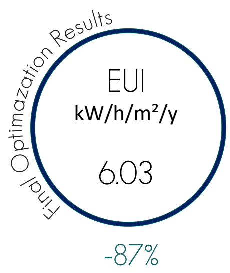
Fig. 266. Average monthly electricity production from the defined system [kWh]

6.3.9. COMPARATIVE ANALYSIS OF ENERGY CONSUMPTION AND PRODUCTION

The final step in evaluating the energy performance of the building that incorporates photovoltaic (PV) panels is to compare the monthly energy use of the building with the production of the PV panels. This comparison is essential to determine the overall energy efficiency of the building.

The values represent the total amount of energy consumed by the building monthly after the final optimization, including heating, cooling, lighting, and other equipment. This value is then compared to the energy use of the building after the reduction of consumption of artificial lighting.

Finally, the energy production of the PV panels is also compared to the energy consumed by the building. Comparing the monthly energy use of a building with the energy production of PV panels is a crucial step in evaluating the energy efficiency of a building.



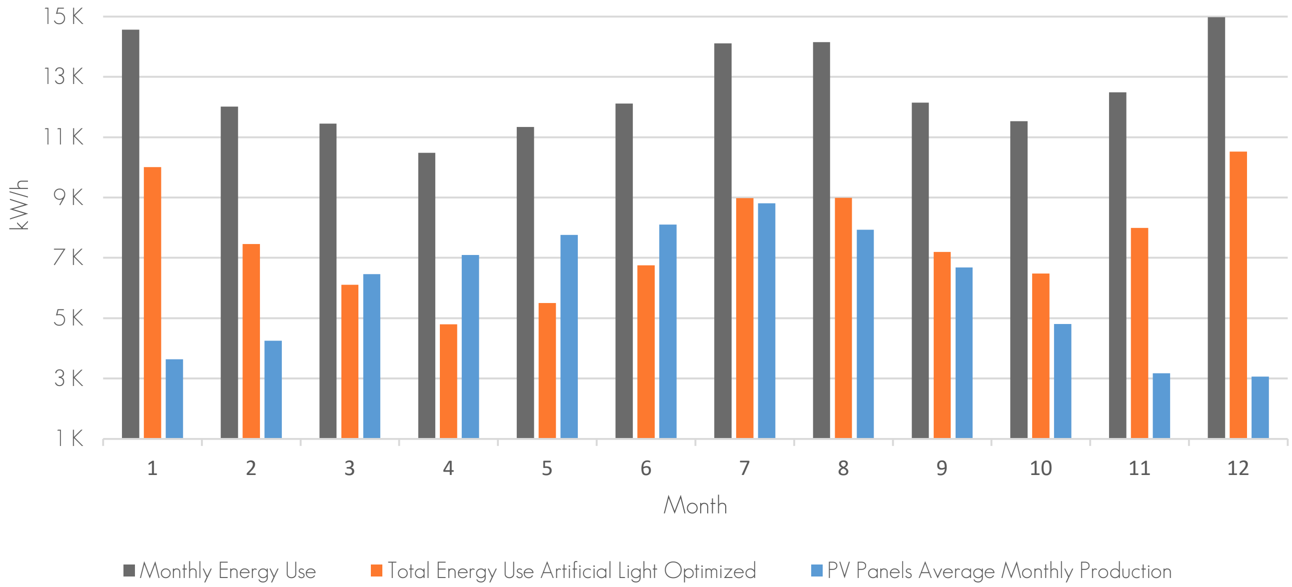


Fig. 270. Energy Consumption vs Energy Production

7

STRUCTURAL DESIGN

The following chapter it will be concentrated in the structural design of the building propos. The structural design process, it is described as follows: The first stage involves load analysis to determine the loads that the building will have to withstand. This analysis includes the weight of the building itself, as well as any external factors such as wind, snow, and seismic loads. Based on this analysis, the wall, slab, and ceiling design are developed for the prefabricated modules.

In addition, a study by Styles et al. (2016) identified three primary methods for assembling modules in modular construction: self-supporting, core-supporting, and frame-supporting modular buildings. These construction styles vary in the level of support they require and are typically chosen based on factors such as the size and intended use of the building, available space, etc.

Once the structural design of the modules is completed, the next step is to design the frame structure that will support them. This involves analyzing the loads transferred from the modules to the frame structure and designing the main and secondary beams and columns accordingly. The frame structure must be strong enough to withstand the loads from the modules and provide a stable foundation for the building.

The schematic design of the foundations and load-bearing walls is the next stage of the structural design process. The foundations must be designed to support the weight of the building and transfer the loads to the ground. Load-bearing walls must also be designed to withstand the loads transferred from the modules and the frame structure. Shear walls are also designed to resist lateral forces such as wind and seismic loads.

7.1

GENERAL STANDARDS

In order to define the main standards for a building's primary structure, it is essential to also specify the material used. The steel frame structure has several advantages over precast concrete. One of the primary benefits is that steel frames are significantly lighter than concrete. This makes transportation and assembly easier and more cost-effective, as smaller cranes can be used, and there is less need for heavy equipment. Additionally, the lighter weight of steel frames reduces the overall weight of the building, which can lead to savings in the foundation design and construction. Another significant advantage of steel frames is their greater design flexibility. Compared to precast concrete, steel frames can be fabricated and assembled on site, allowing for more complex designs and customization. At this stage, general guidelines are provided for reference. It is important to note that for the calculation of these elements, the CALCULATIS software by Stora Enso was utilized. This software complies with the regulations and standards depending on the country, in this case the location of Italy was specified. The software was applied to both the CTL elements and the steel frame structures. The following table for the codes and standards applied in the calculation of these elements.

EN 1993-1-1	EN 1993-1-1 - Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings
EN 1990	EN 1990 - Eurocode ? Basis of structural design
EN 338	EN 338 - Structural timber ? Strength classes
EN 1995-1-1	EN 1995-1-1 - Eurocode 5: Design of timber structures - Part 1-1: General - Common rules and rules for buildings
ETA-14/0349	European Technical Assessment ETA-14/0349 of 02.10.2014
Expertise Rolling shear - no edge gluing, H.J. Blass	Expertise on Rolling shear for CLT
EN 1995-1-2	EN 1995-1-2 - Eurocode 5 — Design of timber structures — Part 1-2: General — Structural fire design
EN 1990	EN 1990 - Eurocode ? Basis of structural design
DM08	NTC2008 - Italian standards for structural design of buildings and constructions - D.M. 14 Gennaio 2008
CNR DT206	CNR-DT 206/2007: Recommendations for the design and execution of timber structures
UNI EN 1995-1-2_NA	UNI EN 1995-1-2 - Italy - National Annex - Eurocode 5: Design of timber structures ? Part 1-2: General ? Structural fire design ? National specifications concerning UNI EN 1995-1-2, national comments and national supplements
UNI EN 1995-1-1_NA	UNI EN 1995-1-1 - Italy - National Annex – Nationally determined parameters – Eurocode 5: Design of timber structures – Part 1-1: General rules and rules for buildings

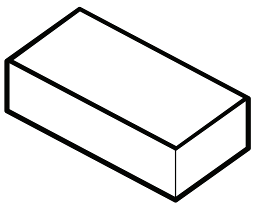
Table. 35. General structural standards

7.2 STRUCTURAL

LOAD ANALYSIS

MODULES STRUCTURAL PRE DESIGN

- Final Roof
- Ceiling
- Modules load baring walls
- Slab
- Cantieliver Slab

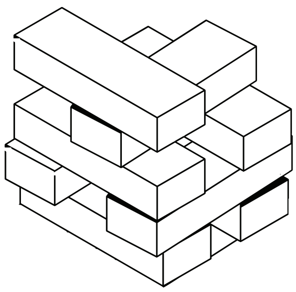


MODULES DESIGN

ASEEMBLY STUDY

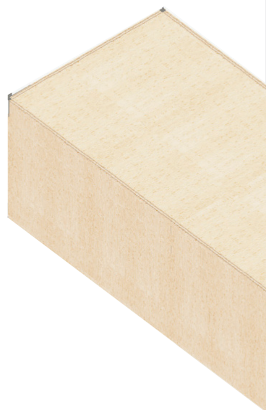
MODULES ASSEBLING ANALYSIS

- Self-supporting modular buildings
- Core-supporting modular buildings
- Frame-supporting modular buildings



ASSEMBLING

CLT Prefabricated

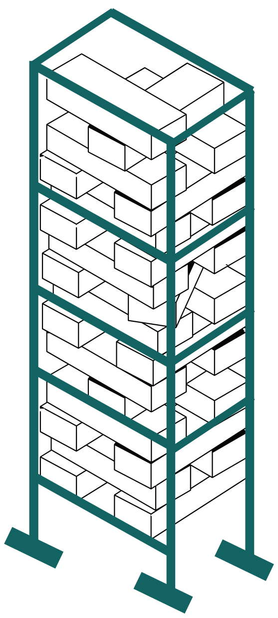


LOAD ANALYSIS

MODULES STRUCTURAL PRE DESIGN

- Common slab
- Secundary beam
- Main Beam
- Load bearing walls
- Shear walls
- Fundations

STRUCTURAL PROPOSAL

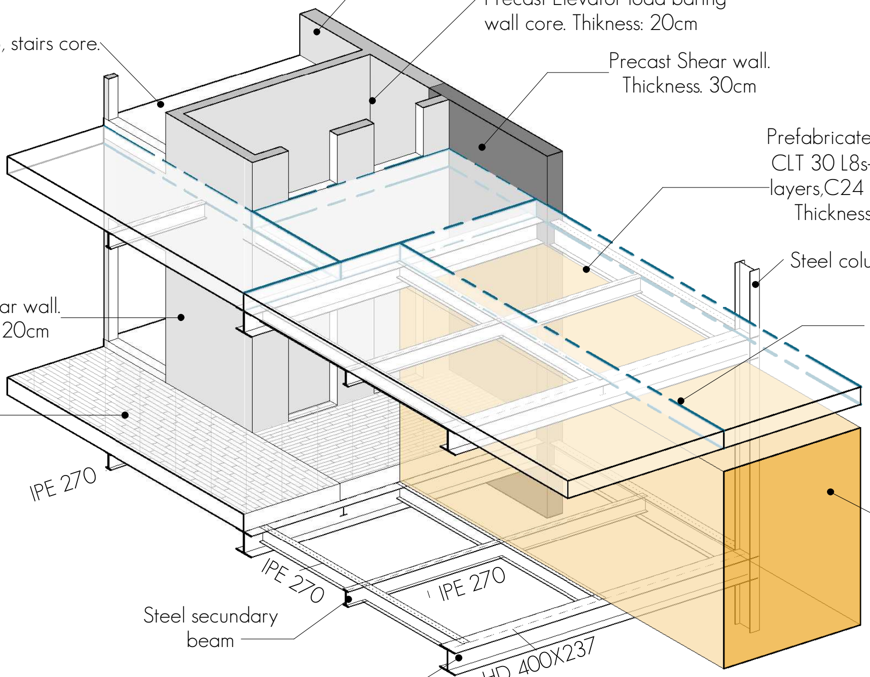


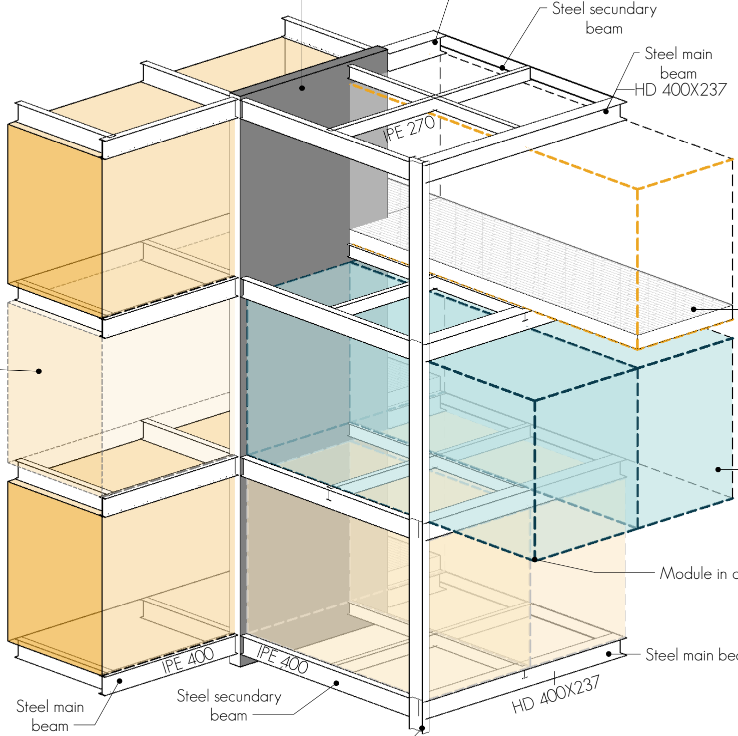
BUILDING DESIGN

Fig. 271. Structural Concept

L CONCEPT

d module





7.3

PROPOSED MODULE STRUCTURE

Fig. 272. CTL Module

The first step of the structural desing it is the definition of the module constructive system, each module it is done by CLT members, walls, roof/ ceiling and slab, Depending of the location of the module in the building, this one will have only ceiling or only roof. As the starting point it was needed to do the load analysis, after this the analysis of each memeber.

7.3.1. LOAD ANALYSIS

This section outlines the load analysis calculations for the modules, taking into account both permanent and variable loads. The analysis begins with the final roof, which includes the rooftop units for the sixth level modules, and the ceiling slab for the intermediate modules. The walls and the module slab must also be considered, with the latter requiring analysis for both cantilever and non-cantilever configurations.

