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# INTEGRATING COST ESTIMATION ANALYSIS AND DESIGN STRATEGIES IN THE ADAPTIVE REUSE OF A HISTORICAL BUILDING: THE CASE STUDY OF EX-PEROTTI BARRACKS IN BOLOGNA

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**ABSTRACT**
This thesis explores sustainable strategies for urban regeneration through the adaptive reuse and partial reconstruction of the Ex-Perotti military barracks in Bologna. The research originates from the C40 Cities Student Housing Competition[1], which served as the conceptual framework and provided the site context and design objectives for the project. The competition's focus on affordability, sustainability, and inclusive community development inspired the academic exploration of how these principles can be translated into a feasible architectural proposal that meets real-world urban needs. While the competition offered a starting point, the work was developed independently as a comprehensive academic study that combines design innovation with analytical evaluation.

The thesis integrates three main components: architectural design, environmental performance assessment, and cost estimation analysis. Through a structured methodology based on the Analytic Hierarchy Process (AHP), multiple façade and construction technologies were compared in terms of cost, energy efficiency, durability, and implementation feasibility. This systematic analysis informed the final technological choice, demonstrating that a ventilated façade system with thermally modified timber (TMT) panels provided the most effective balance between environmental performance, economic efficiency, and architectural expression.

The cost estimation not only guided material selection but also established a framework for evaluating the life-cycle value of sustainable construction choices, ensuring that the proposed design remains both environmentally and financially viable. Architecturally, the project combines modular new construction with the adaptive reuse of existing masonry buildings, creating a cohesive and energy-efficient student housing complex. Communal spaces, green roofs, and shared courtyards are designed to foster social interaction and improve microclimatic conditions, turning the former military site into a dynamic educational and cultural hub.

Ultimately, this research demonstrates how academic design can bridge theory and practice by integrating competition-driven innovation with cost-informed technological decision-making. It contributes to the broader discourse on sustainable urban housing, showing how adaptive reuse, modularity, and analytical design processes can collectively advance the development of affordable, low-carbon, and socially resilient cities. Looking forward, the framework established in this thesis could be expanded through life-cycle carbon assessment, BIM-integrated cost modeling, and comparative applications in diverse climatic contexts. Future implementations and post-occupancy evaluations could provide valuable feedback to refine the proposed methodology and strengthen the connection between conceptual design, economic analysis, and measurable sustainability outcomes.

# CHAPTER 1. INTRODUCTION

## 1.1 Inspiring to C40 competition

This project was inspired by an architectural competition: C40 Cities challenge, which emphasizes sustainable urban development in response to the global housing crisis and climate change. The thesis considers:

*Global Housing Crisis and Urban Sustainability Challenges*: Rapid urbanization has led to a significant housing shortage worldwide, prompting the need for innovative construction methods that not only address the demand for housing but do so sustainably. This project responds to such challenges by proposing cutting-edge technology from design to construction phase.

*Thermally modified timber Wood panels (TMT) as a Sustainable Material:* Thermally modified timber wood panels (TMT) have gained recognition for their environmental benefits, including carbon sequestration and reduced construction waste. Its prefabrication capabilities enable quicker construction times and less environmental disruption on site. Also, according to climatic data of the site, using these wooden panels will affect positively on cost and energy consumption of the buildings.

*Adaptive Reuse and New Construction: Relevance to Urban Housing:* Adaptive reuse and new construction are key strategies for addressing urban housing challenges. Adaptive reuse repurposes existing buildings, reducing waste and preserving cultural value, while new construction enables modern, purpose-built solutions. This thesis explores the integration of both approaches to create sustainable and efficient housing. It also incorporates ventilated façade technology to improve energy performance and indoor comfort in urban living environments.

The C40 Cities competition is an influential global initiative aimed at tackling the climate crisis through innovative and sustainable urban projects. Organized by the C40 Cities Climate Leadership Group, the competition brings together leading cities, architects, and planners to develop solutions that address climate change while enhancing urban resilience and equity. The focus lies on creating projects that are not only environmentally sustainable but also socially inclusive and economically viable. The C40 Cities competition offered a platform to address urban sustainability issues through innovative architectural solutions, focusing on the use of sustainable materials and energy efficient designs[1].

This project is situated within the Ex Caserma Perotti of Bologna, chosen for its potential to demonstrate the possibility of creating student housing which can integrate into existing urban fabrics without compromising the community's character or the environment.

The Ex Caserma Perotti of Bologna, selected as the project site, presents an opportunity to respond to the competition’s challenges and principles. As an urban area characterized by high population density and diverse architectural contexts, the site encapsulates many of the issues modern cities face: the need for low-carbon construction methods, energy-efficient buildings, and spaces that foster social cohesion. Additionally, there is a growing demand for increased green areas, dedicated bicycle paths, and accessible public buildings that enhance livability, promote active mobility, and support community engagement.

The C40 Cities competition emphasizes the integration of sustainability into all aspects of urban design, from material selection to energy performance and community impact. Furthermore, the competition's focus on innovative solutions provided the impetus for incorporating advanced technologies, such as ventilated facade systems and renewable energy strategies, to enhance the project's environmental and social impact.

This project proposes the adaptive reuse of Ex Caserma Perotti, a former military barracks located in Bologna, Italy, into a sustainable student housing complex. The site, originally built in the early 20th century, consists of several low-rise masonry buildings with generous courtyard spaces and solid structural bones that make it well-suited for transformation. The site is strategically located near several university faculties, public transit lines, and green spaces, making it ideal for student life and urban integration.

The transformation addresses the growing demand for affordable student accommodation in Bologna, where the existing student population exceeds the available housing supply. The intervention covers over approximately 18000 square meters of usable area, and is designed student housing units, including both private rooms and shared rooms, along with communal areas such as kitchens, study lounges, laundry facilities, bike storage, and a public-access courtyard.

| International Students in Bologna (2024/2025 Academic Year) | | | | |
|---|---|---|---|---|
| Institution | Total Students | International Students | % International | Source |
| University of Bologna | ~90,000 | 9,826 | ~10.9% | UniboMagazine, Feb 2025 |
| Johns Hopkins SAIS Europe (Bologna Campus) | ~200 | ~140 | ~70% | SAIS Europe |
| Academy of Fine Arts of Bologna | ~2,000 | ~150 | ~7.5% | ABABO Info Sheet 2025 |
| University of Modena and Reggio Emilia (UNIMORE) | ~26,643 | ~1,500 | ~5.6% | UNIMORE – UNICORE |

Table 1– Number of international students

## 1.2 Requirements framework

The physical program for this project is based on the goals and requirements of international architectural competitions. It reflects the design objectives and includes all the necessary functions to support the intended users. The program outlines the various spaces that must be included in the project to meet both functional and experiential needs. This competition comes from the Comune di Bologna for meeting the demands of accommodation of foreigner students and decreasing the expenses of renting in bologna which leads to designed to accommodate 250 to 500 international (foreign) students, providing them with a comfortable, sustainable, efficient, and culturally responsive environment. The physical program consists of the following main functions:

- ***Entrance Lobby and Reception Area****:* A welcoming space for visitors, students, and staff with clear signage and information.
- ***Administrative Offices****:* Including director's office, staff offices, meeting rooms, and support spaces.
- ***Classrooms and Lecture Halls****:* Multiple sizes to support different types of educational activities.
- ***Library and Study Areas****:* Quiet zones, reading rooms, and digital access points for research.
- ***Dormitories/Student Housing*****:** Comfortable residential units with shared and private options.
- ***Cafeteria and Dining Hall****:* A large eating area with a kitchen, storage, and staff rooms.
- ***Recreational and Common Areas****:* Lounges, social spaces, and multi-use rooms to support interaction and relaxation.
- ***Sports and Fitness Facilities****:* Indoor gym, fitness center, and possibly outdoor sports areas.
- ***Medical and Counseling Services****:* A small clinic or health unit and rooms for student support services.
- ***Workshops and Studio Spaces****:* For hands-on learning, art, or technical training.
- ***Cultural Exchange Spaces****:* Rooms dedicated to cultural activities, exhibitions, or events.
- ***Outdoor Courtyards and Green Areas****:* Spaces that promote relaxation and connection with nature.
- ***Restrooms and Service Rooms****:* Located conveniently throughout the facility.
- ***Storage and Maintenance Rooms****:* For cleaning equipment, supplies, and general upkeep.

## 1.3 Challenges and proposals

This site chose to be working in the thesis because of its unique features, such as its location, social needs in the area, historical, cultural, or natural landmarks near the site, potential for architectural, cultural and educational improvement, and the design challenges it presents. Additionally, to meet the needs of urban regeneration in Bologna caused to choose this site for the thesis. The general and specific plan to do with this site and its buildings intend to redesign or repurpose the existing buildings on the site, introduce new functional spaces, improve the spatial quality, and create a distinctive architectural identity that suits the site's context and users' needs according to needs of Comune di Bologna in order to organize the dormitory of foreigner students.

Many urban areas face a shortage of sufficient and affordable housing, coupled with limited access to essential amenities such as markets, fitness centers, and recreational facilities. These facilities are often expensive, making it difficult for residents to maintain a healthy and balanced lifestyle. In addition, many cities lack sustainable design and environmentally friendly buildings, contributing to higher energy consumption, carbon emissions, and environmental degradation. This combination of social and environmental challenges highlights the urgent need for integrated solutions that address both affordability and sustainability.

To respond to these challenges, this thesis adopts a multi-faceted design approach. To tackle housing shortages and affordability, the study explores:

- Modular construction techniques to reduce building costs and construction time,
- Adaptive reuse of underutilized buildings to maximize existing resources.

To enhance access to daily needs and improve quality of life, the work proposes:

- Mixed-use developments that integrate residential and commercial spaces,
- Walkable community hubs that encourage active lifestyles,
- Affordable on-site facilities within housing complexes,
- Dedicated spaces for social and leisure activities foster community engagement.

To improve sustainability, the thesis incorporates:

- Green building materials,
- Ventilated façades to increase energy efficiency and comfort,
- Renewable energy systems such as solar power,
- Expansion of green spaces to reduce the urban heat island effect and enhance air quality.

Through this comprehensive approach, the thesis aims to promote more affordable, accessible, and sustainable urban environments that improve quality of life while reducing ecological impacts.

## 1.4 Thesis main topics

**1. Affordable Student Housing Design**

This thesis explores innovative housing strategies such as modular construction and adaptive reuse to reduce construction costs and provide accessible accommodation tailored to student needs.

**2. Integration of Mixed-Use Development**

The project investigates the incorporation of markets, gyms, and leisure facilities within or near housing developments to support student lifestyles and reduce the need for long-distance travel.

**3. Enhancement of Community and Shared Spaces**

Design solutions focus on creating flexible communal areas that promote social interaction, collaboration, and well-being among students.

**4. Urban Connectivity and Mobility**

The thesis addresses the importance of walkability, bicycle infrastructure, and public transportation links to ensure students have safe and convenient access to essential services and institutions.

**5. Environmental and Social Resilience**

By increasing green areas and designing adaptable, low-impact buildings, the project aims to improve the urban microclimate and contribute to long-term community resilience.

**6. Sustainable Building Practices**

A major scope includes the implementation of sustainable technologies, such as ventilated façades, green roofs, and renewable energy systems, to minimize the environmental footprint of student housing.

**7. Technological alternative economic evaluation**

This thesis provides a holistic design framework that addresses critical gaps in urban student housing by combining affordability, functionality, and sustainability. Through integrated solutions that respond to economic, social, and environmental challenges, the proposal contributes to a more equitable and livable urban environment for students and the broader community.

# CHAPTER 2. METHODOLOGY

## 2.1 Research methodology

This thesis employs a Design-Based Research Methodology (DBR) that combines theoretical analysis with iterative design practice. As an architectural project dealing with both new and adaptive reuse buildings, the research follows a structured yet flexible process that allows for deep understanding of material, cultural, and environmental conditions. The methodology consists of three major phases which are Analytical Research, Design Exploration and Integration and Evaluation that are explained below.

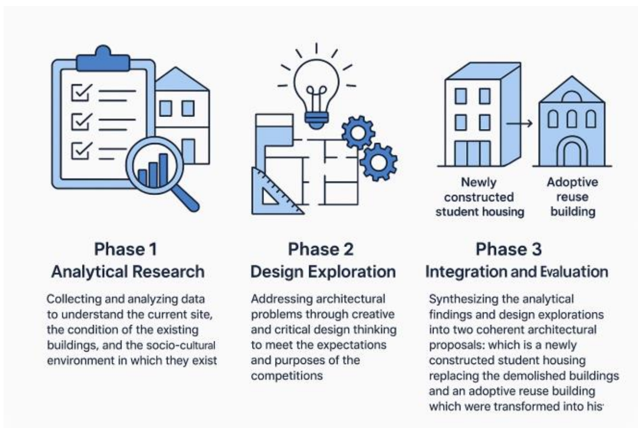



Figure 1 – Three major phases of methodology

## 2.2 Data collections and analysis

A detailed analysis of the existing conditions was carried out through the following steps:


Figure 2 – Data collection phases

This information formed the foundation for both the design decisions and the strategy for either demolition or preservation. A comprehensive site study was conducted to assess the physical, environmental, structural, and cultural conditions of the two existing buildings on the academic campus. The survey included measured drawings, photographic documentation, and analysis of sun path, wind direction, and user circulation patterns. One building was found to be structurally unsafe and unsuitable for reuse, justifying its demolition, while the other showed cultural and architectural value, making it appropriate for adaptive reuse. Environmental data such as climate, daylight, and ventilation potential informed sustainable design strategies. User behavior, spatial functionality, and accessibility were also studied to ensure that both the new and reused buildings would respond effectively to students' needs.

## 2.3 Integrated design approach

The design methodology in this thesis is rooted in an integrated context-responsive, user-centered, and sustainability-driven approach. It combines analytical thinking, creative exploration, and technical problem-solving to address both the demolition and replacement of outdated buildings, as well as the internal transformation of a historically valuable structure.

**Construction system**

The structural system for the site is chosen based on factors such as the function of the building, the span requirements, local environmental conditions like earthquakes or climate, available materials and construction techniques, and overall project budget. The structural system is selected based on various factors:

- **Function of the building:** Large halls require wide spans, so steel or pre-stressed concrete may be suitable.
- **Local climate and risks:** In earthquake-prone areas, lighter or more resilient systems are preferred.
- **Budget and cost-efficiency**
- **Availability of materials and construction methods:** What's accessible in the region impacts your choice.

There are two different kinds of design which are Top-down and Bottom-up. Top-down design starts with a big-picture or high-level concept or overall plan, begins with the overall form, function, and aesthetic of the building then breaks it down into smaller, detailed parts like designing floors, rooms, circulation paths, materials, and technical details. Bottom-up design starts with designing individual parts or units and then combines them to create the complete building. Start by designing individual rooms or functional units based on specific needs. Then combine and arrange these to create larger systems or whole buildings. Often used in modular, prefabricated approaches[2].

The design method that was chosen is top-down, meaning that start with a general concept, massing, and layout before moving into detailed design decisions. This approach helps maintain a clear overall vision throughout the design process also, facilitates coordination across disciplines and Reduces risk of redundant or conflicting subsystems.

**Connection system**

A connection system refers to how different building elements (like walls, floors, columns, and beams) are joined together structurally and functionally. Proper connections ensure stability, safety, load transfer, and durability of the building. Each material (wood, steel, concrete, drywall, etc.) has its own method of connection based on its properties. Wood elements are connected using nails, screws, bolts, metal plates, or dowels. For larger structures, steel connectors or timber joinery (like mortise and tenon) may be used. Engineered wood, like TMT or glulam, often requires custom steel connectors for strength and fire safety[3].

There are types of structural or non-structural connections that can be used in the buildings:

- **Rigid (Fixed) Connections** – Resist rotation and movement, used for structural stability.
- **Pinned Connections** – Allow rotation but not movement, used in frames and trusses[4].
- **Sliding or Expansion Joints** – Allow movement due to temperature or settlement, common in facades and long spans.
- **Mechanical Fasteners** – Bolts, screws, nails, anchors, used in most materials.
- **Welded or Cast Connections** – For steel and concrete elements.

Proper connection systems must manage moisture movement, thermal expansion, and fire resistance. Drywall typically mounts to metal or wood studs using clips that allow movement and reduce thermal bridging[5]. For concrete substrates, expansion anchors or concrete screws are used; their design must consider substrate conditions (e.g., cracks, reinforcement) to ensure secure and durable connections. These connection systems are designed to allow for movements such as thermal expansion or settlement to prevent cracking[6].

**Facade**

Technological facades are modern, advanced building envelopes that use innovative materials, durable, and sustainable systems. These facades go beyond traditional walls. They can include double-skin systems, dynamic shading, solar panels, ventilated cladding, and smart glasses. They're designed to improve energy efficiency, comfort, and aesthetics of a building. In the case of thesis (Student housing), facades help reduce energy costs, improve indoor air quality, and require low maintenance, which is ideal for buildings with many occupants[7].

These facades also give a modern look, attracting students and meeting university sustainability goals. The advantages of these facades are:

- Energy Efficiency
- Sustainability
- Durability
- Aesthetic Appeal

- Smart Features

The most common facade types in student housing are[8]:

- Double-skin façades (for thermal insulation and ventilation)
- Photovoltaic facades (generate electricity)
- Dynamic shading systems (adjust to sun conditions)
- Ventilated rainscreens (keep moisture out and allow air flow)

**Materials**

Sustainable and Eco-Friendly Materials: These are used to reduce environmental impact.

- **Thermally Modified Timber (TMT)**: Durable, chemical-free wood for cladding and facades.
- **Recycled Steel**: Structural and decorative, often used in adaptive reuse.
- **Reclaimed Wood**: From old buildings, reused in walls, flooring, or furniture.
- **Cross-Laminated Timber (CLT)**: High structural strength with sustainability, offering reduced carbon emissions, fast construction, and excellent thermal performance

Modern materials: Used for performance, energy efficiency, and smart building systems[9], [10].

- **Glass Facades**: Often double or triple-glazed, sometimes integrated with solar panels.
- **Ventilated Cladding Systems**: Like aluminum composite panels (ACP) or fiber cement, great for energy-efficient facades.
- **Phase Change Materials (PCM)**: Embedded in walls to store/release heat.

Materials in Adaptive Reuse Projects: Focus on preservation, integration, and sustainability[10], [11].

- **Exposed Brick / Concrete**: Often retained from the original structure for an industrial look.
- **Steel Reinforcement**: Added to old structures to improve strength.
- **Recycled Materials**: Such as reclaimed bricks, wood, and even tiles.

**Renewable energy**

Student housing facilities present an excellent opportunity for implementing renewable energy systems due to their consistent energy demands and potential for educational integration. Various technologies can enhance sustainability, reduce utility costs, and promote environmental awareness among students. Solar energy is the most adaptable option, with photovoltaic (PV) panels converting sunlight into electricity for general use, and solar water heaters reducing energy consumption for domestic hot water needs. These are particularly suitable for buildings with accessible rooftops and high hot water usage[12].

Geothermal systems, such as ground source heat pumps, provide a stable and efficient method for year-round heating and cooling, especially in campuses with available land for installation[13]. Wind turbines, though dependent on consistent airflow, can complement solar systems and offer additional renewable capacity in suitable environments. To enhance system efficiency, battery storage systems ensure energy availability even during low production times, while smart energy management systems monitor and optimize consumption, reducing waste and improving overall building performance. Together, these renewable energy solutions can significantly reduce the environmental footprint of student housing while supporting educational and financial sustainability goals.

| Number | Renewable Energy Source | Device | Function | Suitability in Student Housing | Key Benefits |
|---|---|---|---|---|---|
| 1 | Solar Energy | Photovoltaic (PV) Panels | Convert sunlight into electricity | Rooftops of dorms or apartment buildings | Reduces electricity bills, low maintenance, can be paired with storage |
| 2 | Solar Thermal | Solar Water Heaters | Use solar power to heat water | High hot water usage areas (bathrooms, kitchens) | Saves energy on water heating, simple installation, eco-friendly |
| 3 | Geothermal Energy | Ground Source Heat Pumps (GSHPs) | Extract heat from the ground for heating/cooling | Campuses with open land or retrofitting potential | Highly efficient heating/cooling, long lifespan, stable year-round output |
| 4 | Wind Energy | Small Urban Wind Turbines | Generate electricity from wind | Areas with steady wind (e.g. coastal or elevated locations) | Supplements solar, compact models available, renewable and clean |
| 5 | Energy Storage | Battery Storage Systems | Store excess renewable energy | Anywhere solar/wind systems are installed | Reliable backup, maximizes renewable usage, supports grid independence |

Table 2 – Types of Renewable energy source

## 2.4 Cost estimation approach

Cost estimation analysis is the process of forecasting the financial resources required to complete a project. It includes calculating the total expected costs for labor, materials, equipment, overhead, and other factors throughout the project lifecycle. This analysis is critical in architecture, engineering, and construction, for considering the total cost and making plan for the construction future to suitable and cost able results.

Purpose of Cost Estimation

- Budget Planning: Ensures the client and team understand the investment needed.
- Feasibility Assessment: Determines if a project is financially viable before execution.
- Resource Allocation: Helps in allocating funds appropriately across various phases.
- Bidding and Tendering: Used by contractors to propose competitive offers.
- Risk Management: Identifies potential financial risks and cost overruns early.

**Cost Estimation Methods**

In this thesis, the parametric cost estimation method is applied to evaluate construction costs based on measurable parameters such as area or volume. For key building elements like facades unit costs are assigned per square meter. After calculation, this method provides the cost per square meter for some element, as well as the total estimated construction cost of the project. This approach is efficient for early-stage design analysis and cost comparison between alternatives. For ventilated facades, which are increasingly used in contemporary construction, cost plays an especially critical role. These systems can offer long-term benefits such as improved energy efficiency and building durability, but their initial and overall expenses remain a central concern for investors, designers, and project managers.

Because building projects typically involve limited budgets and strict financial planning, a clear understanding of facade costs is essential for making reliable decisions. Without a structured approach, there is a risk of underestimating or overlooking important financial implications, which can affect the success of the project in both the short and long term. To address this need, decision-making methods that allow systematic cost evaluation are highly valuable. The Analytic Hierarchy Process (AHP) provides a useful framework for this purpose. AHP is designed to handle complex decision problems by organizing them into a hierarchy and allowing for structured comparisons. In the context of ventilated facades, this method can be applied specifically to the assessment of cost, ensuring that economic considerations are clearly prioritized and consistently evaluated.

**Cost estimation conclusion**

In conclusion, Cost estimation analysis is a foundational tool for project control and success. It informs budget strategies, supports feasibility decisions, and allows stakeholders to understand financial commitments. Although estimation carries uncertainty, systematic approaches, digital tools, and professional judgment can greatly increase its reliability

# CHAPTER 3. CASE STUDIES

## 3.1 Case study 1 (Ex Caserma Mameli - Milan)

The Ex Caserma Mameli in Milan was initially a substantial military barracks utilized by the Carabinieri. Eventually, the complex fell into disuse, resulting in a gap within the city's urban landscape. The thesis project envisions the barracks as a mixed-use living space that accommodates both student housing and assisted living facilities for the elderly. The design improves public access by transforming previously restricted military courtyards into communal areas featuring green spaces, cafés, and a library. Existing structures are upgraded with energy-efficient enhancements, including improved insulation and strategies for natural lighting[14].