PERMANENT LOADS (G)

Construction Element		Thickness (m)	Specific weigth (kN/m3)	Load Value (kN/m2)
Roof	Synthetic membrane	0.003	6.8	0.0204
	Homathem	0.024	1.4	0.0336
	CLT 140 L5s	0.14	4.7	0.658
	Wooden battens 40/50	0.05	0.5	0.025
	Mineral wool	0.05	0.18	0.009
	Fire-protection plasterboard	0.015	8	0.12
	Ceiling plaster	0.02	20	0.4
			SCREED	**0.608**
	Total Floor			**1.266**

Table. 36. Roof permanent loads

Construction Element		Thickness (m)	Specific weigth (kN/m3)	Load Value (kN/m2)
Terrace slab	Cement screed	0.07	20	1.4
	Impact sound insulation	0.04	0.68	0.0272
	Gravel fill	0.05	18	0.9
	CLT 140 L5s	0.14	4.7	0.658
	Wooden battens 40/50	0.06	0.5	0.03
	Mineral wool	0.07	0.18	0.0126
	Fire-protection plasterboard	0.015	8	0.12
			SCREED	**2.4898**
	Total Slab			**3.1478**

Table. 37. Terrace slab permanent loads

Construction Element		Thickness (m)	Specific weigth (kN/m3)	Load Value (kN/m2)
Ceiling slab	CLT 80 L3S	0.08	4.7	0.376
	Insulation	0.05	1	0.05
	Ceiling plaster	0.02	20	0.4
			SCREED	**0.4**
	Total Slab			**0.826**

Table. 38. Ceiling slab permanent loads

Construction Element		Thickness (m)	Specific weigth (kN/m3)	Load Value (kN/m2)
Exterior **Wall** 3D Finishing	3D Twix Finishing	0.05	20	1
	Aluminum substructure with	0.1	0.0079	0.079
	Thermal acustic layer, wool panel.	0.15	1	0.15
	CLT 100 CS3	0.1	4.7	0.47
	Wood battens with thermal insulation	0.05	1	0.05
	Two layer gypsum board	0.03	20	0.6
	Total Exterior Wall	considering the openings 30%		**1.6443**
	Total Exterior Wall	linear		**0.5481**

Table. 39. Exterior wall-3D finishing permanent loads

Construction Element		Thickness (m)	Specific weigth (kN/m3)	Load Value (kN/m2)
Exterior **Wall** Fibercement	Fibercement panel	0.05	20	1
	Aluminum substructure with	0.1	0.0079	0.079
	Thermal acustic layer, wool panel.	0.065	1	0.065
	CLT 100 CS3	0.1	4.7	0.47
	Wood battens with thermal insulation	0.05	1	0.05
	Two layer gypsum board	0.03	20	0.6
	Total Exterior Wall			2.185
	Total Exterior Wall	linear		0.7283333

Table. 40. Exterior wall-Fiber cement finishing permanent loads

Construction Element		Thickness (m)	Specific weigth (kN/m3)	Load Value (kN/m2)
Module Slab	Tiles	0.02	20	0.4
	Self leveling layer	0.01		0.016
	Cement bonded particle board	0.04	13.5	0.54
	Wood fiber therm base	0.1	2.5	0.25
	Self leveling layer	0.0002	1	0.0002
	CLT 80 L3S	0.3	4.7	1.41
	Insulation	0.05	1	0.05
			SCREED	1.2562
	Total Slab			2.6662

Table. 41. Module slab permanent loads

VARIABLE LOADS (Q)

•Partitions loads: Given the light and dry nature of inner partitions that they require to be <1.0 KN/m, they are assumed as a uniformly distributed variable load of qk= 0.50KN/m2 (EN 1991-1-1§6.3.1.2 (8).

Interior Wall	Description			Load Value (kN/m2)
	Q Internal walls for typical Floor			0.5
	Total Interior Wall			**0.5**

Table. 42. Interior walls variable loads

•Imposed loads were set according to the guidelines provided by the Eurocode 1, Part 1–1 section 6.3: Characteristics Values of imposed loads.

Imposed Loads	Description		Load Value (kN/m2)
According to Eurocode 1, Part 1-1, Section 6.3 EN 1991-1-1 §6.3	Roof NA		0.5
	Total Imposed load		**0.5**
	Roof TOP		2.5
	Total Imposed load		**2.5**
	Residential		2
	Total Imposed load		**2**

Table. 43. Imposed loads

•Snow load: The Eurocode specifies the requirements for calculating loads caused by the accumulation of snow on exposed, non-vertical surfaces of a structure.

Snow loads	Description		Load Value (kN/m2)
(EN 1991-1-3 §5.2, 5.3.2	μi snow load coefficient	α <30°	0.8
	Ce Exposure coefficient	Normal topography	1
	Ct Thermal coefficient	Low thermal transmittance	1
	Sk snow load on the ground	Provincia di Milano	1.5
	Total Snow load S		**1.2**

Table. 44. Snow load

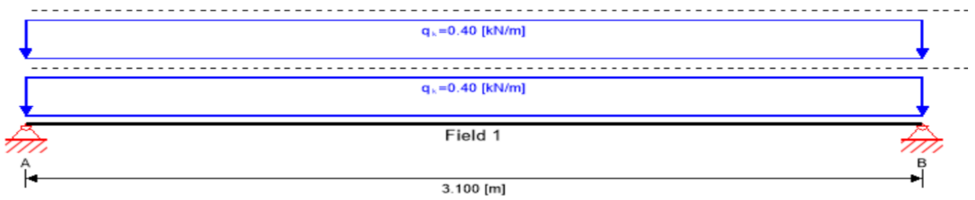
7.3.2. ELEMENTS DESIGN

In this section, the focus is on the design of each element. Starting from the roof, and ceiling slab, the loads are transmitted to the walls and eventually to the module slab, which can be designed with or without a cantilever. By the end of this section, a comprehensive understanding of how each element works together to create a strong and stable structure will be obtained. the following table, explain the main material data used by the CLT calculations, where the strength class is C24 pine ETA (2019)

Material	$f_{m,k}$ [N/mm²]	$f_{t,0,k}$ [N/mm²]	$f_{t,90,k}$ [N/mm²]	$f_{c,0,k}$ [N/mm²]	$f_{c,90,k}$ [N/mm²]	$f_{v,k}$ [N/mm²]	$f_{r,k\ min}$ [N/mm²]	$E_{0,mean}$ [N/mm²]	G_{mean} [N/mm²]	$G_{r,mean}$ [N/mm²]
C24 pine ETA (2019)	24.00	14.00	0.12	21.00	2.50	4.00	1.70	12,000.00	690.00	50.00

7.3.2.1 CEILING SLAB

The ceiling slab, located in the intermediate levels, is the primary element to examine. It carries solely the dead load and its self-weight. Refer to the calculation results depicted below for further insight.

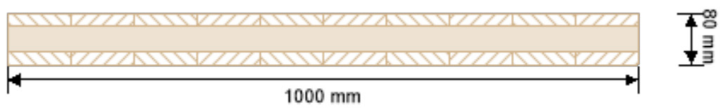


Dead load

Self weight structure

Material description

Layer	Thickness	Orientation
1	20.0 mm	0°
2	40.0 mm	90°
3	20.0 mm	0°
t_{CLT}	**80.0 mm**	



ULS Design 11%

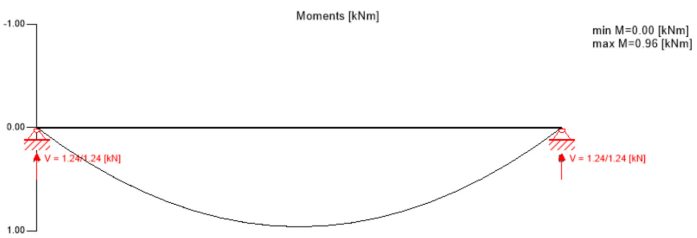
ULS Flexural design

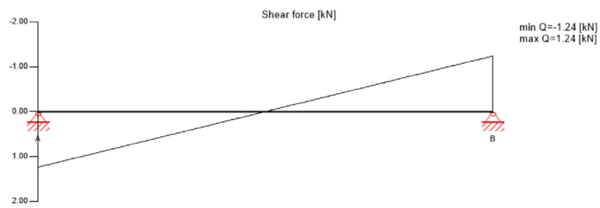
Field	Dist. [m]	$f_{m,k}$ [N/mm²]	γ_m [-]	k_{mod} [-]	$k_{sys,y}$ [-]	$f_{m,y,d}$ [N/mm²]	$M_{y,d}$ [kNm]	$\sigma_{m,y,d}$ [N/mm²]	Ratio	
1	1.55	24.00	1.35	0.60	1.10	11.73	1.25	-1.34	11 %	LCO1

ULS Shear analysis

Field	Dist. [m]	$f_{v,k}$ [N/mm²]	γ_m [-]	k_{mod} [-]	$f_{v,d}$ [N/mm²]	V_d [kN]	$\tau_{v,d}$ [N/mm²]	Ratio	
1	3.1	4.00	1.35	0.60	1.78	-1.61	0.03	1 %	LCO1

Diagrams





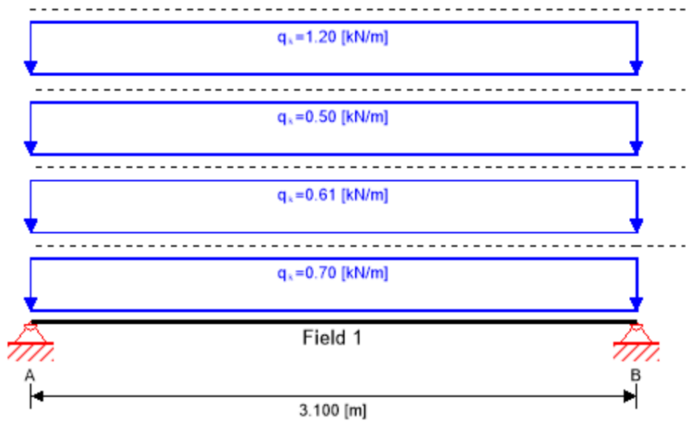
SLS Design 47%, Maximum deformation 2.39 mm

SLS Vibration 42%

Fig. 273. Calculations, Diagrams, and Results for Ceiling Slabs

7.3.2.2 ROOF SLAB

The roof slab is the next element located in the modules at the seventh level, which are exposed to the elements. However, they do not have permanent access and are only accessible for maintenance purposes. Please see below for the calculations.



Snow load altitude < 1000 m a.s.l

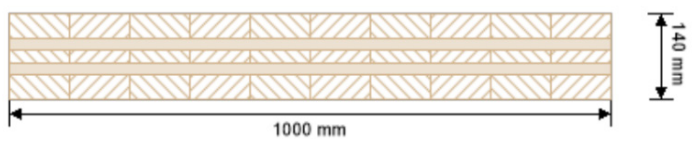
Live load. Cat. H: Roof (only access for maintenance)

Dead load

Self weight structure

Material description

Layer	Thickness	Orientation
1	40.0 mm	0°
2	20.0 mm	90°
3	20.0 mm	0°
4	20.0 mm	90°
5	40.0 mm	0°
t_{CLT}	**140.0 mm**	



ULS Design 8%

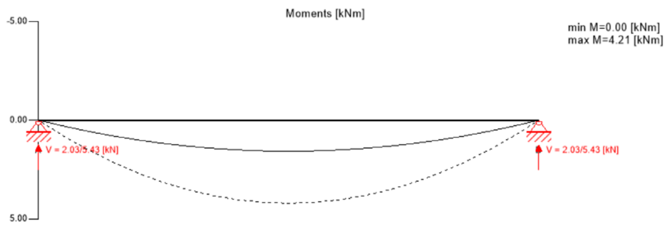
ULS Flexural design

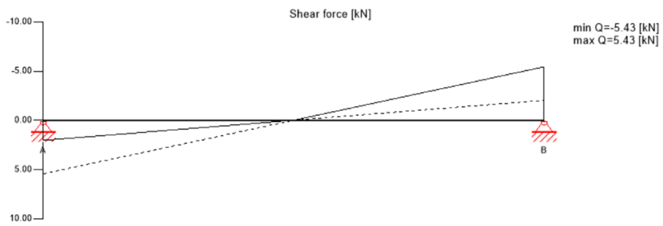
Field	Dist. [m]	$f_{m,k}$ [N/mm²]	γ_m [-]	k_{mod} [-]	$k_{sys,y}$ [-]	$f_{m,y,d}$ [N/mm²]	$M_{y,d}$ [kNm]	$\sigma_{m,y,d}$ [N/mm²]	Ratio	
1	1.55	24.00	1.35	0.90	1.10	17.60	4.21	-1.39	8 %	LCO2

ULS Shear analysis

Field	Dist. [m]	$f_{v,k}$ [N/mm²]	γ_m [-]	k_{mod} [-]	$f_{v,d}$ [N/mm²]	V_d [kN]	$\tau_{v,d}$ [N/mm²]	Ratio	
1	3.1	4.00	1.35	0.90	2.67	-5.43	0.05	2 %	LCO2

Diagrams





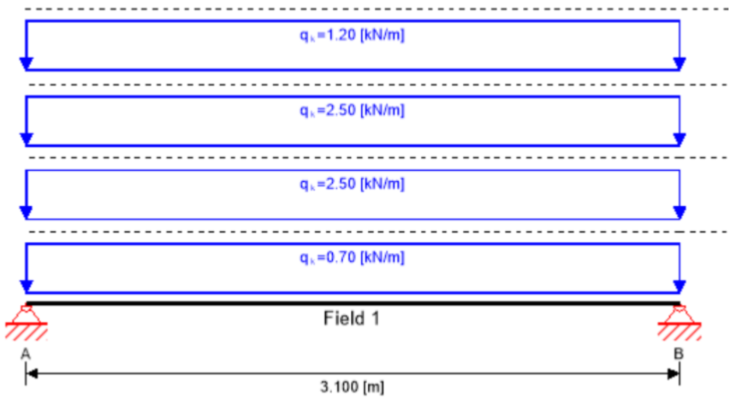
SLS Design 17%, Maximum deformation 2.39 mm

SLS Vibration 0%

Fig. 274. Calculations, Diagrams, and Results for final roof slabs

7.3.2.3 ROOF TOP

This element located in the modules at the sixth level, which are exposed to the elements. However, they have permanent access and are only accessible for maintenance purposes. Refer to the calculation results depicted below for further insight.