1. General Information

- Title: Former Mameli Barracks – Urban Redevelopment
- Authors / Subjects: Masterplan: Onsite studio (A. Lunati, G. Floridi)/initiative: Ardian (purchased by CDP Real Asset)
- Location: Viale Giovanni Suzzani 125, Niguarda–Bicocca district, Milan
- Land Area (PA): ~101,490 m²
- Minimum transfer of 50% of the land area equal to a minimum of 50,745 m²
- UT Index (project): 0.70 m²/m²
- Planned Gross Floor Area (GFA): ~71,043 m² (35,522 m² for urban uses, 35,522 m² for social housing)

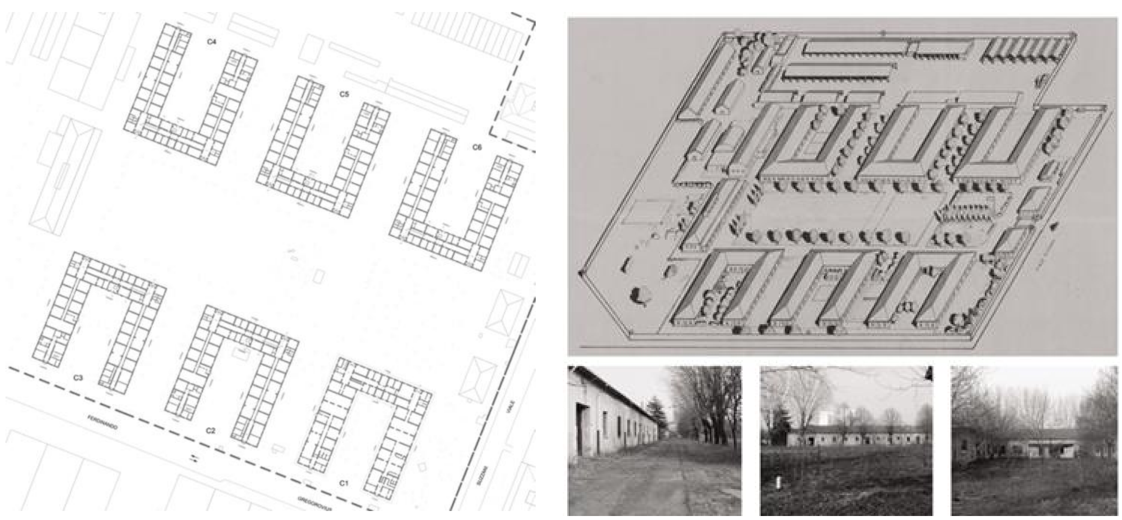


Figure 3 – Ex caserma Mameli (existing)

2. Building Type / Functional Program

- Type: Regeneration of a military complex in an area with a mixed-use function
- Planned Use: ~50% social housing, 42% residential, 8% tertiary/commercial/public services
- Amenities: public spaces, greenery, neighborhood amenities

3. Project Concept

- Urban Objectives: Restoration of the urban fabric, regeneration of brownfield sites, insertion of new differentiated volumes
- Public Space: Large central urban park as a supporting structure

Figure 4 – Ex caserma Mameli (3D- existing)

4. Spatial and Distribution Solutions

- Reuse + New Construction: Selective renovation of existing buildings, new buildings integrated into the context
- Permeability: Pathways pedestrian and cycle paths connecting the area to Niguarda-Bicocca and public transport

5. Technical/construction aspects

- Techniques/materials: building retrofit + new structures; To be defined in the implementation phases
- Setting: Northeast Milan area, well served by the road and infrastructure system

Figure 5 – New ex caserma Mameli

6. Critical Issues and Strengths

- Strength: scale of the project =social mix, services, greenery, reuse
- Critical Issues: procedural complexity, need to balance economic needs between social housing and the market

7. Project Costs and Expenses

- The municipal resolution and the urban planning plan provide for costs of nearly €11 million, primarily for the renovation of the barracks, urban planning interventions, and the creation of the park and public spaces. unione-immobiliareUrbanfilemilanoevents.it
- Specifically, urban development works worth over €14 million are earmarked, including roads, utilities, road improvements, and green space redevelopment.
- The "barracks" C1, C2, and C3 (approximately 11,650–11,600 m²) will be renovated for educational, cultural, and social services and will be made available to the municipality. Resolutions Archive[14].
- The central public park will cover approximately 30,950–31,000 m², with an additional 3,000 m² designated for plazas and green spaces. Furthermore, the tree budget includes the planting of 600 new trees, in addition to the existing 476.

## 3.2 Case study 2 (Ex Caserma Sani - Bologna)

The Sani Barracks is a large, disused military complex comprising 26 buildings of varying sizes, construction periods, types, and state of preservation. These include warehouses, row buildings, and specialized production facilities, including two silos. The area features large green spaces crossed by several paved paths and yards.

This project aims to redevelop the former Sani barracks in Bologna into a new segment of a long green park that stretches along the North-South axis of the city, bridging the Bolognian district and the fair district. The design features a clear layout defined by four gardens and two pedestrian pathways around which the buildings are arranged. The largest structure is a public secondary school located in the North-West corner, encircled by a forest of trees yet easily accessible from the Bolognian district. Special attention is focused on developing housing typologies that cater not only to traditional families but also to temporary residents, long-term immigrants, students, and others interested in experimenting with communal living arrangements[15].


Figure 6– Ex caserma Sani (location & 3D)

1. General Information

- Title: Redevelopment of the former barracks Sani into a mixed-use neighborhood
- Stakeholders: CDP Investimenti SGR (client), international competition 2016–2017 (DOGMA winner)
- Location: Via Ferrarese / Via Stalingrado, Bologna (over 10 hectares)
- Procedure status: POC 2015–2016, competition 2016–2017, PUA authorized 2020
- Land area: 46,087 m²
- Minimum transfer of 50% of the land area equal to a minimum of 50,745 m²
- Gross Floor Area (GFA): > 110,000 m² (70% housing and 30% administrative, retail, and artisanal service spaces)

Figure 7– Ex caserma Sani (existing)

2. Building type / Functional program

- Mix: residential, offices, local retail, new urban park, school; Enhancement of valuable buildings

3. Project concept / Guiding idea

- Urban structure: 4 gardens + 2 pedestrian axes (North-South linear park)

4. Spatial and distribution solutions

- Internal pedestrian/cycle network, significant reduction in car traffic; building fronts facing gardens and axes

5. Technical and construction aspects

- Implementation phases via PUA (Urban Development Plan); reuse + new construction; urbanization works to be carried out by the implementing entity
- Linear Park as climate infrastructure; soft mobility, shaded and vegetated spaces

6. Critical issues and strengths

- Strengths: urban scale, functional mix, school/park facilities
- Critical issues: procedural complexity, coordination of reuse/new


Figure 8– New ex caserma Sani

7. Project Costs and Expenses

The redevelopment of Ex Caserma Sani in Bologna is a large-scale urban regeneration project encompassing approximately 10 hectares of land and over 50,000 m² of built area. The project includes the adaptive reuse of existing buildings, construction of new residential and commercial spaces, and the creation of public and recreational areas. Estimated construction costs range from €81 million to €135 million, depending on the complexity of restoration, materials, and infrastructure. These figures reflect both the scale of the project and the investment required to integrate historical preservation with modern urban development.

## 3.3 Case study 3 (Ex Caserma Garibaldi - Milano)

The Ex Caserma Garibaldi complex covers an area of approximately 20,000 square meters. The redesign repurposes around 60% of the facility to introduce new civic and cultural functions. Some original structures in poor condition were carefully dismantled to accommodate new developments. The neoclassical façade was preserved and restored to maintain the historical integrity of the building. Sustainable materials were selected throughout the project to minimize environmental impact, and energy-efficient systems were integrated to reduce the carbon footprint[16].

Figure 9– Ex caserma Garibaldi (existing)

1. General Information

- Title: Former Garibaldi Barracks
- Author: Studio Beretta Associati
- Client: Università Cattolica del Sacro Cuore (Catholic University of the Sacred Heart
- Location: Piazza Sant'Ambrogio 5, Milan
- Planned Gross Floor Area (GFA): 53,000 m²

2. Building Type / Functional Program

- Type: Adaptive reuse / historic building conversion; military barracks converted into university campus/didactic + services.

- Planned Use: University campus functions: classrooms / lecture halls, main auditorium ("aula magna"), service spaces, common spaces, amenities for students.
- Amenities: Large-capacity lecture halls (some underground) including an aula magna with ~700-776 seats.
- Emphasis on restoring/correcting historic architectural features; also, sustainability systems: LEED Gold certification, WELL protocol, variable-air systems, potential geothermal use, acoustic comfort, natural lighting.

3. Project Concept

- Urban Objectives: To expand the Università Cattolica's campus (complement / synergy with historic campus at Largo Gemelli) by using a central, heritage-rich building. Also Preserve the historic structure, its architectural identity, layout (courtyards, roof forms), while adapting it for modern educational uses.
- Public Space: The north courtyard will include an underground portion with large halls, and a glazed volume above serving as a light well / vertical circulation hub. Also, main entrance on Piazza Sant'Ambrogio preserved / enhanced, opening up the colonnade more fully.

4. Spatial and Distribution Solutions

- Emphasis on light delivery: corridors with natural light, light well in the north courtyard.
- Removing additions from the 1970s in the historic building to restore the original courtyard geometry.
- Vertical circulation (stairs, lifts) placed within natural hubs / atria to facilitate movement.

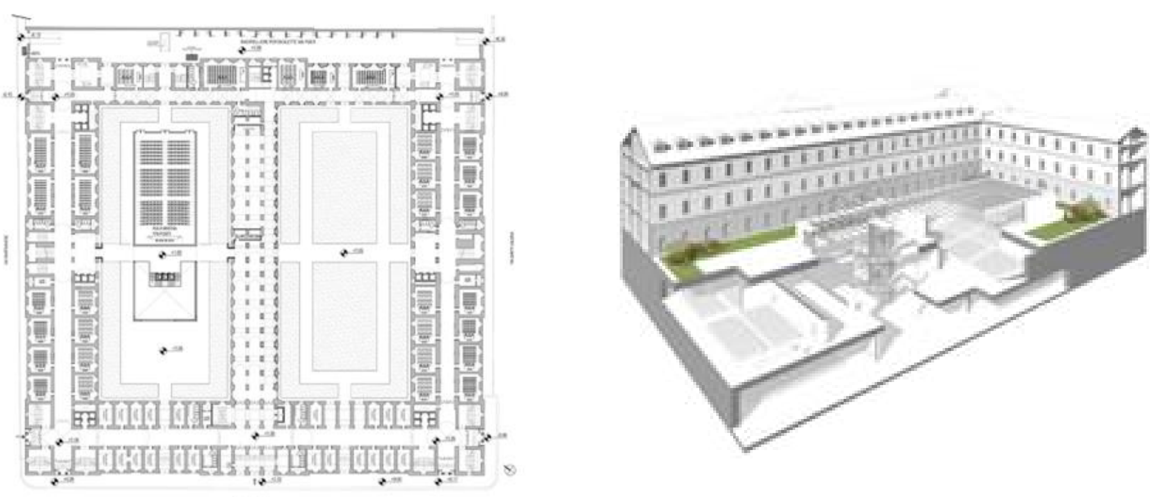


Figure 10– Ex caserma Garibaldi (new plan and 3D)

5. Technical/construction aspects

- Techniques/materials: Conservation of historic masonry, façades, and vaulted ceilings; seismic reinforcement, roof reconstruction with lighter steel/timber systems, and insertion of new underground reinforced-concrete spaces in the north courtyard.