Snow load altitude < 1000 m a.s.l

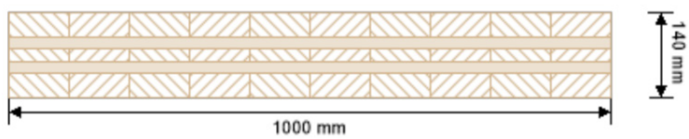
Live load. Cat. A: Domestic, residential

Dead load

Self weight structure

Material description

Layer	Thickness	Orientation
1	40.0 mm	0°
2	20.0 mm	90°
3	20.0 mm	0°
4	20.0 mm	90°
5	40.0 mm	0°
t_{CLT}	**140.0 mm**	



ULS Design 20%

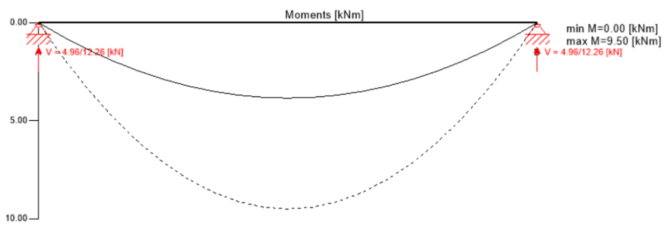
ULS Flexural design

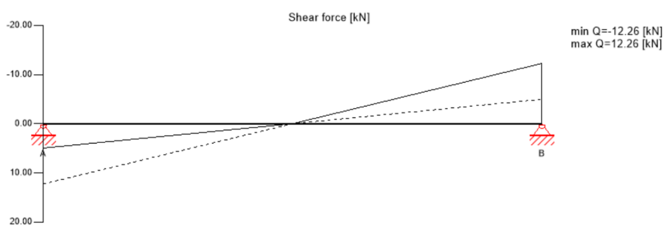
Field	Dist. [m]	$f_{m,k}$ [N/mm²]	γ_m [-]	k_{mod} [-]	$k_{sys,y}$ [-]	$f_{m,y,d}$ [N/mm²]	$M_{y,d}$ [kNm]	$\sigma_{m,y,d}$ [N/mm²]	Ratio	
1	1.55	24.00	1.35	0.80	1.10	15.64	9.50	-3.15	20 %	LCO4

ULS Shear analysis

Field	Dist. [m]	$f_{v,k}$ [N/mm²]	γ_m [-]	k_{mod} [-]	$f_{v,d}$ [N/mm²]	V_d [kN]	$\tau_{v,d}$ [N/mm²]	Ratio	
1	3.1	4.00	1.35	0.80	2.37	-12.26	0.12	5 %	LCO4

Diagrams





SLS Design 45%, Maximum deformation 2.39 mm

SLS Vibration 0%

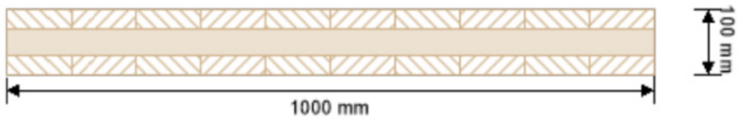
Fig. 275. Calculations, Diagrams, and Results for final rooftop/ terrace slab.

7.3.2.4 WALLS

In this section, the focus is on the design of the different types of walls, depending on the size of the opening in each one. It is important to highlight that depending on the type of modules, some walls will be the same. The table below explains the characteristics of the material. This CLT module was standardized for all the perimeter walls of the module.

Material description

Layer	Thickness	Orientation
1	30.0 mm	90°
2	40.0 mm	0°
3	30.0 mm	90°
t_{CLT}	**100.0 mm**	



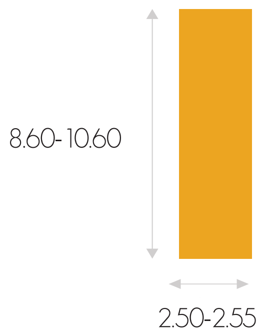
Material	$f_{m,k}$ [N/mm²]	$f_{t,0,k}$ [N/mm²]	$f_{t,90,k}$ [N/mm²]	$f_{c,0,k}$ [N/mm²]	$f_{c,90,k}$ [N/mm²]	$f_{v,k}$ [N/mm²]	$f_{r,k\ min}$ [N/mm²]	$E_{0,mean}$ [N/mm²]	G_{mean} [N/mm²]	$G_{r,mean}$ [N/mm²]
C24 pine ETA (2019)	24.00	14.00	0.12	21.00	2.50	4.00	1.70	12,000.00	690.00	50.00

Fig. 276. General spects for module walls calculations

In the table below, the different types of walls needed to be calculated depending on the distance and the openings are described.

MODULE	TOTAL	TOTAL NEEDED	DISTANCE 2.55	DISTANCE 8.60	DISTANCE 10.60
A	4	3	2	1	0
B	6	3	1	0	2
C	6	1	0	0	1
D	6	1	1	0	0
E	6	3	1	0	2
F	8	1	0	0	1
TOTAL WALLS	12				

Table. 45. Walls calculations distribution.



The table shows the general load imposed on each wall module. The diagrams describe the load transfer and how they are acting on the walls of the module. The calculation were done by different nodes analysis, the results depicted in the following pages for further insight.

LOADS	LOAD [KN/M]
G1 WALL	1.46
G2 SHEAR	1.30
TOTAL	2.8

Table. 46. Walls load analysis

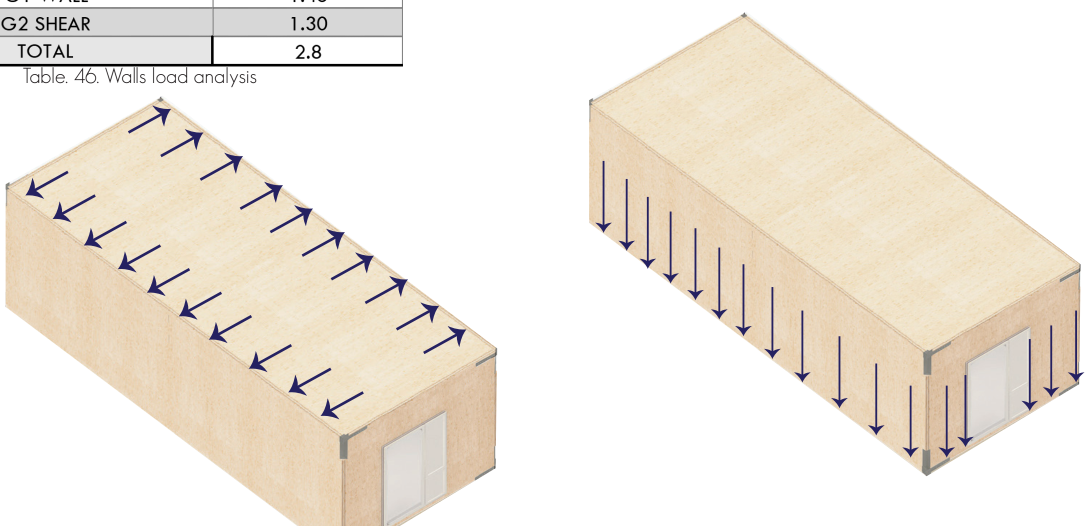


Fig. 277. Walls load transfering

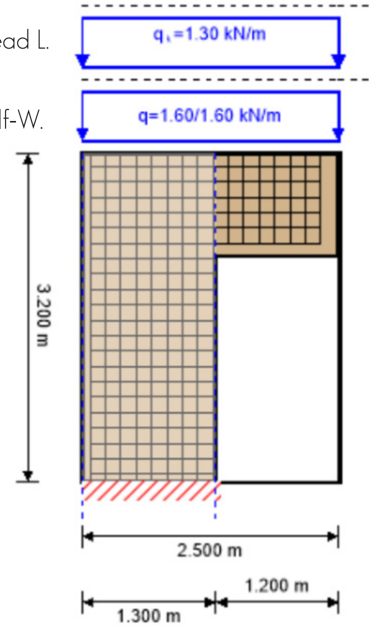
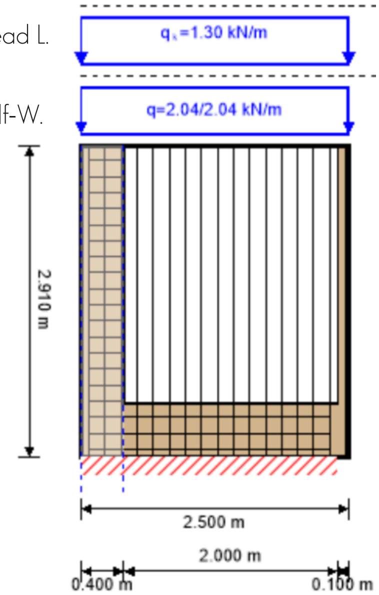
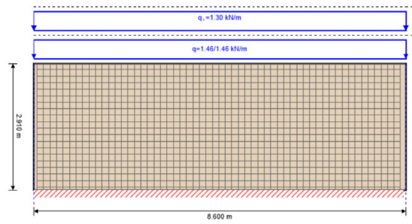
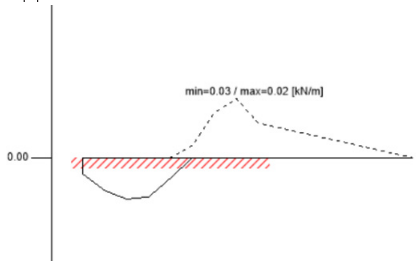
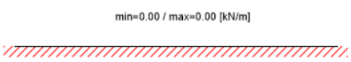
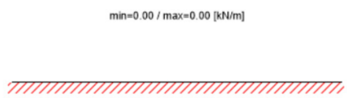
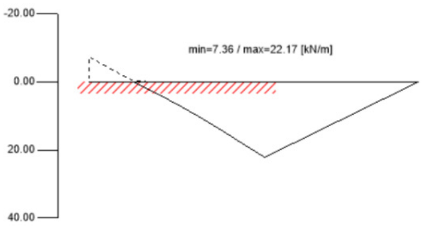
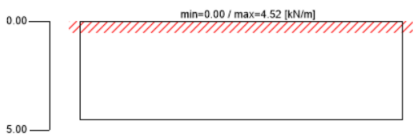
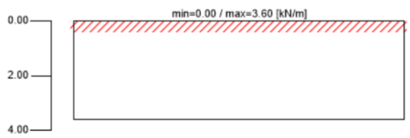
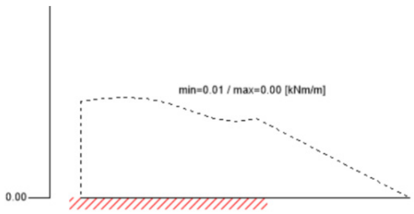
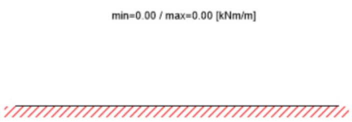
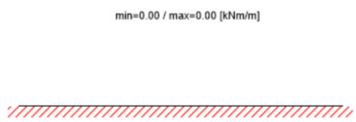
Module type: A	Module type: A	Module type: A
Wall section description Dead L. Self-W. 	Wall section description Dead L. Self-W. 	Wall section description Dead L. 1.30 kN/m Self-W. 1.46 kN/m  Length: 8.60m Height: 2.91m
Support reaction- Horinzontal min/ max 	Support reaction- Horinzontal min/ max 	Support reaction- Horinzontal min/ max 
Support reaction- Vertical min/ max 	Support reaction- Vertical min/ max 	Support reaction- Vertical min/ max 
Support reaction- moment min/ max 	Support reaction- moment min/ max 	Support reaction- moment min/ max 
ULS Design 14%	ULS Design 1%	ULS Design 1%
SLS Design 9%	SLS Design 0%	SLS Design 0%

Table. 47. Module A walls Calculations, Diagrams, and Results.