- Setting: Use of traditional brick and plaster finishes alongside modern systems; integration of recycled/low-emission materials, acoustic treatments, high-efficiency HVAC (with potential geothermal), and LEED Gold / WELL certification targets.

6. Critical Issues and Strengths

- Strength: Good spatial layout, sustainability and certification commitments, heritage value
- Critical Issues: Complexity of structural / seismic upgrades, Costs are presumably high, heritage constraints

7. Project Costs and Expenses

The Università Cattolica del Sacro Cuore purchased the former Caserma Garibaldi in Milan in 2015 for €88 million. The structural and engineering works, entrusted to Redesco, are valued at around €55.5 million. The first phase of redevelopment, covering approximately 11,500 m² in the Santa Valeria wing, requires an investment of over €30 million, partly due to delays that have increased costs. Considering the overall surface of about 53,000 m² and the scope of restoration, seismic reinforcement, and modern systems installation, the final expenditure is expected to be substantially higher as the project progresses.

Figure 11 – New ex caserma Garibaldi

| Case study 1 (Ex Caserma Mameli - Milan) | |
|---|---|
| Pros | Cons |
| urban regeneration with mixed uses<br>extensive public green spaces<br>energy-efficient building upgrades | complex procedures<br>economic balance challenges<br>unclear technical implementation |
| Case study 2 (Ex Caserma Sani - Bologna) | |
| Pros | Cons |
| connects city districts<br>diverse housing options<br>strong educational and community focus | historic building constraints<br>long timeline<br>high resource requirements |
| Case study 3 (Ex Caserma Garibaldi - Torino) | |
| Pros | Cons |
| Heritage Preservation<br>Educational & Civic Focus<br>Sustainability & Modern Systems | High Costs<br>Complex Structural Work<br>Heritage Constraints |

Table 3 – Pros and cons of case studies

# CHAPTER 4. DESIGN PROCESS

## 4.1 Context of Ex Caserma Perotti

The proposed transformation pertains to a section of the former 'G. Perotti' barracks area, a complex dating back to the early 1940s, located on the eastern outskirts of Bologna near the ring road and motorway Junction. The area is located on the outskirts of a portion of the city, planned and built post-World War II and is characterized by a robust network of green spaces, slow mobility routes and a strong presence of services for the population. To the south lies a district designated for Affordable and Popular Housing constructed in the 1970s, complemented by Detailed Plans established in response to Bologna's 1985 PRG.

In the immediate context, several initiatives are underway that will shape the future configuration of the area such as the construction of a complex designed for public functions and the offices of the Revenue Agency, in another section of the former 'Perotti' barracks. The creation of new services and planned networking interventions make the area particularly attractive for green and inclusive urban regeneration, including services, public spaces and housing[17].

Figure 13 – Location of the Ex caserma Perotti

Figures 14 – Existing buildings

## 4.2 Urban context

The neighborhood exemplifies the inherent challenges of high urban density, characterized by constrained land availability and an escalating demand for residential development. The built environment is predominantly composed of mid-rise and high-rise structures, generating a compact urban fabric that necessitates strategies for optimized spatial efficiency. Nevertheless, the presence of localized green areas and pedestrian-oriented corridors offers valuable potential for incorporating biophilic principles and fostering community-oriented spatial interventions within the project context.


Figure 15– Location of different buildings surrounding site

## 4.3 Climate and Environmental Factors

Bologna has a humid subtropical climate with hot summers and cold winters. Based on EPW data, the average annual temperature is about 13°C, with summer highs around 31.7°C and winter lows down to −3.1°C. The city receives approximately 1,142 kWh/m² of global horizontal solar radiation annually, with 53.7% being diffuse, indicating moderate sun exposure. These conditions highlight the need for good insulation, solar control, and natural ventilation in building design.

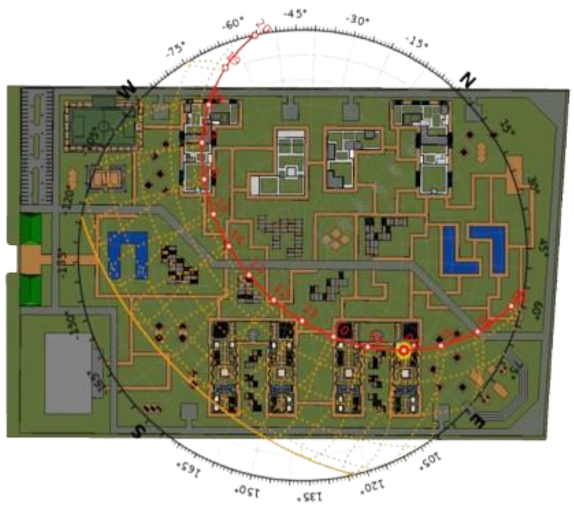


Figure 16– Solar path of site

**Wind diagram**

Wind rose diagram represents the frequency and direction of winds at specific location over a period of time. These diagrams can be effective in order to understanding wind patterns and other various fields like construction and environmental studies. The diagrams showed data in different seasons according to the climatic database of Bologna.

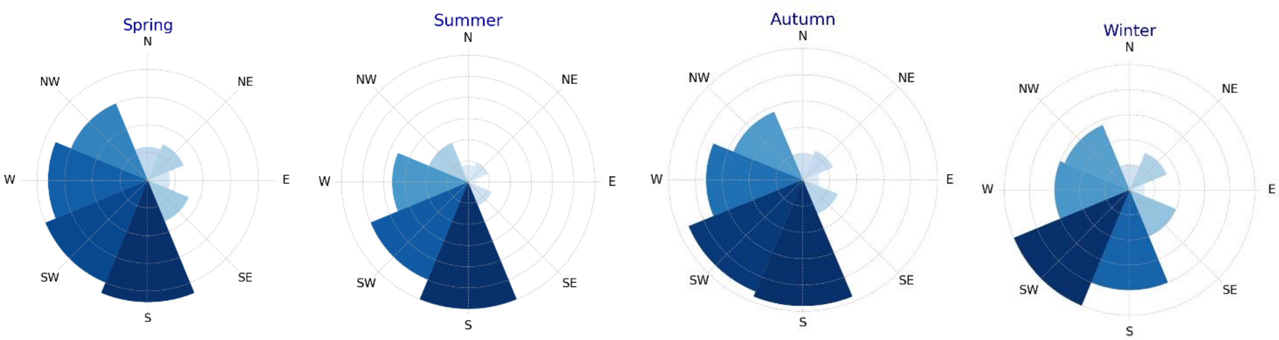
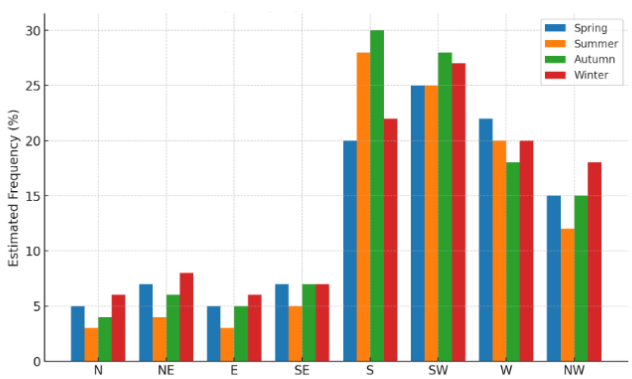



Figure 17 – Wind diagram of site



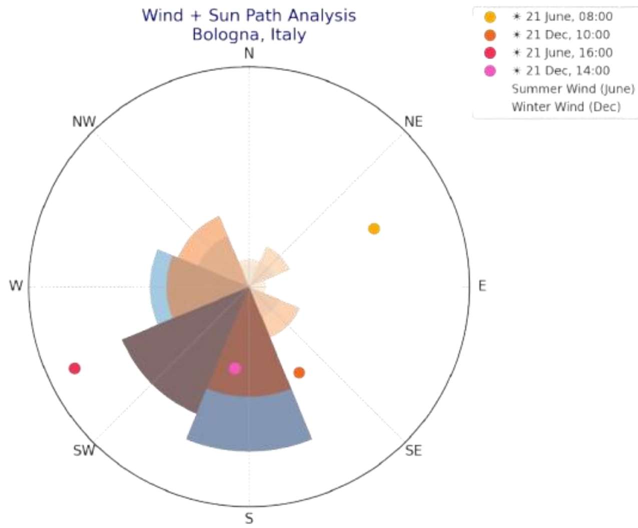



Figure 18– Wind and sun path analysis

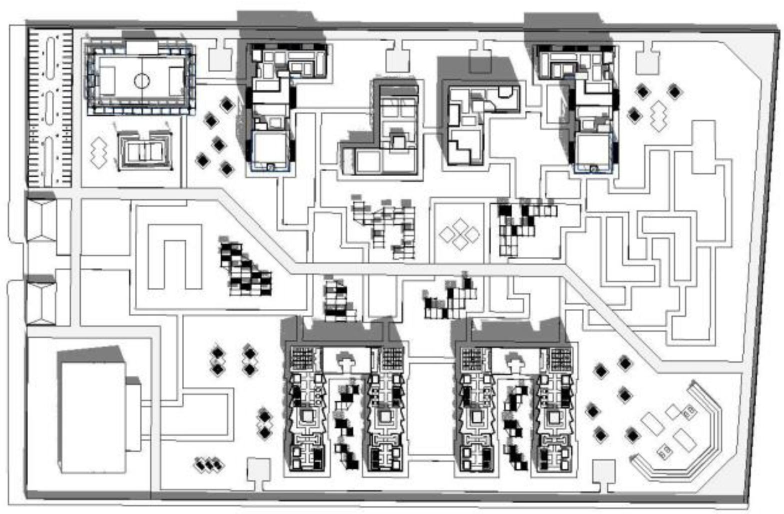
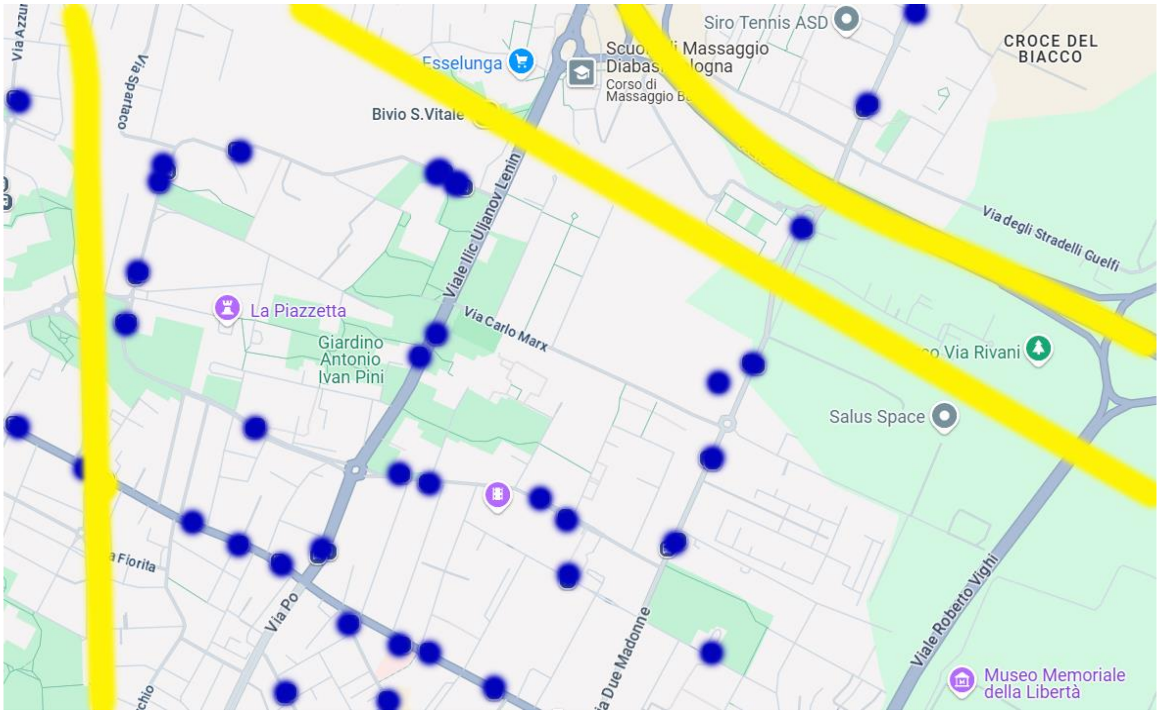


Figure 19– Shading of buildings

## 4.4 Transportation and Connectivity

Ex Caerma Perotti demonstrates strong integration within Bologna's comprehensive public transport network, encompassing metro, tram, and bus services. Such connectivity advances the project's sustainability agenda by prioritizing collective mobility over private vehicle use, thereby contributing to the reduction of carbon emissions. Moreover, the site's strategic proximity to primary roadways and established cycling infrastructure enhances overall accessibility while promoting multimodal mobility solutions for future residents.