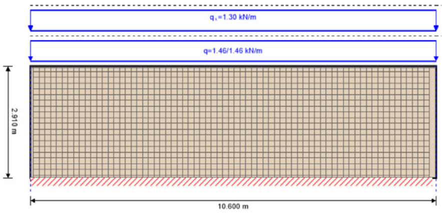
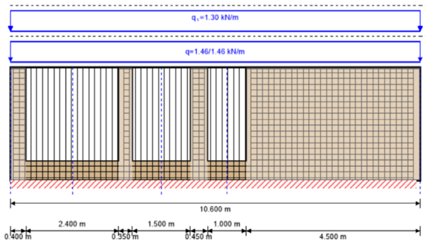
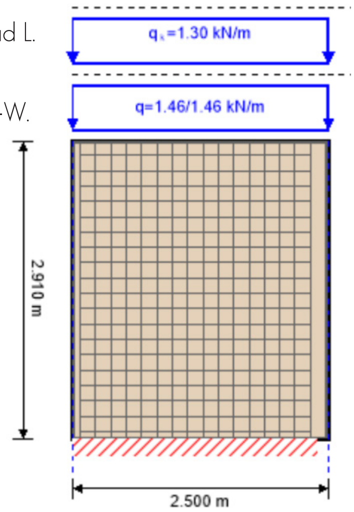
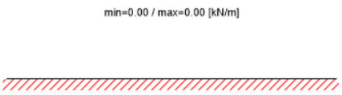
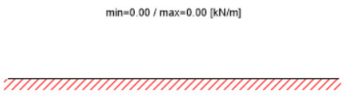
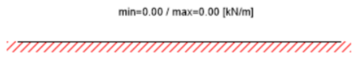
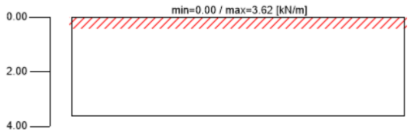
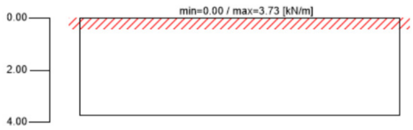
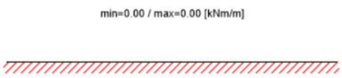
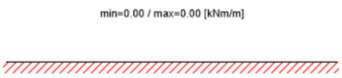
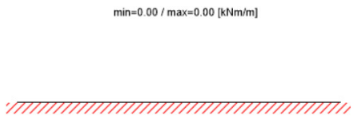
Module type: B Wall section description Dead L. 1.30 kN/m Self-W. 1.46 kN/m  Length: 10.60m Height: 2.91m	Module type: B Wall section description Dead L. 1.30 kN/m Self-W. 1.46 kN/m  Length: 10.60m Height: 2.91m	Module type: B Wall section description Dead L. Self-W. 
Support reaction- Horinzontal min/ max 	Support reaction- Horinzontal min/ max 	Support reaction- Horinzontal min/ max 
Support reaction- Vertical min/ max 	Support reaction- Vertical min/ max 	Support reaction- Vertical min/ max 
Support reaction- moment min/ max 	Support reaction- moment min/ max 	Support reaction- moment min/ max 
ULS Design 1%	ULS Design 1%	ULS Design 1%
SLS Design 0%	SLS Design 0%	SLS Design 0%

Table. 48. Modules B,C walls Calculations, Diagrams, and Results.

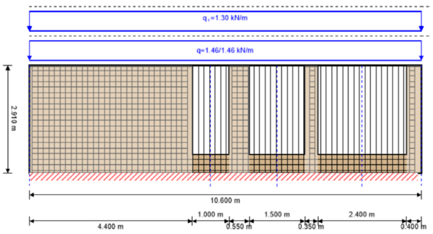
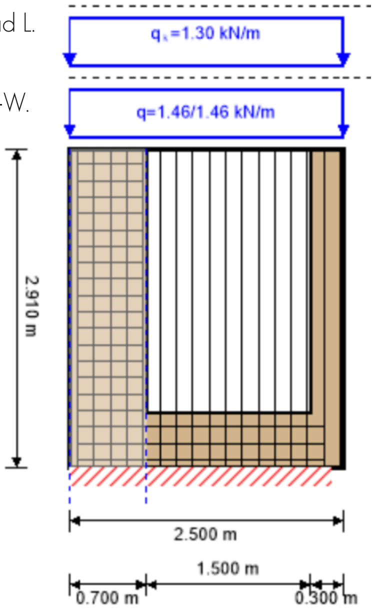
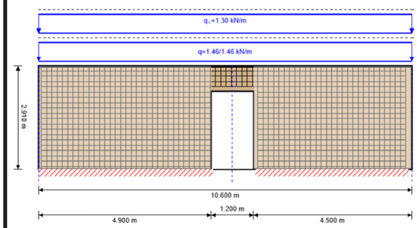
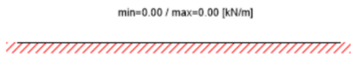
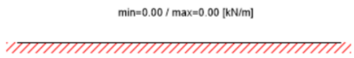
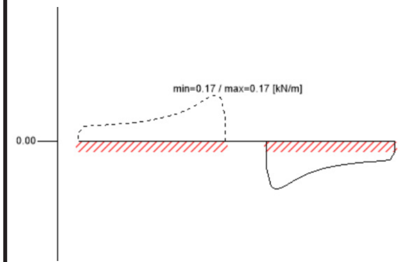
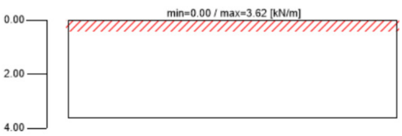
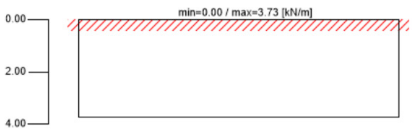
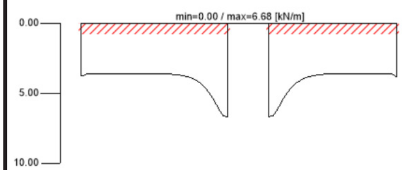
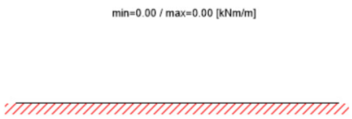
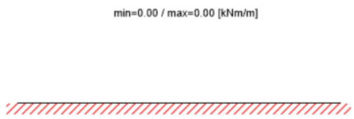
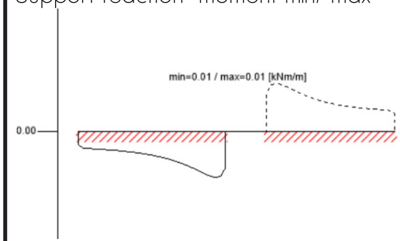
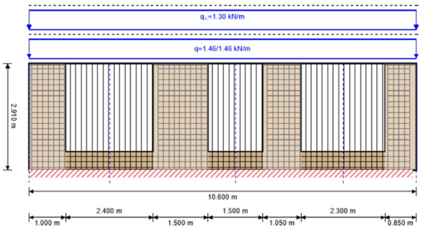
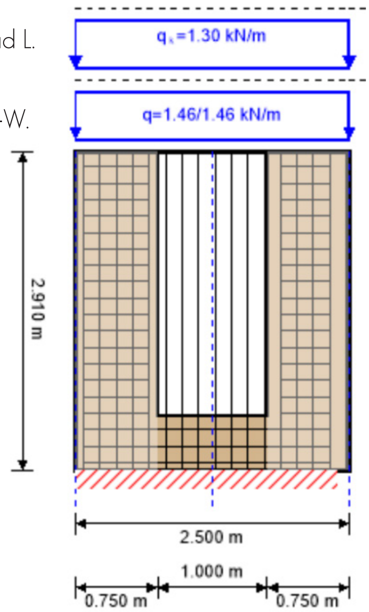
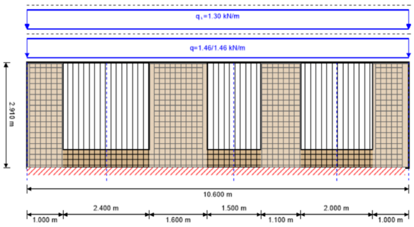
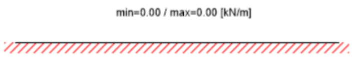
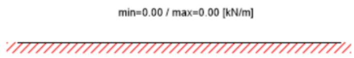
Module type: C	Module type: D	Module type: E
Wall section description Dead L. 1.30 kN/m Self-W. 1.46 kN/m  Length: 10.60m Height: 2.91m	Dead L. Self-W. 	Wall section description Dead L. 1.30 kN/m Self-W. 1.46 kN/m  Length: 10.60m Height: 2.91m
Support reaction- Horinzontal min/ max 	Support reaction- Horinzontal min/ max 	Support reaction- Horinzontal min/ max 
Support reaction- Vertical min/ max 	Support reaction- Vertical min/ max 	Support reaction- Vertical min/ max 
Support reaction- moment min/ max 	Support reaction- moment min/ max 	Support reaction- moment min/ max 
ULS Design 1%	ULS Design 1%	ULS Design 5%
SLS Design 0%	SLS Design 0%	SLS Design 1%

Table. 49. Modules C,D walls Calculations, Diagrams, and Results.

<table>
<tr>
<td>Module type: E
Wall section description
Dead L. 1.30 kN/m
Self-W. 1.46 kN/m

Length: 10.60m
Height: 2.91m</td>
<td>Module type: E
Dead L.
Self-W.
</td>
<td>Module type: F
Wall section description
Dead L. 1.30 kN/m
Self-W. 1.46 kN/m

Length: 10.60m
Height: 2.91m</td>
</tr>
<tr>
<td>Support reaction- Horinzontal min/ max
</td>
<td>Support reaction- Horinzontal min/ max
</td>
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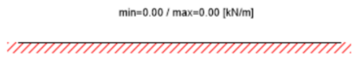</td>
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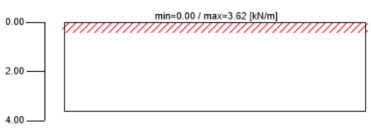
<td>Support reaction- Vertical min/ max
</td>
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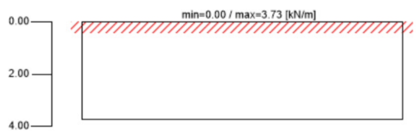
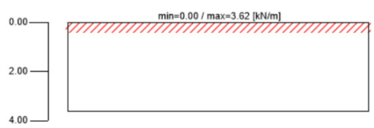
</td>
<td>Support reaction- Vertical min/ max
</td>
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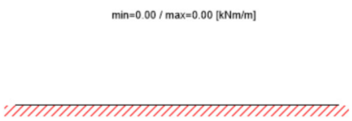
<td>Support reaction- moment min/ max
</td>
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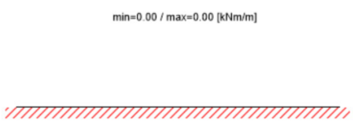
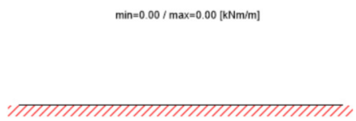
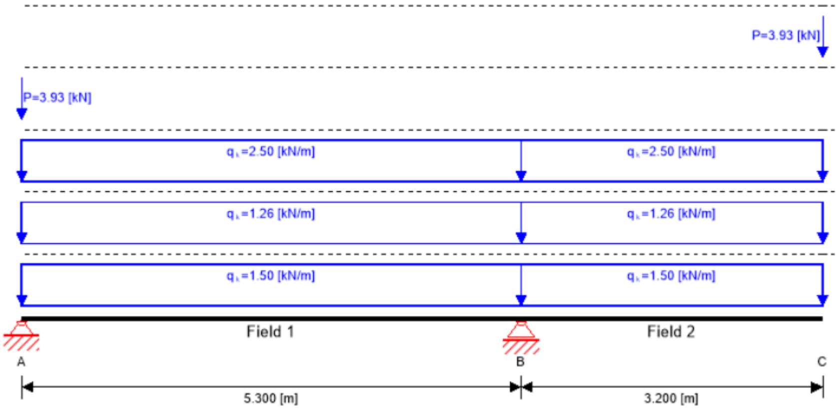
</td>
<td>Support reaction- moment min/ max
</td>
</tr>
<tr><td>ULS Design 1%</td><td>ULS Design 1%</td><td>ULS Design 1%</td></tr>
<tr><td>SLS Design 0%</td><td>SLS Design 0%</td><td>SLS Design 0%</td></tr>
</table>

Table. 50. Modules E,F walls Calculations, Diagrams, and Results.

7.3.2.5 MODULE SLAB

After analyzing the walls, it was necessary to transmit those loads in order to design the module slab. This element was designed to withstand the cantilever. Refer to the calculation results depicted below for further insight.



Dead load

Dead load

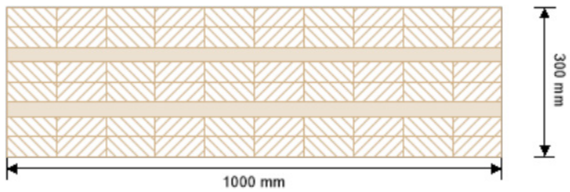
Live load. Cat. A: Domestic, residential

Dead load

Self weight structure

Material description

Layer	Thickness	Orientation
1	40.0 mm	0°
2	40.0 mm	0°
3	30.0 mm	90°
4	40.0 mm	0°
5	40.0 mm	0°
6	30.0 mm	90°
7	40.0 mm	0°
8	40.0 mm	0°
t_{CLT}	**300.0 mm**	



ULS Design 25%

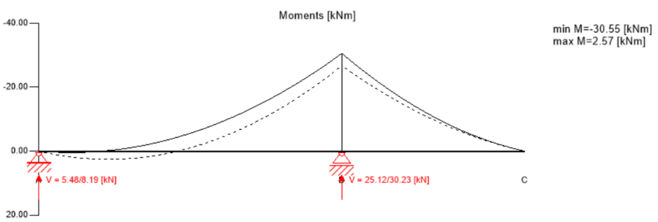
ULS Flexural design

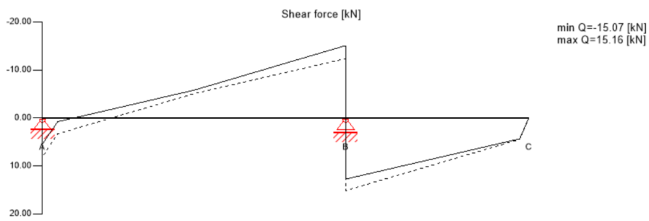
Field	Dist. [m]	$f_{m,k}$ [N/mm²]	γ_m [-]	k_{mod} [-]	$k_{sys,y}$ [-]	$f_{m,y,d}$ [N/mm²]	$M_{y,d}$ [kNm]	$\sigma_{m,y,d}$ [N/mm²]	Ratio	
1	5.3	24.00	1.35	0.80	1.10	15.64	-53.92	3.92	25 %	LCO2
2	0.0	24.00	1.35	0.80	1.10	15.64	-53.92	3.92	25 %	LCO2

ULS Shear analysis

Field	Dist. [m]	$f_{v,k}$ [N/mm²]	γ_m [-]	k_{mod} [-]	$f_{v,d}$ [N/mm²]	V_d [kN]	$\tau_{v,d}$ [N/mm²]	Ratio	
1	5.3	4.00	1.35	0.80	2.37	-29.62	0.14	6 %	LCO2
2	0.0	4.00	1.35	0.80	2.37	28.59	0.13	6 %	LCO2

Diagrams





SLS Design 81%, Maximum deformation 9.62 mm SLS Vibration 0%

Fig. 278. Calculations, Diagrams, and Results for module floor slab.