Highway, train path

Bus stations

Figure 20– Main streets and highways


Highway, train path

Site

Main streets

Figure 21 – Bus stations and highways

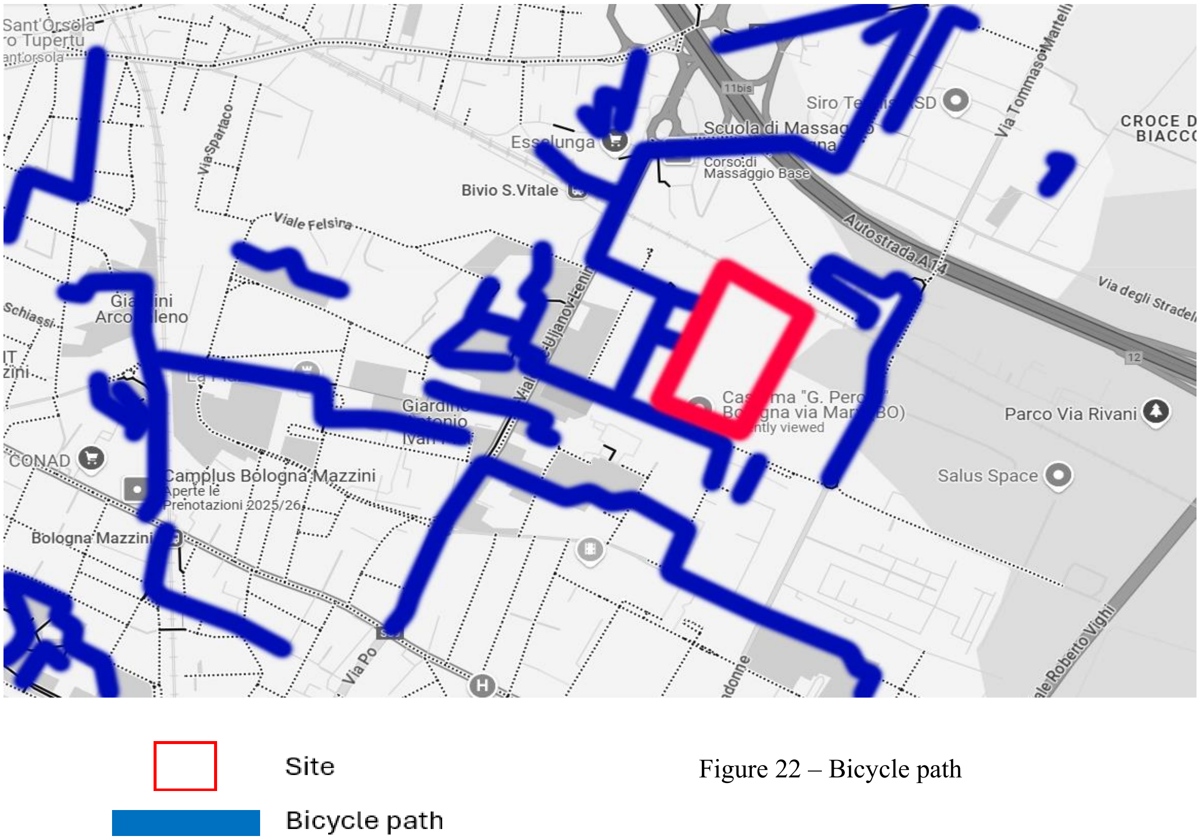



Figure 22 – Bicycle path

## 4.5 Influence of the Site on Design Decisions

The urban fabric and architectural variety of Ex Caserma Perotti played a key role in shaping the decision to employ a modular design strategy, organizing micro-housing units into dense and efficient clusters. The presence of green areas and pedestrian pathways informed the inclusion of shared outdoor spaces and landscaped elements within the development. In addition, the site's strong connectivity and favorable climatic conditions supported the use of sustainable construction materials, such as TMT, in combination with advanced energy-efficient technologies, ensuring alignment with the project's environmental and social aspirations.

**Challenges**: The high population density and limited land availability pose constraints on design flexibility. Additionally, integrating the student housing complex design into the existing urban fabric without disrupting the neighborhood's character with several public spaces requires careful planning.

**Opportunities**: The site's location, connectivity, and emphasis on sustainability present unique opportunities for creating a model urban housing project that sets a benchmark for sustainable design in dense urban environments.

# CHAPTER 5. ARCHITECTURAL DESIGN

## 5.1 Bridging Heritage and Modernity

The housing strategy accommodates between 250 and 500 students through a modular system that integrates both shared rooms and studio apartments (Monolocale) within both the adaptive reuse and the new buildings. This dual typology responds to the diverse needs of contemporary students balancing affordability, flexibility, and cultural living preferences. Shared rooms promote collective living, encouraging daily interaction, collaboration, and cross-cultural exchange. In parallel, studio units provide privacy and independence, meeting the expectations of international and Erasmus students as well as those seeking a more autonomous lifestyle. In the adaptive reuse buildings, the design preserves and improves a key external wall and maintains the overall historic form, ensuring that the site's memory and architectural identity are respected.

Within this framework, new interior programs introduce modular housing in dialogue with the past. The new buildings, by contrast, explore contemporary form-making, shifting in shape while integrating the same modular housing types to ensure cohesion across the site. By distributing both typologies across historic and contemporary structures, the project avoids a rigid separation between "traditional" and "modern" living. Instead, it establishes a cohesive and inclusive residential ecosystem, where preserved heritage walls and forms stand alongside innovative architecture, equally supporting community and individuality. This modular approach ensures adaptability to different financial circumstances and social preferences, while reinforcing the thesis concept of Bridging Heritage and Modernity demonstrating that old and new architecture can together host a flexible, sustainable, and diverse student community.

**Contextual Integration**:

- **New Buildings**: Linear forms create courtyards for student interaction, oriented to maximize sunlight/shading.
- **Adaptive Reuse Buildings**: Preserve historic façades while retrofitting interiors for modern housing needs.

In the the Spatial Strategy site's juxtaposition of new buildings (L-shaped) and adaptive reuse buildings **(**C**-**shaped) presents an opportunity to explore architectural "layers" temporal (past/future), functional (private/communal), and material (old/new). The concept frames the design as a living ecosystem where history and innovation coexist, fostering a dynamic student community.

**Spatial Layer**: Courtyards as Connectors

- **Hybrid Circulation**: The L and C shapes create a chain of interconnected courtyards, each with a distinct identity:

- **Memory Garden**: Landscaped with native plants and reclaimed materials.
- **Innovation Plaza**: Hardscaped for events, with movable furniture.
- **Pathways**: Meandering walkways trace the original site circulation (echoing historic paths) but widen into modern social nodes.

**Programmatic Zoning:**

- Ground Floors (Both Zones): Shared mensa, public and private study room, bar, game room maker spaces to encourage interaction among users.
- Upper Floors: Tiered privacy (private and shared suites in old buildings, micro-studios in new).
- Roof: there are green roofs in adoptive reuse and new buildings in order to increase the level of sustainability and green spaces of site which can be also effective for the students.
- Passive Social Design: Window placements in L/C shapes frame views into courtyards, creating "natural surveillance" and chance encounters.

**Material Layer**:

- New buildings: TMT (Thermally modified timber) for speed of installation and sustainability, with steel/concrete accents that weather over time (refer to figure number 42 showing material stratification and façade composition).
- Old buildings: Preserved and then restored historic external walls and converted to sustainable ones with suitable strategies (refer to figure number 44 showing material stratification and façade composition).

## 5.2 Master Plan

The site plan for Ex-Perotti military barracks project was meticulously crafted to align principles of sustainability and community integration. The layout was strategically designed to optimize land use and foster a sense of community among residents, considering the urban context, improvement of green area, environmental considerations, and the project's overarching sustainability goals.

Urban Context and Integration: Set within the vibrant neighborhood of Via Carlo Marx in Bologna, the project seeks to weave itself into the existing urban fabric through strategies of connectivity and permeability. A system of pedestrian, cycling, and vehicular axes organizes the site, establishing both primary and secondary pathways that structure movement and create a legible spatial hierarchy. At their intersection, a central node emerges as a communal gathering point—an urban "heart" that fosters encounters and strengthens the sense of community. Complementing this network, modular bicycle parking is integrated near the student residences, while a car park for external users is positioned at the site entrance to reduce internal traffic and noise. Acoustic strategies further enhance comfort, ensuring that outdoor spaces remain welcoming and vibrant. In this way, the site becomes not only an efficient framework for circulation and access, but also a dynamic landscape of shared spaces that balance mobility, sustainability, and social interaction.

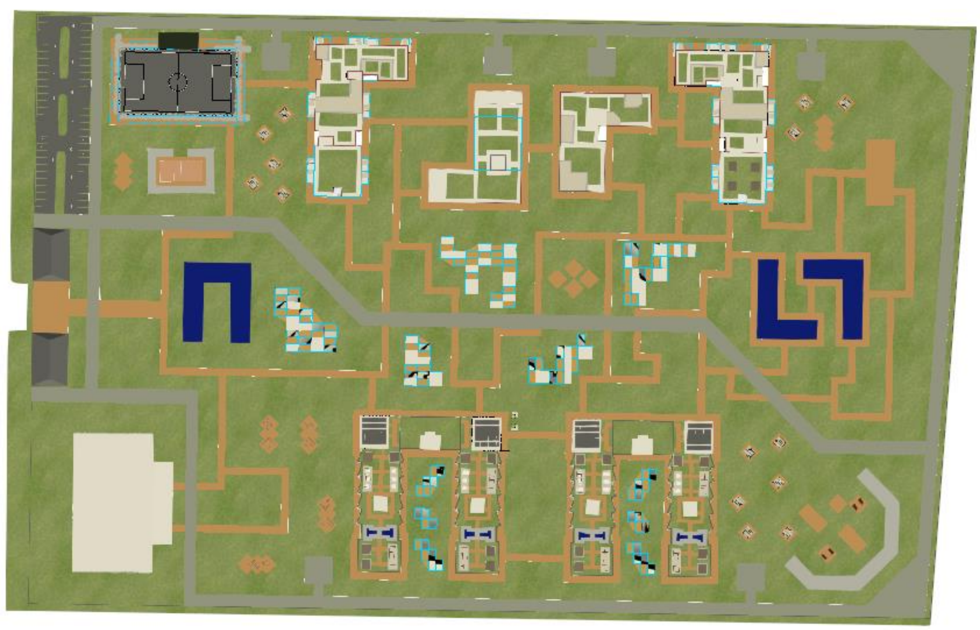


Figure 23 – Master plan

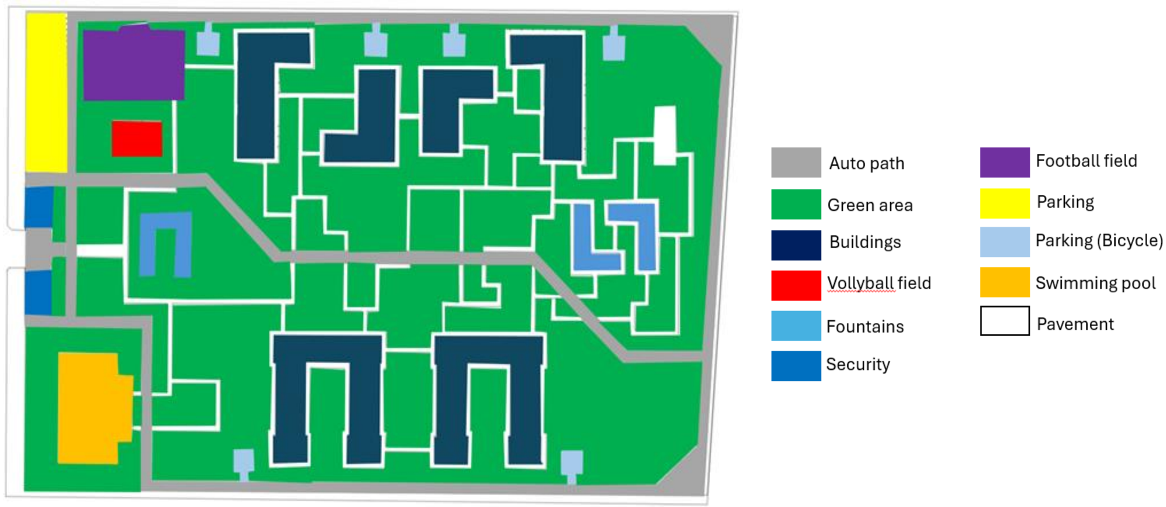



Figure 24 – Site elements

*Community Spaces*: The convergence of the pedestrian axes forms the central communal heart of the site, a space that is visually connected to the surrounding buildings through shared balconies overlooking it. This spatial arrangement transforms the node into both a social catalyst and a visual connector, extending views toward Ex Caserma Perotti and reinforcing ties to the broader urban context. Conceived as adaptable landscapes, the communal areas accommodate a range of activities, nurturing everyday encounters and cultivating a strong sense of community belonging.

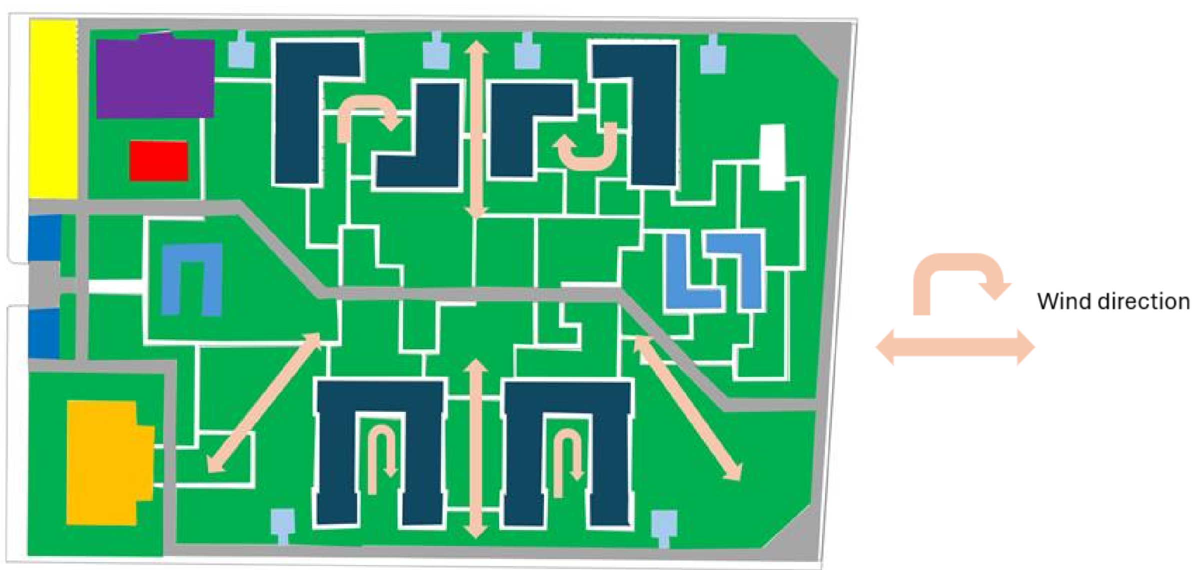



Figure 25 – Wind direction

*Environmental Considerations*: The orientation and placement of the buildings were carefully determined through solar and wind analyses, ensuring optimal natural light and ventilation. This strategy minimizes dependence on artificial lighting and mechanical cooling, directly supporting the project's commitment to energy efficiency.

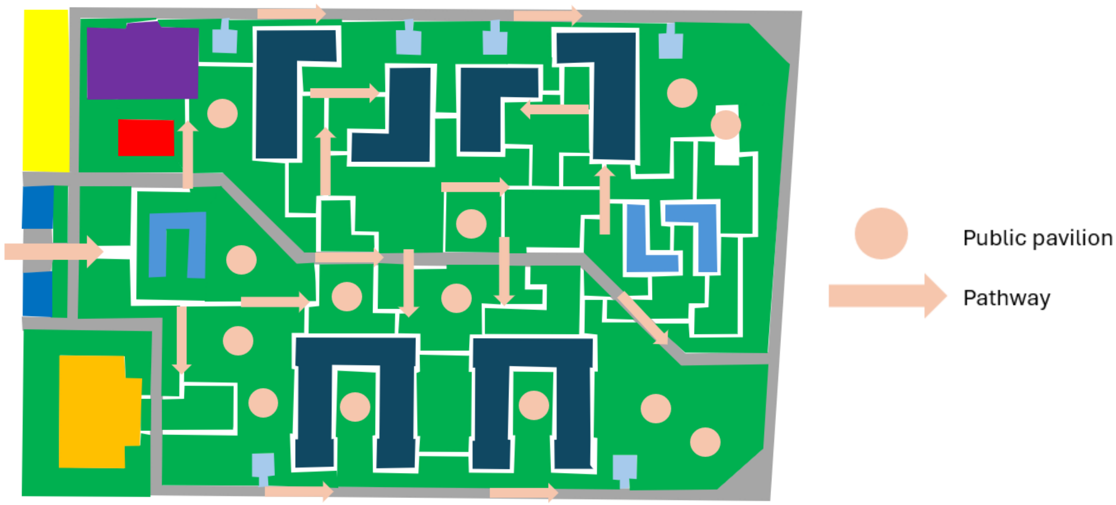
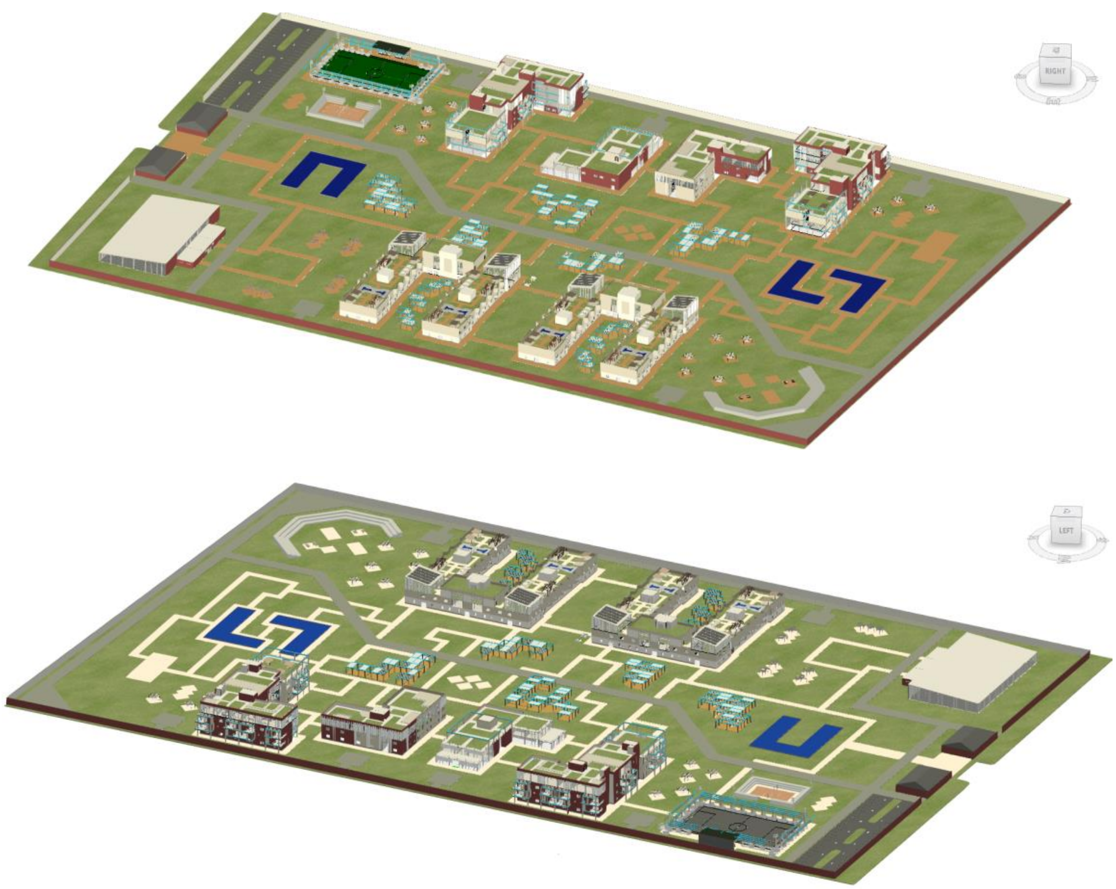



Figure 26– Site access

*Accessibility and Connectivity*: The pedestrian pathways are integrated with the city's broader transit network. This integration encourages a car-free lifestyle among residents, supporting sustainability by reducing fossil fuel dependence and enhancing residents' quality of life through improved air quality and reduced traffic noise.



Figures 27– Viewer Perspective of the area

Figure 28– site plan

## 5.3 Building volumes concept

The building form is generated through the composition of simple geometric blocks. Starting from pure volumes, parts are added, subtracted, and carved to create courtyards, light wells, and terraces. This process defines clear functional zones and creates spaces for interaction and circulation. The final L-shaped configuration balances solid and void, combining functional efficiency with an open architectural expression.