7.4 BUILDING STRUCTURAL SYSTEM

Modular buildings can be constructed using three main structural systems: self-supporting, core-supporting, and frame-supporting.

- Self-supporting modular buildings are made up of prefabricated three-dimensional or volumetric units, and are assembled using load-bearing walls and/or columns made from two-dimensional flatpack systems. These units are stacked and connected to each other through vertical and horizontal ties into a building frame system, but are limited to a height of four to six stories and are not suitable for hybrid modular construction due to height limits and increased costs.
- Core-supporting modular buildings have modules surrounding a reinforced concrete or steel core that provides lateral stability, typically for tall apartments. However, the structural role of the modules in transferring vertical loads to the foundation makes it impossible to interchange the living modules without compromising the stability of the entire structure.
- Frame-supporting modular buildings use a supporting frame with several stories of modules placed upon it. This system allows flexibility in design and can support either one module or a group of modules. The columns or walls of the modules must be aligned with the beams of the supporting frame to allow appropriate vertical load transfer. Horizontal loads are transferred via moment-resisting connections and/or bracing. A single structural form or a combination of two or more forms can be employed in modular buildings.

The images below depict the three types of modular construction mentioned. After analyzing the various methods of module assembly, it can be concluded that the frame-supporting approach is the optimal solution for this project. This is due to several key factors, including the fact that it is a hybrid construction, the modules are positioned differently on each floor, and there are also elevators present.

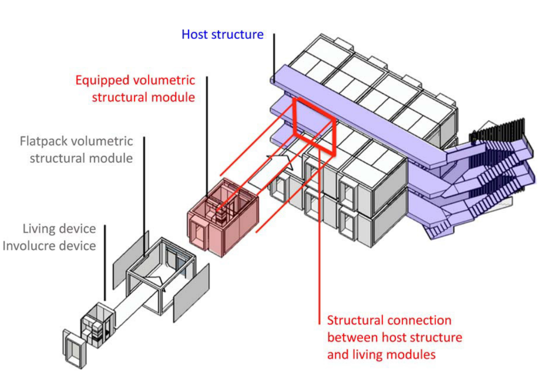


Fig. 279. Hybrid contruction diagram

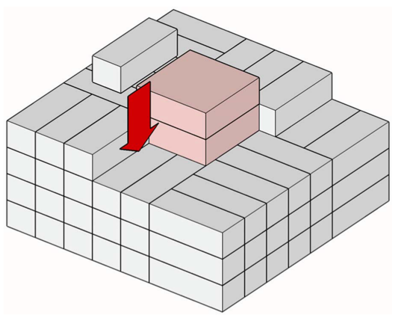


Fig. 280. Core-supporting modular system

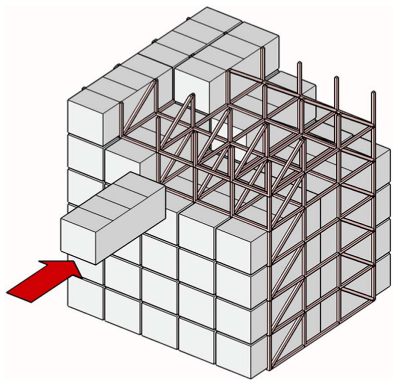


Fig. 281. Frame supporting modular system

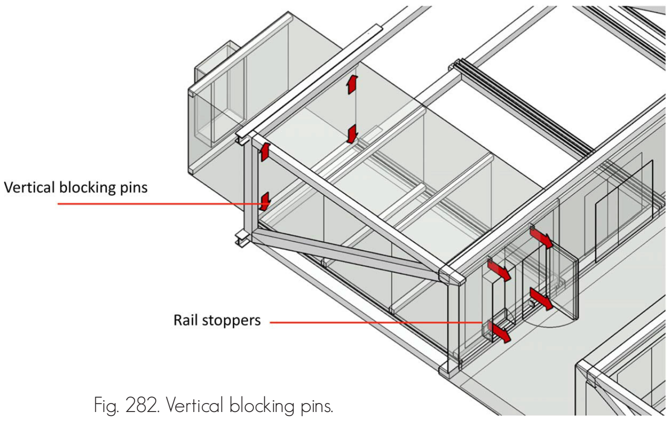


Fig. 282. Vertical blocking pins.

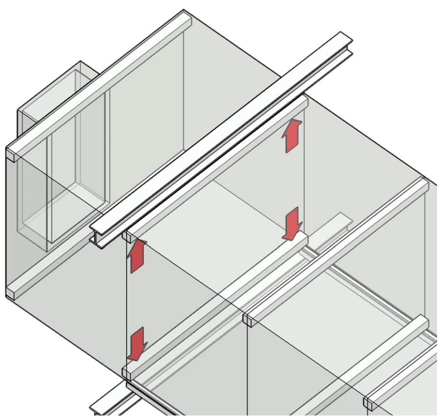


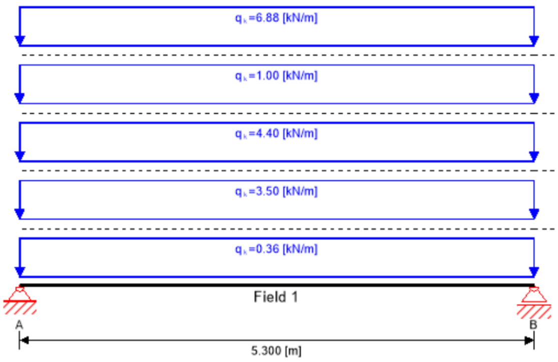
Fig. 283. Access to vertical blocking pin installation points.

7.5 BUILDING STRUCTURE SOLUTION

To properly aggregate the modules using the frame-supporting method, it is necessary to transfer loads between elements, as explained in the previous section. The modules will be connected to the beams of the frame structure. This section will be dedicated to the analysis and design of the steel frame structure, starting with primary and secondary beams, followed by columns and foundations. Lastly, we will cover the schematic design of other elements such as shear walls and load-bearing walls.

7.5.1 BEAMS

7.5.1.1 SECUNDARY BEAM



Live load. Cat. A: Domestic, residential

Dead load

Dead load

Dead load

Self weight structure

Material Values

Material	$f_{m,k}$ [N/mm²]	$f_{t,0,k}$ [N/mm²]	$E_{0,mean}$ [N/mm²]	G_{mean} [N/mm²]
Steel S275	275.00	430.00	210,000.00	80,700.00

Material description

Name	Height [mm]	Width [mm]	t_f [mm]	t_w [mm]	Area [cm²]	I_y [cm⁴]	I_z [cm⁴]	W_y [cm³]	W_z [cm³]	I_w [cm⁶]	I_d [cm⁴]	i_y [cm]	i_z [cm]	$W_{y,pl}$ [cm³]	$W_{z,pl}$ [cm³]
IPE 270	270	135	10.2	6.6	45.94	5790	419.9	428.9	62.2	70580	15.94	1.123	0.302	484	96.95

Combination: 1.30/1.00 * LC1:self-weight structure + 1.30/1.00 * LC2:dead load + 1.30/1.00 * LC3:dead load + 1.30/1.00 * LC 4:dead load + 1.50/0.00 * LC5:live load cat. A: domestic, residential areas

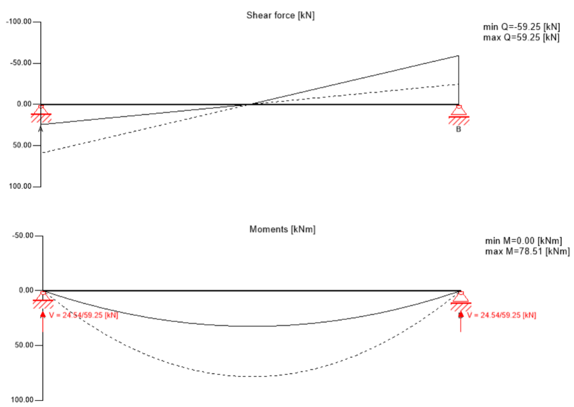
ULS Design 66%

Flexural design							
Qkl =	1			Comb.	LCO2		
M_{Ed} =	78.51	kNm		M_{Rd} =	133.10	kNm	
Ratio	59	%	<		100	%	✓
Utilization ratio						**59 %**	

Shear analysis							
Qkl =	1			Comb.	LCO2		
V_{Ed} =	59.25	kN		V_{Rd} =	351.41	kN	
Ratio	17	%	<		100	%	✓
Utilization ratio						**17 %**	

Flexural design + Shear analysis							
Qkl =	1			Comb.	LCO2		
V_{Ed} =	5.93	kN		V_{Rd} =	351.41	kN	
M_{Ed} =	77.72	kNm		M_{Rd} =	133.10	kNm	
Ratio	58	%	<		100	%	✓
Utilization ratio						**58 %**	

Diagrams

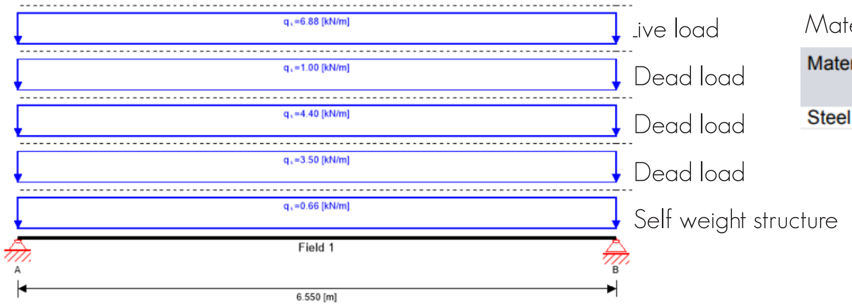


SLS Design 77%, Maximum deformation 13.6 mm

Field	L_{ref} [m]	Limit [mm]	$w_{calc.}$ [mm]	Utilization
1	5.3	L/300 = 17.7	13.6	77 %

Fig. 284. Calculations, Diagrams, and Results for building-Secundary beam

7.5.1.2 SECONDARY PERIMETER BEAM



Material Values

Material	$f_{m,k}$	$f_{t,0,k}$	$E_{0,mean}$	G_{mean}
	[N/mm²]	[N/mm²]	[N/mm²]	[N/mm²]
Steel S275	275.00	430.00	210,000.00	80,700.00

Material description

Name	Height	Width	t_f	t_w	Area	I_y	I_z	W_y	W_z	I_w	I_d	i_y	i_z	$W_{y,pl}$	$W_{z,pl}$
	[mm]	[mm]	[mm]	[mm]	[cm²]	[cm⁴]	[cm⁴]	[cm³]	[cm³]	[cm⁶]	[cm⁴]	[cm]	[cm]	[cm³]	[cm³]
IPE 400	400	180	13.5	8.6	84.46	23130	1318	1156	146.4	490000	51.08	1.655	0.395	1307	229

Combination: 1.30/1.00 * LC1:self-weight structure + 1.30/1.00 * LC2:dead load + 1.30/1.00 * LC3:dead load + 1.30/1.00 * LC 4:dead load + 1.50/0.00 * LC5:live load cat. A: domestic, residential areas

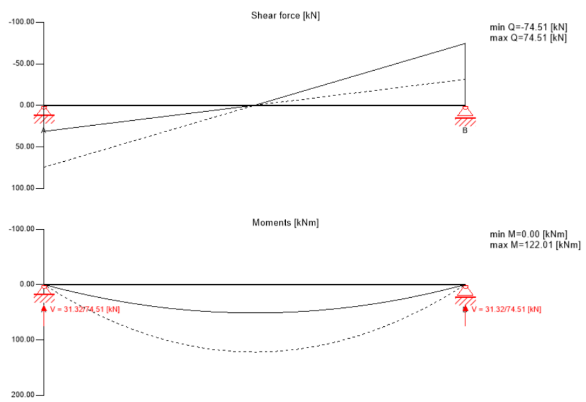
ULS Design 38%

Flexural design							
Qkl =	1			Comb.	LCO1		
M_{Ed} =	117.48	kNm		M_{Rd} =	359.43	kNm	
Ratio	33	%	<		100	%	✓
Utilization ratio						**33 %**	

Shear analysis							
Qkl =	1			Comb.	LCO1		
V_{Ed} =	123.95	kN		V_{Rd} =	677.81	kN	
Ratio	18	%	<		100	%	✓
Utilization ratio						**18 %**	

Flexural design + Shear analysis							
Qkl =	1			Comb.	LCO1		
V_{Ed} =	38.51	kN		V_{Rd} =	677.81	kN	
M_{Ed} =	117.48	kNm		M_{Rd} =	359.43	kNm	
Ratio	33	%	<		100	%	✓
Utilization ratio						**33 %**	

Diagrams



SLS Design 37%, Maximum deformation 8.1 mm

Field	L_{ref}	Limit	$w_{calc.}$	Utilization
	[m]	[mm]	[mm]	
1	6.6	L/300 = 21.8	8.1	37 %

Fig. 285. Calculations, Diagrams, and Results for building- Secundary perimetral beam

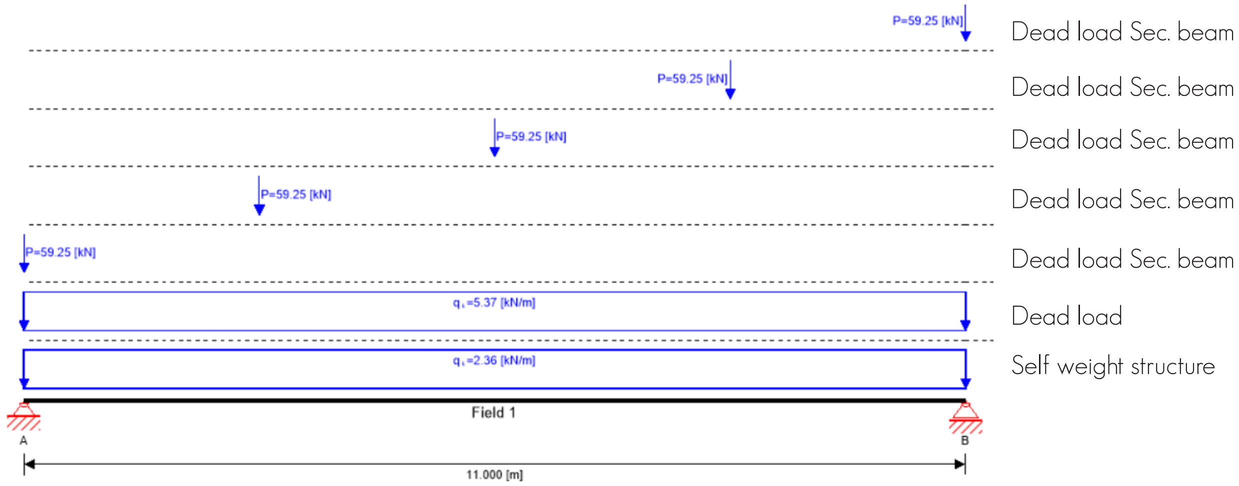
The following table describes the different types of secondary beams, including the intermediate, perimeter, and middle core ones.

SECUNDARY BEAMS	PROFILE TYPE	WIGHT (KN/m)	LENGTH (m)	QUATITY	WIGHT (KN)
Intermediates	IPE 270	0.36	5.00	10	18.00
5 AB´ & 4B"D	HD 400 x 237	2.36	18.15	1	42.83
1CD & 5CD	IPE 400	0.66	6.60	4	17.42

Table. 51. Total secunday beams by floor

After calculating the loads on the intermediate and perimeter secondary beams, they are transferred to the main beam as a punctual load.

7.5.1.3 MAIN BEAM CANTILEVER



Name	Height	Width	t_f	t_w	Area	I_y	I_z	W_y	W_z	I_w	I_d	i_y	i_z	$W_{y,pl}$	$W_{z,pl}$
	[mm]	[mm]	[mm]	[mm]	[cm²]	[cm⁴]	[cm⁴]	[cm³]	[cm³]	[cm⁶]	[cm⁴]	[cm]	[cm]	[cm³]	[cm³]
HD 400 x 237	380	395	30.2	18.9	300.9	78780	31040	4146	1572	9489000	825.4999	1.618	1.016	4686	2387

Combination: 1.30/1.00 * LC1:self-weight structure + 1.30/1.00 * LC2:dead load + 1.30/1.00 * LC3:dead load + 1.30/1.00 * LC4:dead load + 1.30/1.00 * LC5:dead load + 1.30/1.00 * LC6:dead load + 1.30/1.00 * LC7:dead load

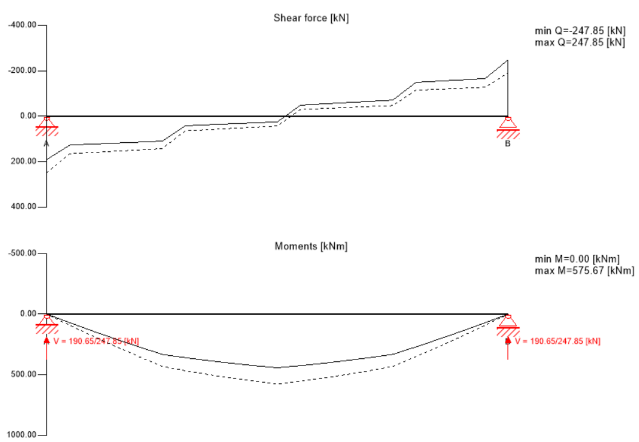
ULS Design 50%

Flexural design								
Qkl =	1			Comb.	LCO1			
M_{Ed} =	575.67	kNm		M_{Rd} =	1288.65	kNm		
Ratio	45	%	<		100	%		✓
Utilization ratio							45 %	

Shear analysis								
Qkl =	1			Comb.	LCO1			
V_{Ed} =	247.85	kN		V_{Rd} =	1223.93	kN		
Ratio	20	%	<		100	%		✓
Utilization ratio							20 %	

Flexural design + Shear analysis								
Qkl =	1			Comb.	LCO1			
V_{Ed} =	42.96	kN		V_{Rd} =	1223.93	kN		
M_{Ed} =	575.67	kNm		M_{Rd} =	1288.65	kNm		
Ratio	45	%	<		100	%		✓
Utilization ratio							45 %	

Diagrams



SLS Design 89%, Maximum deformation 32.5 mm

Field	L_{ref}	Limit	$w_{calc.}$	Utilization
	[m]	[mm]	[mm]	
1	11.0	L/300 = 36.7	32.5	89 %

Material Values

Material	$f_{m,k}$	$f_{t,0,k}$	$E_{0,mean}$	G_{mean}
	[N/mm²]	[N/mm²]	[N/mm²]	[N/mm²]
Steel S275	275.00	430.00	210,000.00	80,700.00

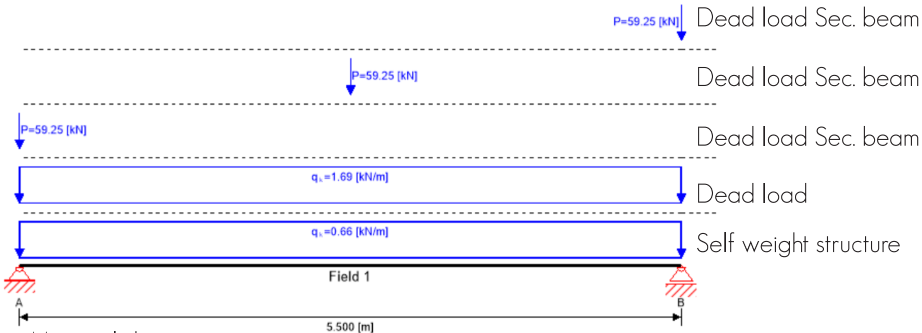
Fig. 286. Calculations, Diagrams, and Results for building-Canteliver main beam

The calculation of the beam that will be carrying the cantilever of the modules was the most critical one, since it also has a length of 11m. It was selected a HD section to have more space to anchor and place the modules, and ensure a safe height between them. At same thime this beam was generalize in all the main beams with the lenght of 11m. The following table describes the different types of main beams:

MAIN BEAMS	PROFILE TYPE	WIGHT (KN/m)	LENGTH (m)	QUATITY	LOAD (KN)
11m	HD 400 x 237	2.36	11.00	4	103.84
5.3m	IPE 400	0.66	5.30	4	13.99

Table. 52. Total main beams by floor

7.5.1.4 MAIN BEAM INTERNAL MEMBER



Material description

Name	Height	Width	t_f	t_w	Area	I_y	I_z	W_y	W_z	I_w	I_d	i_y	i_z	$W_{y,pl}$	$W_{z,pl}$
	[mm]	[mm]	[mm]	[mm]	[cm²]	[cm⁴]	[cm⁴]	[cm³]	[cm³]	[cm⁶]	[cm⁴]	[cm]	[cm]	[cm³]	[cm³]
IPE 400	400	180	13.5	8.6	84.46	23130	1318	1156	146.4	490000	51.08	1.655	0.395	1307	229

Combination: 1.30/1.00 * LC1:self-weight structure + 1.30/1.00 * LC2:dead load + 1.30/1.00 * LC3:dead load + 1.30/1.00 * LC 4:dead load + 1.30/1.00 * LC5:dead load

ULS Design 38%

Flexural design

Qkl =	1			Comb.	LCO1		
M_{Ed} =	117.48	kNm		M_{Rd} =	359.43	kNm	
Ratio	33	%	<		100	%	✓
Utilization ratio						**33 %**	

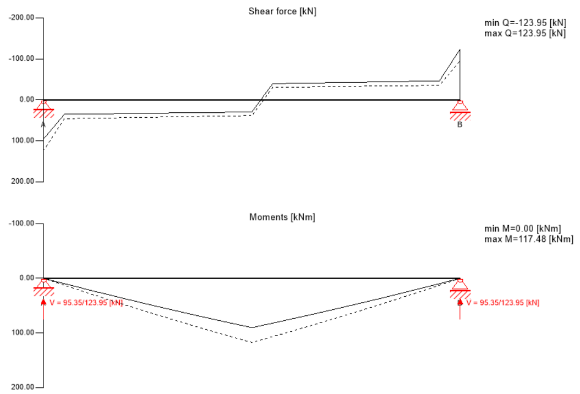
Shear analysis

Qkl =	1			Comb.	LCO1		
V_{Ed} =	123.95	kN		V_{Rd} =	677.81	kN	
Ratio	18	%	<		100	%	✓
Utilization ratio						**18 %**	

Flexural design + Shear analysis

Qkl =	1			Comb.	LCO1		
V_{Ed} =	38.51	kN		V_{Rd} =	677.81	kN	
M_{Ed} =	117.48	kNm		M_{Rd} =	359.43	kNm	
Ratio	33	%	<		100	%	✓
Utilization ratio						**33 %**	

Diagrams



SLS Design 26%, Maximum deformation 4.8 mm

Field	L_{ref}	Limit	$w_{calc.}$	Utilization
	[m]	[mm]	[mm]	
1	5.5	L/300 = 18.3	4.8	26 %

Fig. 287. Calculations, Diagrams, and Results for building-internal main beam

The following table summarizes the different types of beams and their approximated total load in both frames. These values will be added for the steel column calculation.

MAIN BEAMS	PROFILE TYPE	WIGHT (KN/m)	LENGTH (m)	QUATITY	LOAD (KN)
11m	HD 400 x 237	2.36	11.00	4	103.84
5.3m	IPE 400	0.66	5.30	4	13.99
				SUBTOTAL	117.83
SECUNDARY BEAMS	PROFILE TYPE	WIGHT (KN/m)	LENGTH (m)	QUATITY	WIGHT (KN)
Intermediates	IPE 270	0.36	5.00	10	18.00
5 AB´ & 4B"D	HD 400 x 237	2.36	18.15	1	42.83
1CD & 5CD	IPE 400	0.66	6.60	4	17.42
				SUBTOTAL	78.26
				TOTAL	196.09
Beam self incidence, Total beams by floors (with steel)			g1, Beam=	0.98045	KN/m2

Table. 53. Total beams loads by floor

7.5.2 COLUMNS

After the calculation of the influences of the beams in the structure, we proceed to the calculation of the steel column. The base calculation was done with the following material specifications. The column C6 is critical since it carries the beams holding the cantilever in all levels. Below are the parameters and data calculated for this element.

Material description

Name	Height [mm]	Width [mm]	t_f [mm]	t_w [mm]	Area [cm²]	I_y [cm⁴]	I_z [cm⁴]	W_y [cm³]	W_z [cm³]	I_w [cm⁶]	I_d [cm⁴]	i_y [cm]	i_z [cm]	$W_{y,pl}$ [cm³]	$W_{z,pl}$ [cm³]
IPE 400	400	180	13.5	8.6	84.46	23130	1318	1156	146.4	490000	51.08	1.655	0.395	1307	229

Compressive force design

Qkl =	1			Comb.	LCO1		
N_{Ed} =	-674.11	kN		N_{Rd} =	2322.65	kN	
Ratio	29	%	<		100	%	✓
Utilization ratio							**29 %**

Buckling design

Qkl =	0			Comb.	LCO1		
χ_y =	1.00	-		χ_z =	0.86	-	
N_{Ed} =	-674.11	kN		N_{Rd} =	2322.65	kN	
N_{Ed} =	-674.11	kN		N_{Rd} =	1996.26	kN	
Ratio	34	%	<		100	%	✓
Utilization ratio							**34 %**

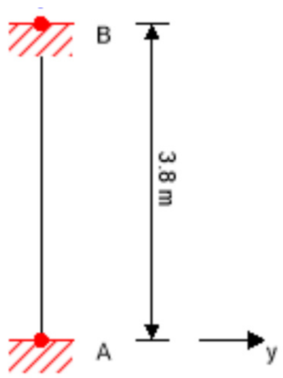


Fig. 288. Base line of falculations, Diagrams, and Results for building-steel column

For the load analysis, it was necessary to determine the location of the column. Depending on the frame, the Cr factor may change. The main loads and the chosen section are described in the table below.