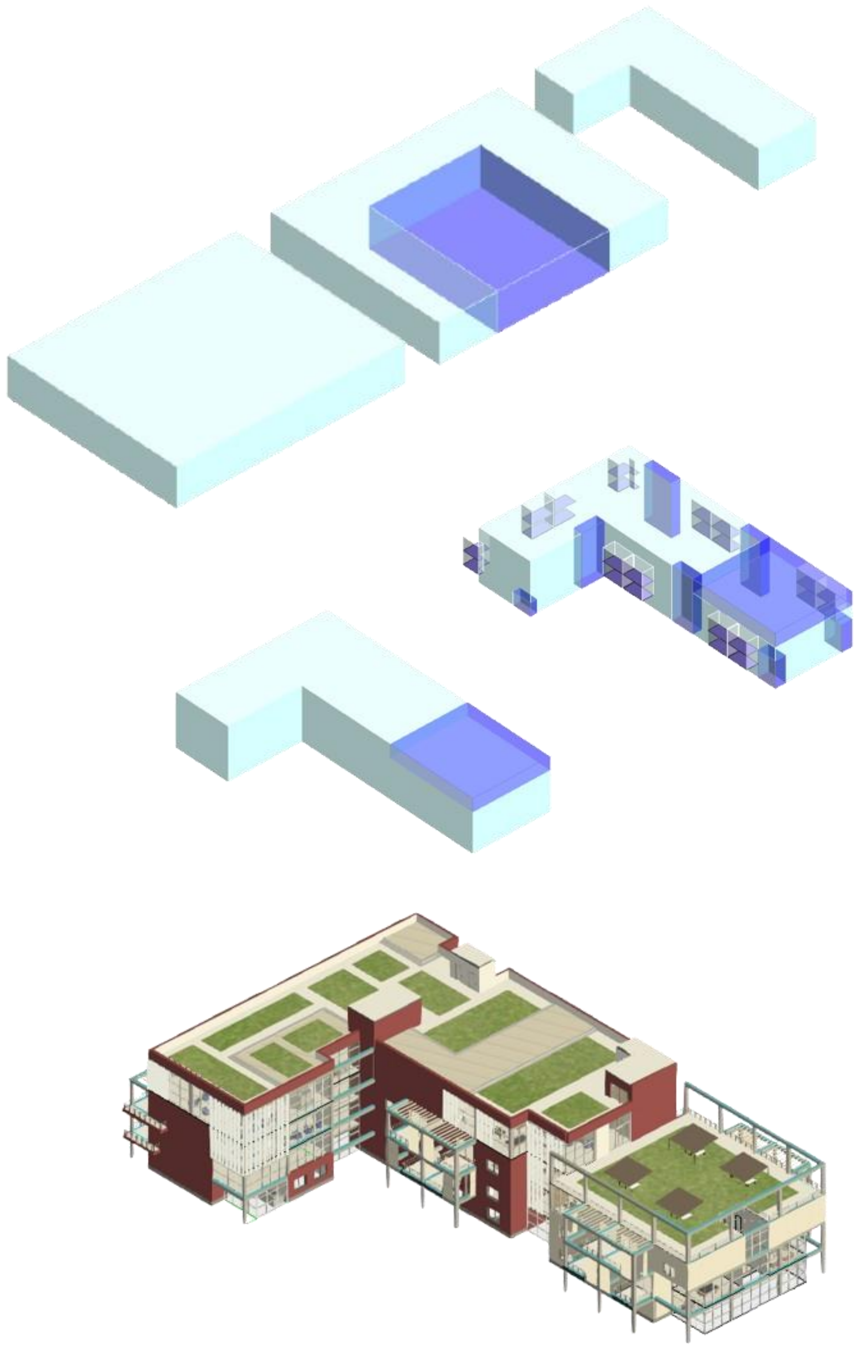


Figure 29– L-shaped Volume design

## 5.4 Layout criteria

The floor plans for the Ex Caserma Perotti project have been meticulously developed to facilitate interaction among residents and ensure accessibility within each building block. A central design element is the deliberate placement of communal balconies on both sides of every building, ensuring universal access for all residents. These balconies are integral to the project, acting as key communal spaces where individuals can congregate, connect with others, and enjoy the outdoor surroundings. By providing these shared spaces, the design fosters social cohesion and cultivates a strong sense of community among the building's occupants.

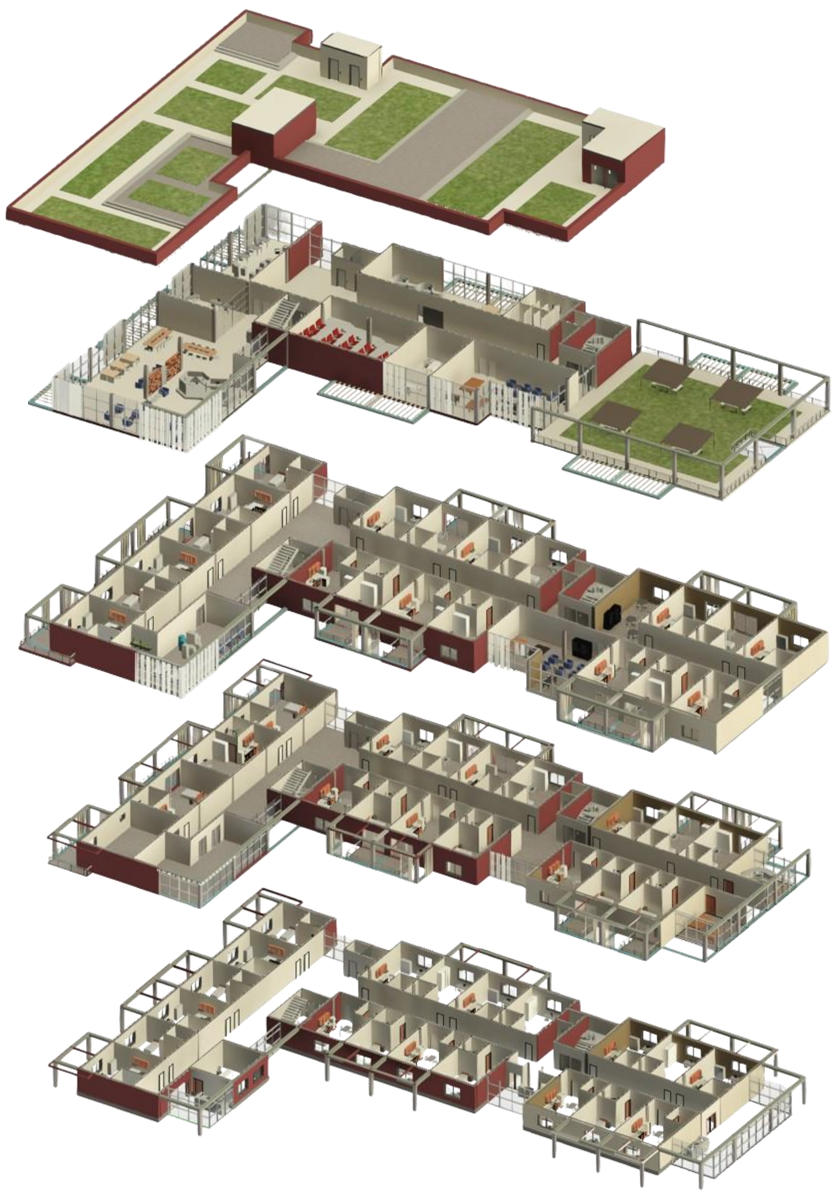


Figure 30– Diagram of floors (New building-D)

**Public spaces:** In both the adaptive reuse and new buildings, public spaces are strategically positioned on each floor, adjacent to the staircases. These spaces are designed to maximize natural light, creating a bright and inviting environment. Additionally, careful attention has been given to acoustic insulation, ensuring that these areas offer a comfortable and conducive atmosphere for students, promoting both interaction and relaxation without the disturbance of noise.

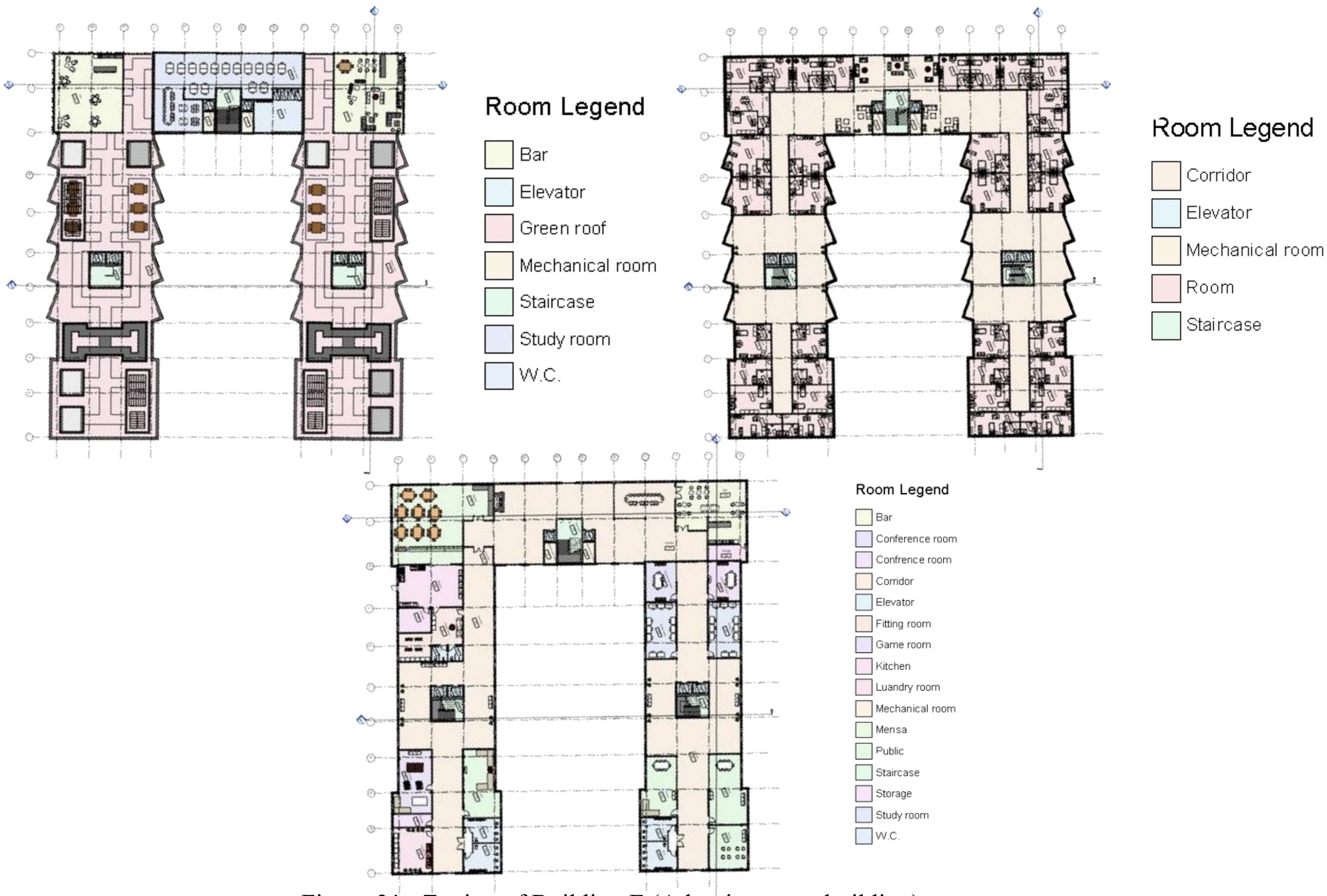


Figure 31– Zoning of Building E (Adoptive reuse building)


Figure 32– Diagram of Building E (Adoptive reuse building)

### 5.4.1 Room vs Studio

In student housing, a room typically refers to a private sleeping space within a larger shared apartment, where common areas like the kitchen, bathroom, and living room are shared with other students. In contrast, a studio is a fully self-contained unit that combines the sleeping area, kitchen, and private bathroom into one compact living space. Studios offer greater privacy and independence, making them attractive to students who prefer a quieter and more personal environment. However, they require more infrastructure, such as individual plumbing and ventilation, which increases construction and utility costs**.** Rooms allow for higher density and more social interaction, as students share common facilities. Choosing between rooms and studios depends on the project's goals, budget, and the expectations of the student population, especially in a university city like Bologna.

| Feature | Room | Studio |
|---|---|---|
| Function | Private bedroom, usually part of a shared apartment | Self-contained unit (bedroom, kitchen, and bathroom) |
| Kitchen | Shared with other tenants | Private, integrated kitchenette |
| Bathroom | Usually shared | Private bathroom |
| Living space | Shared (common living/dining) | Combined in one open area |
| Privacy | Moderate | High |

Table 4– Difference of shared room vs studio

#### Benefits of Studio Units in Student Housing

- **Greater Privacy and Independence**: Students have their own space for studying, cooking, and relaxing, which is ideal for focused academic life.
- **Improved Health & Hygiene**: Private bathrooms and kitchens reduce risks of illness (especially in the post-COVID era).
- **Market Appeal**: Studios are more attractive for international students and upper-year students who prefer autonomy.
- **Efficient for Short-Term Rentals**: These can be used for tourists or visiting faculty during summer breaks, improving ROI.