	FRAME 1		FRAME 2		
COLUMN	corner	Middle column/core	Middle column/core	Middle column	Corner
Cr	1	1	1	1	1
Influence Area	22.825	14.575	29.15	19.67625	7.425

Table. 54. Cr and influence area depending of the column location

TYPE	LOADS				$n_{k,i}=g_{k,i}+q_{k,i}$	$N_{k,i}=G_{k,i}+Q_{k,i}$	Accumulated load	Chosen Section	Column Self-Weight [kN]
	G1 (KN/m2)	G2 (KN/m2)	Q (Imposed)	Q (snow)					
ROOF	2.25	0.61	0.50	1.20	4.55	103.96			
RESI.	1.64	2.49	2.50	1.20	7.83	178.68	103.96	IPE 400	2.52
RESI.	2.58	1.26	2.50	0.00	10.27	234.34	285.16	IPE 400	2.52
RESI.	2.58	1.26	2.50	0.00	10.27	234.34	522.01	IPE 400	2.52
RESI.	2.58	1.26	2.50	0.00	10.27	234.34	758.87	IPE 400	2.52
RESI.	2.58	1.26	2.50	0.00	10.27	234.34	995.72	IPE 400	2.52
RESI.	2.58	1.26	2.50	0.00	10.27	234.34	1232.58	IPE 400	2.52
RESI.	2.58	1.26	2.50	0.00	10.27	234.34	1469.44	IPE 400	2.52
Ground	3.33	1.26	2.50	0.00	7.09	161.75	1706.29	IPE 500	3.45
Basement	3.33	1.26	2.50	0.00	7.09	161.75	1871.50	IPE 500	3.45
			Total floors loads			2012.16			
			Total for foundation			2036.70			

Table. 55. Column C6 load analysis and section selecction

LEVEL	TYPE	Middle column/core			
		$N_{k,i}=G_{k,i}+Q_{k,i}$	Acumulated Load	Chosen section	Column Self-Weight [kN]
8th	ROOF	66.38			
7th	RESI.	114.10	66.38	IPE 400	2.52
6th	RESI.	149.64	183.67	IPE 400	2.52
5th	RESI.	149.64	335.82	IPE 400	2.52
4th	RESI.	149.64	487.98	IPE 400	2.52
3rd	RESI.	149.64	791.46	IPE 400	2.52
2nd	RESI.	149.64	943.62	IPE 400	2.52
1st	RESI.	149.64	1095.78	IPE 400	2.52
0	Ground	103.29	1247.93	IPE 400	3.45
-1	Basement	103.29	1354.67	IPE 400	3.45
		Total floors loads	1461.41		

Table. 56. Middle core column load analysis and section selecction

After giving a coherent section for the rest of the columns, it was necessary to understand the loads. The chosen section for them is described in the tables below..

LEVEL	TYPE	Middle column/ frame 2			
		Nk,i=Gk,i+Qk,i	Acumulated Load	Chosen section	Column Self-Weight [kN]
8th	ROOF	89.61			
7th	RESI.	154.03	89.61	IPE 400	2.52
6th	RESI.	202.01	246.84	IPE 400	2.52
5th	RESI.	202.01	451.36	IPE 400	2.52
4th	RESI.	202.01	655.89	IPE 400	2.52
3rd	RESI.	202.01	862.11	IPE 400	2.52
2nd	RESI.	202.01	1066.64	IPE 400	2.52
1st	RESI.	202.01	1271.17	IPE 400	2.52
0	Ground	139.44	1475.70	IPE 500	3.45
-1	Basement	139.44	1618.59	IPE 500	3.45
		Total floors loads	1761.48		

Table. 57. Midle core column in frame 2- load analysis and section selecction

LEVEL	TYPE	Corner column frame 2			
		Nk,i=Gk,i+Qk,i	Acumulated Load	Chosen section	Column Self-Weight [kN]
8th	ROOF	33.82			
7th	RESI.	58.12	33.82	HE 220 A	2.52
6th	RESI.	76.23	95.13	HE 220 A	2.52
5th	RESI.	76.23	173.88	HE 220 A	2.52
4th	RESI.	76.23	252.63	HE 220 A	2.52
3rd	RESI.	76.23	333.07	HE 220 A	2.52
2nd	RESI.	76.23	411.82	HE 220 A	2.52
1st	RESI.	76.23	490.57	HE 220 A	2.52
0	Ground	52.62	569.32	HE 220 A	3.45
-1	Basement	52.62	370.24	HE 220 A	3.45
		Total floors			

Table. 58. Corner core column in frame 2- load analysis and section selecction

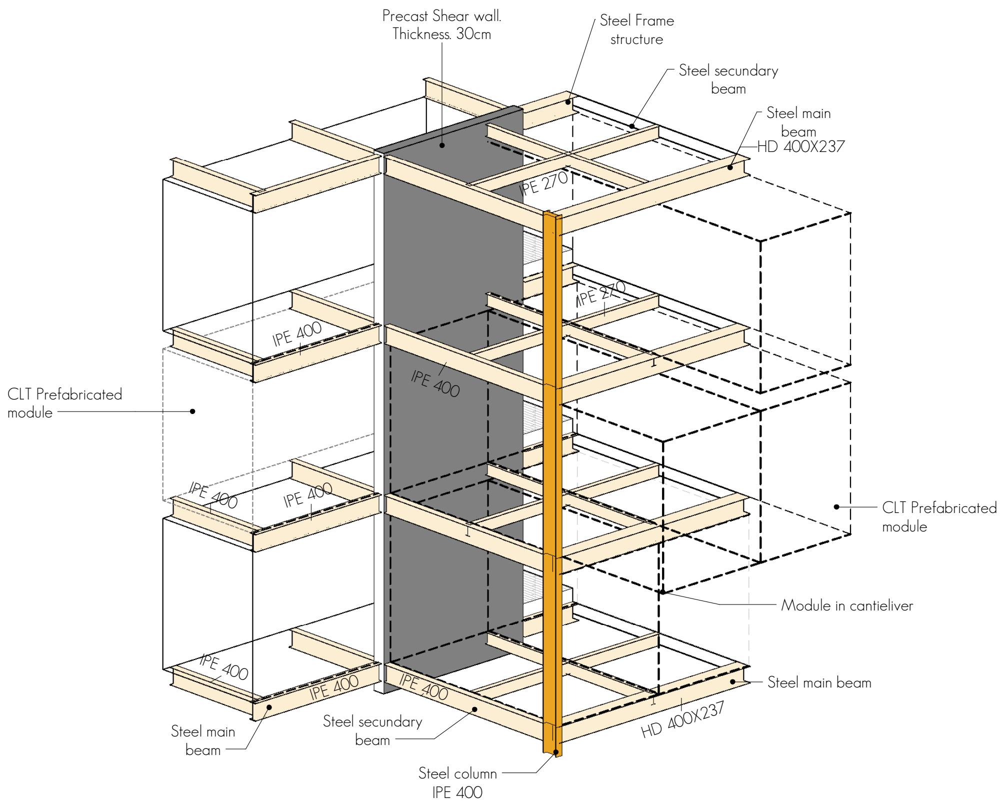


Fig. 289. Frame structure 3D diagram

7.5.3 FOUNDATION

The following table explains the load analysis, considering the slab of the basement floor. For the total axial load, it takes into account the accumulated load acting on column C6.

LOADS	SLS [KN/m]	ULS [KN/m]
G1	4.77	6.20
G2	2.00	3.00
Total permanent G	6.77	9.20
Q imposed	2.00	3.75
Q walls	0.50	0.75
Total variable Q	2.50	4.50
TOTAL	9.27	13.70

Table. 59. Foundation- Load analysis

LOADS	SLS [KN/m]	ULS [KN/m]
N	2036.70	2851.38
TOTAL	2045.97	2865.08

Table. 60. Total axial load

Cr	1
Influence Area	22.825
Supported façade length	4.2

Column C6 influence area

Table. 61. Cr and influece area Column C6

After this, the axial load N was calculated according to the SLS and ULS, considering the influence area, giving at the end the total load analysis, in the table below. It is important to highlight that to design the footing Ned = Pd, and the soil resistance is assumed to be 0.35 MPa.

Knowing that the required steel area it is $A_{,req} \geq \frac{Ned}{\sigma t.soil} =$, having as a result 4.98m2, we can calculate the footing dimensioning (based on the needed formulas), as it is specified in the following table:

a	320	cm
b	320	cm
a'	50	cm
b'	50	cm
da	75	cm
db	75	cm
A footing	10.24	m2
ca	125	cm
cb	125	cm
Po	69.95	KN
Prc	1286.66	KN

Table. 62. Foundation- Pre-dimensioning

As a final step, the concrete cover was calculated and the anchorage length for the steel bars (=20mm) was determined; the accompanying table is a description and summary of this data, with a Cnom=25mm and lbd=350mm.

Cmin,b [mm]	16	mm
Cmin,dur [mm]	15	mm
ΔCdev [mm]	10	mm
Cnom [mm]	25	mm

lb,rqd,10	735.00	mm
lb,min	217.00	mm
cd	25.00	mm
lbd	350.00	mm

Table. 65. Foundation- Concrete cover

Following the previous data, the steel resistance is verified in both sides. Based on the formulas to design the resistance steel area, according to the following formulas from the concrete resistance, one has we calculate the base reinforcement of the footing.

$$P_{rc} \cong P_o + 2 \times 0.4 d_a b' f_{cd} \frac{1}{1+\lambda_a^2} + 2 \times 0.4 d_b a' f_{cd} \frac{1}{1+\lambda_b^2}$$

Where $P_o \cong \frac{a'b'}{ab} P_d$ and for the verification Prc > Pd. In the table below, it is a summary of all the data calculated for the concrete resistance and the base reinforcement.

STEEL RESISTANCE - SIDE A and B		
C	1208.70	cm
pd	2865.08	KN
P'a	447.67	KN
la	80.00	cm
λa	1.067	cm
Φ sa	20	mm
n° bars	8	
Asa	25.12	mm2
Prs	1842.06	KN
Prs> pd	2865.08	NO

Table. 63. Foundation- Steel resistance

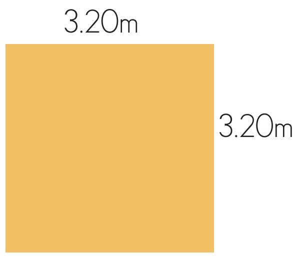


Fig. 290. Footing dimensions

CRITICAL PERIMETER FOOTING AND COLUMN.

Then following the previous steps, it was needed to verify that is carried out evaluating the capacity on the critical perimeter, according to the following requirements:

$$P'_r = 0.25 u d f_{ctd} \kappa (1 + 50 \rho_s)$$

and another one within the **perimeter of the column**

$$P''_r = 0.4 u_o d f_{cd} / (1 + \lambda^2),$$

Furthermore, the critical perimeter U, taking into consideration the coefficient of increase the thing of the slab/footing K=1.

u	1987.85	cm
u0	1280.00	cm
k	1.00	
ρ s	0.268%	
θ	52.00	
λ	1.07	
Ac	210.67	mm2
P'r	5705.87	KN
P''r	305363.83	KN
Pr	5705.87	KN
pr> pd-po	2795.13	OK

Table. 64. Critical perimeter in footing and column

At the end it was necessary to verify that pr> pd-po, that at the end the footing is working in an optimum resistance.

A shear wall and a load-bearing wall are both structural elements that are commonly used in building construction. While there are some similarities between the two, they differ in terms of their primary functions and how they resist different types of loads.

- A shear wall is a structural element that resists lateral forces such as wind and earthquake loads. It is typically a vertical wall made of reinforced concrete or masonry that is designed to transfer the lateral loads to the foundation. Shear walls are generally located at the perimeter of a building or in the center of a building, where they can provide support against lateral forces.
- On the other hand, a load-bearing wall is a structural element that supports vertical loads such as the weight of the floors and roof. Load-bearing walls are typically located at the perimeter of a building or in the center of a building, where they can provide support for the floors and roof above.

In summary, while both shear walls and load-bearing walls are important structural elements in building construction, they serve different purposes and resist different types of loads. Using precast concrete for these elements can offer several advantages, including improved quality control, faster construction times, increased durability, and better design flexibility. The image bellow show the assembeling of the modules in the frame structure.

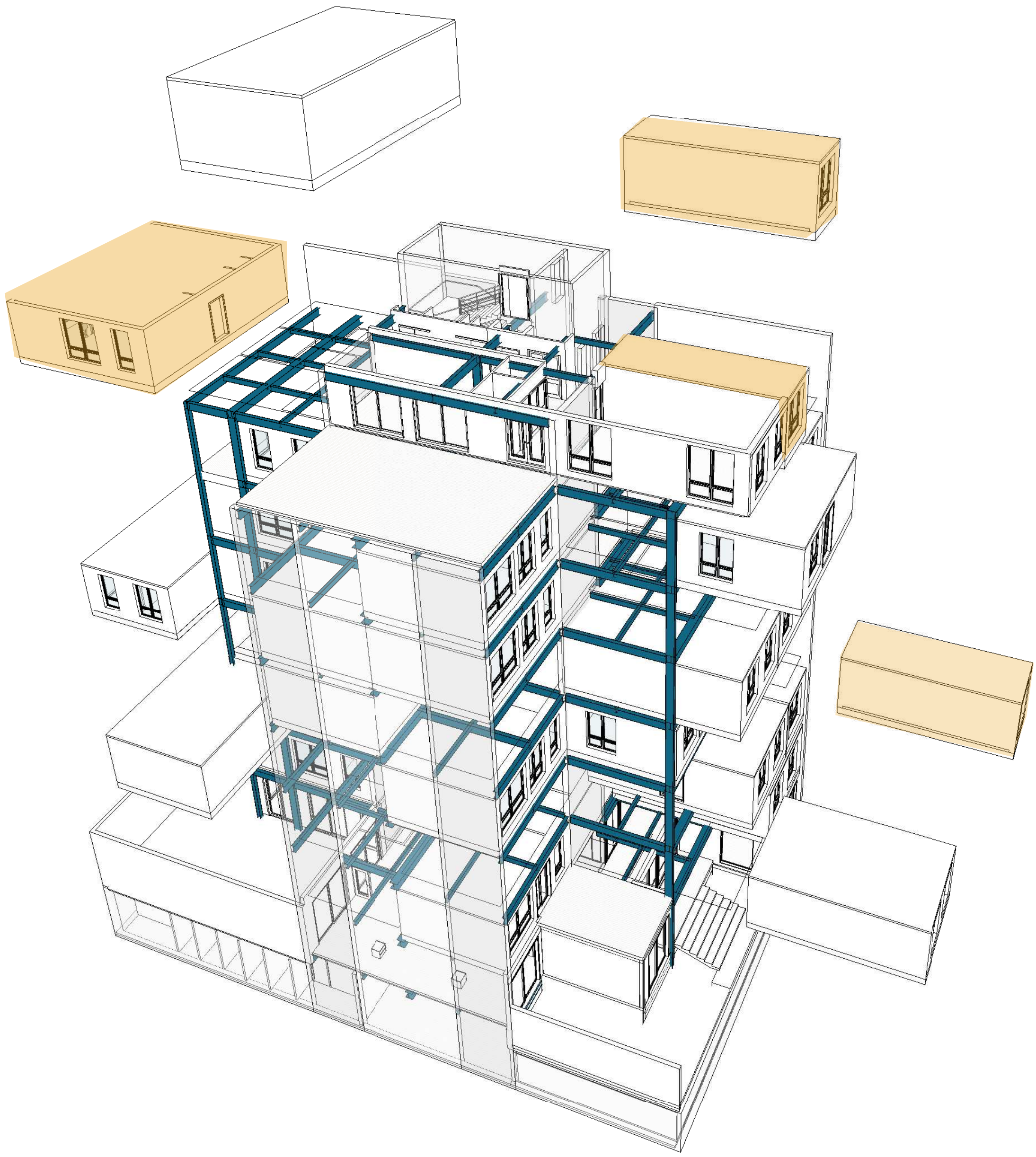
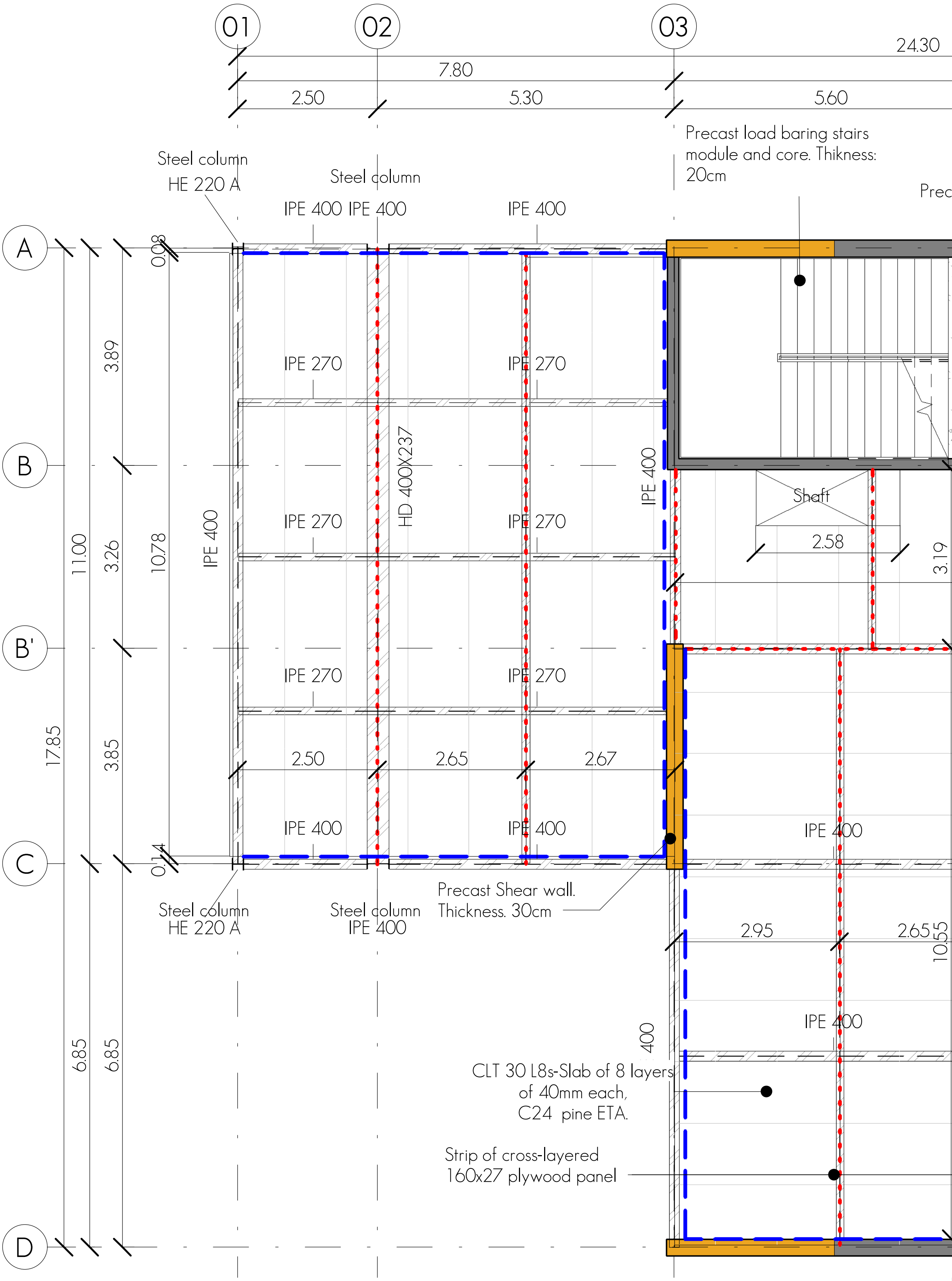


Fig. 291. Modules aggregation and assembling in steel frame structure.

7.6 STRUCTURAL TYPICAL FLOOR PLAN



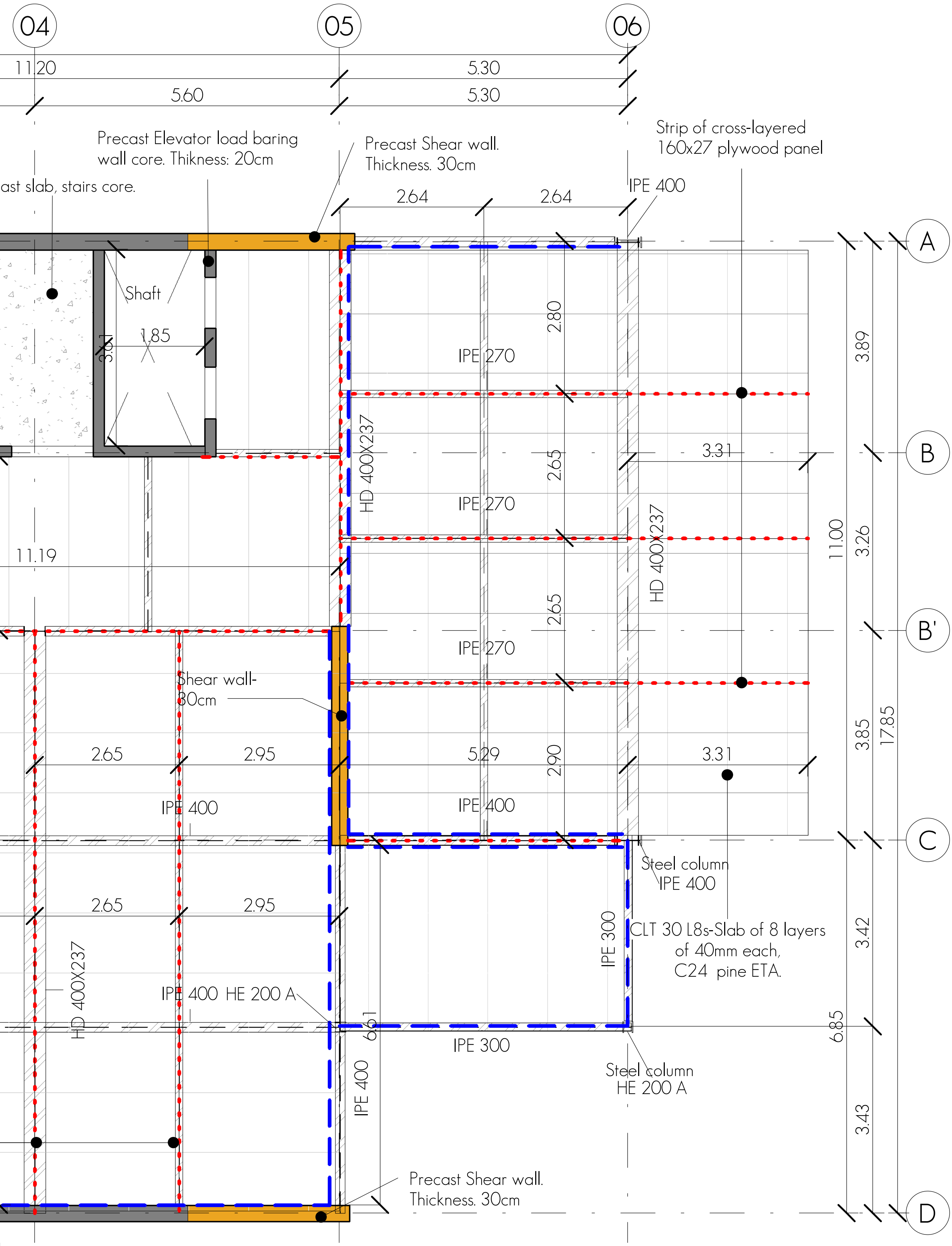


Fig. 292. Structural typical floor plan.

8

CONCLUSIONS

This thesis project focused on the study and analysis of housing modular units and their adaptability in various contexts and locations. The Microhome concept, which promotes minimalism and multifunctional spaces, served as the basis for exploring different lifestyle options and advantages as a housing solution. The exploration of recent movements like Microhomes has highlighted the need to rethink traditional housing solutions and the benefits of minimalism and multifunctional spaces. By exploring the different solutions that can be achieved with the same square meters, this study has emphasized the importance of considering household types when designing modular housing units. Furthermore, the flexibility and smart furniture solutions can help to optimize internal space functionality.

The applicability of this kind of project has been demonstrated in different housing building solutions, such as student housing, hostels, affordable and social housing, multifamily housing, and luxury apartments. Moreover, the modularity of this solution offers the opportunity to configure different housing solutions with only one typology of module or a mix of them. Additionally, the study of the limitations and constraints related to the context of the site provides insight into how to design adaptable modular housing units.

The comparison of different materials and solutions for modular housing has given a baseline of the pros and cons for each material like CLT. The selection criteria depend on the context, location, and budget of the client. The structural study has provided general guidelines on the basic steps to take into consideration in this kind of project. Additionally, the study of the presence of cantilevers in a modular building has shown that it is a challenging solution that requires careful consideration. This thesis project also presented a solution for a hybrid modular prefabricated building that can be applied to similar sites, considering the limitations and constraints related to the context.

The presence of cantilevers in a modular building was challenging, but the structural study gave general guidelines on how this kind of solution can be done, serving as a general guide for the basic steps to take into consideration in these kinds of projects. Furthermore, as a sustainable building that applies different kinds of technologies, it is essential to highlight that optimizing spaces is easier with less area.

In terms of daylighting, this study analyzed how to light up spaces naturally based on the solar exposure and the amount of natural light available. It also demonstrated how to reduce sun illumination in certain areas through the use of louvers.
In terms of energy, it is crucial to study the city and climate conditions and leverage them in our favor, such as natural ventilation. Overall, this thesis project provides guidance on how to design and implement modular housing units in various contexts while considering sustainability and adaptability. This study's findings can serve as a basis for further research and development in this field, leading to innovative and sustainable housing solutions for different types of users.

This project addresses the concerns often raised about microhomes, particularly regarding their limited space and ability to be adaptable to different situations, contexts, and needs. It also demonstrates that these prefabricated modular units can be utilized in various conditions and locations, serving as a baseline for affordable housing, social housing, and other housing typologies. Furthermore, the smaller area of microhomes facilitates energy-efficient building practices, making it easier to reduce energy consumption and promote sustainability.

Overall, this thesis project aimed to provide guidance on this kind of project that, depending on the design, can help have the initial steps in this kind of projects. This project can be a singular unit on a site plot, an extension for existing residential buildings, or a typical module building. It is essential to highlight that this project's sustainable building approach applies different technologies, making it a viable solution

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