#### Challenges of Studio Layouts

- **Higher Construction and MEP Costs**: Each unit requires its own plumbing, ventilation, and kitchen setup which is increasing capital expense.
- **Greater Floor Area Per Student**: Studios reduce overall density. You house fewer students per square meter than shared units.
- **Energy and Maintenance Load**: More appliances and systems per unit mean higher ongoing utility and maintenance costs.
- **Reduced Social Interaction**: Fewer shared spaces may impact community feeling unless complemented by vibrant common areas.

## 5.4.2 Module Configurations

**Entrance and Service Module:** This module strategically houses the entrance and bathroom facilities, maximizing space efficiency. The updated layout improves accessibility to these essential services directly from the entrance, enhancing convenience and eliminating the need for corridors within the unit.

**Kitchen and Dining Module:** Located immediately adjacent to the entrance module, this area facilitates a seamless transition to cooking and dining spaces. Its positioning adjacent to the entrance enhances the functional flow and accessibility, making it easier for residents to engage in cooking and dining activities upon entering the unit.

**Living and Night Zone Module:** This module serves as a combined living and sleeping area, crafted for flexibility and privacy. The thoughtful open plan supports various lifestyle needs and living arrangements, optimizing the use of space for relaxation and rest.

**Natural Light and Ventilation:** The design incorporates large openings on the northern and southern facades to ensure ample natural light and promote effective cross-ventilation, reducing reliance on artificial lighting and mechanical ventilation. In contrast, the eastern and western facades feature fewer openings to minimize solar heat gain during the mornings and evenings, thereby maintaining a comfortable internal temperature and enhancing the building's overall energy efficiency.

The strategic modular configuration and the thoughtful placement of openings are designed to create a harmonious living environment that maximizes environmental sustainability and supports modern urban living. This modular approach not only streamlines the construction process with prefabricated elements but also significantly reduces on-site construction time and environmental impact, illustrating a profound commitment to sustainable building practices.

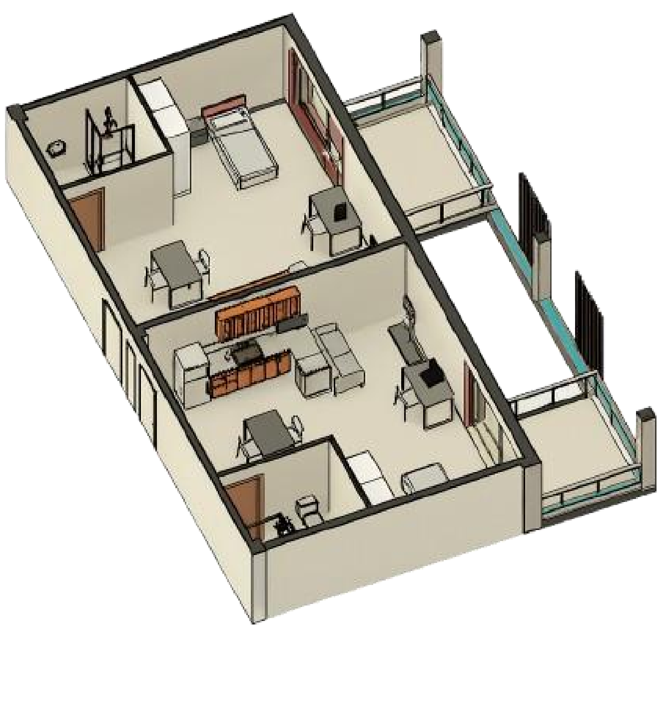


Figure 33– Example of studios

## 5.5 Sustainability principles

**Increasing green areas**: Expanding green spaces across the site enhances biodiversity, reduces the urban heat island effect, and improves the overall microclimate. These areas also provide psychological and recreational benefits for residents. The cost of implementation is generally low to medium, depending on the scale and planting strategy, though maintenance must be factored in.

**Creating green roofs**: Green roofs serve as natural insulators, reducing the need for heating and cooling while also absorbing rainwater to minimize runoff. They add visual and ecological value to the building. While the initial cost is medium to high due to waterproofing and structural reinforcement, they provide long-term energy savings and environmental benefits.

**Introducing parking and biking path**: Designing dedicated parking areas and bicycle paths encourage sustainable transport, reduce traffic congestion, and supports healthier lifestyles. These elements improve accessibility and integrate the site into the broader urban mobility network. The cost is relatively low to medium, depending on the materials used and the extent of the infrastructure.

**Creating markets, gyms, and sport spaces**: Incorporating markets, gyms, and sports facilities within or near the student accommodation meets lifestyle needs and promotes social interaction and physical wellness. These spaces also generate economic and communal activity. The construction and outfitting of such facilities come at a medium to high cost but offer long-term value and utility.

**Using renewable energy sources**: Photovoltaic panels provide renewable energy for the site, reducing dependence on fossil fuels and lowering electricity bills. This contributes to the energy self-sufficiency and environmental responsibility of the project. Although the upfront cost is medium-too high, the investment pays off overtime through energy savings and potential incentives.

Benefits of Photovoltaic Panels are:

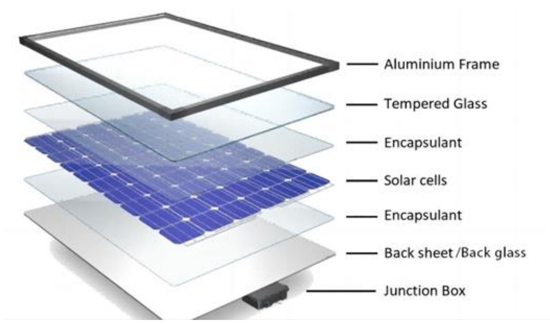
- **Renewable Energy Source**: PV panels utilize the sun limitless resource—to generate power without producing greenhouse gases or pollutants[18].
- **Energy Cost Reduction**: By generating on-site electricity, buildings with PV panels can significantly reduce utility costs, especially in regions with high solar potential.
- **Low Operating Costs**: Once installed, PV systems require minimal maintenance and have long lifespans, often exceeding 25 years.
- **Grid Independence**: PV systems can be connected to the grid, support net metering, or function off-grid, offering flexibility in energy management[19].
- **Environmental Benefits**: Unlike fossil fuel sources, PV systems produce no noise, emissions, or waste, contributing to a cleaner environment.

Modern PV technology is highly adaptable and offers numerous opportunities for architectural integration:

- **Urban Applications**: Rooftops of residential, commercial, and public buildings offer vast untapped surfaces for solar energy generation.
- **Modular and Scalable Design**: PV systems can be tailored in size and layout to suit various building types and energy demands.
- **Incentives and Support**: Many countries offer financial incentives, tax credits, and subsidies to promote PV adoption, making it a more viable investment.

PV panels can be installed in several ways, depending on the building type and desired application that according to the desires of this thesis, system of Roof-Mounted System chose which is the most common method, where panels are fixed to flat or sloped roofs using racks or mounting rails[20].

The purposes of using photovoltaic panels in the adoptive reuse buildings are to produce clean and renewable energy by converting sunlight into electricity without generating greenhouse gas emissions, helping to reduce the building's environmental impact. Also, they significantly reduce energy bills by generating free electricity on-site, and any surplus energy can often be fed back into the grid to receive financial credit. In addition, installing PV panels improves the building's energy performance, helping it meets Italy's Nearly Zero Energy Building (NZEB) requirements and improving the Energy Performance Certificate (APE) rating[21].



Figures 34– Photovoltaic panels

$$E_{pv} = P_{nom} \times H_eff \times PR$$

$$E_{pv} = 0.425 \times 1300 \times 0.80 = 442\text{KWh/year per panel}$$

$$442\text{KWh/year} \times 20 \text{ panels} = 8840\text{Kwh/year}$$

| Item | Value |
|---|---|
| Lighting type | LED |
| Power per fixture | 10 W (typical for desk or room LED) |
| Usage per day | 6 hours (average in student housing) |
| Annual usage per lamp | 10 W × 6 h/day × 365 days = 21.9 kWh/year |

Table 5– Information of LED Lamp

$$\frac{8840KWh/year}{21.9KWh/year}=403$$

Finally, using photovoltaic panel can be effective in order to produce the energy for turning on 403 lamps for the building.

**Creating public space for social community**: Public spaces are designed to encourage community engagement, provide areas for rest and recreation, and enhance the social character of the site. These spaces also improve walkability and connectivity. The cost is generally low to medium depending on the design elements included, such as seating, paving, and landscaping.

**Using dry construction for walls and partitions**: Dry construction methods such as prefabricated walls and partitions allow for faster, cleaner installation with less on-site waste and water use. These systems are easily modified, offering flexibility for future changes. The cost is low to medium and often more economical than traditional wet methods[22], [23].

The connection of drywall to steel structure happens from head, bottom and vertical fixing which were explained below:

1. **Connection for top track (Head of Wall):**
- Use self-drilling screws or power-actuated fasteners to fix the U-channel track to the underside of the steel deck.
- Allow for slip movement in head joints (especially in seismic zones or for fire-rated walls) using:
  - Slotted deflection tracks
  - Slip clips (e.g., Clark Dietrich, Simpson Strong-Tie)

2. **Options to attach drywall near steel columns (vertical fixing):**
- Furring channels: Install hat channels or z-channels across the steel column to create a surface for drywall.
- Direct framing: Fasten metal studs or runners to the web or flange of steel columns using:
  - TEK screws (self-drilling screws for metal)
  - Clamp brackets (if no drilling is allowed into structure)
- Add Unistrut or box channels for more complex framing or to wrap columns.

3. Connection for bottom Track (bottom of wall):
- Base track (U-profile) is fixed into the concrete topping over steel deck with:
  - Concrete screws (e.g. Tapcon)
  - Powder-actuated nails
- If no concrete: attach directly to steel deck ribs using self-drilling screws and steel shims for level adjustment.

**Using ventilated façade**: The building envelope utilizes a ventilated façade system**,** an innovative cladding approach that features a gap between the exterior wall and the cladding material. This cavity enables natural air circulation, which plays a key role in regulating internal temperatures, managing moisture, and boosting overall energy performance[7]. By facilitating continuous airflow, the system reduces the formation of thermal bridges and adds an extra layer of insulation, contributing to a cooler indoor environment in summer and greater heat retention in winter. This passive strategy reduces the building's reliance on mechanical heating and cooling systems, thereby lowering operational energy consumption. In addition, the ventilated façade helps preserve the structural integrity of the building by minimizing condensation and protecting against weather.

- **Improved Energy Performance:** Ventilated façades help minimize the reliance on mechanical heating and cooling systems by enhancing the building's natural thermal regulation, leading to long-term energy savings throughout its operational life.
- **Effective Moisture Control:** The ventilated air cavity creates continuous airflow that prevents moisture buildup, thereby reducing the likelihood of mold formation and protecting the structural envelope from water-related damage.
- **Design Versatility:** This façade system allows for a wide range of architectural expressions, offering flexibility in terms of materials, colors, and surface finishes, which helps architects align both aesthetic goals and functional needs.
- **Environmental Sustainability:** By utilizing long-lasting materials that require minimal upkeep, ventilated façades support sustainable construction practices. Additionally, they can be tailored to include eco-friendly components and technologies that reduce the building's overall environmental footprint.

**Using the louvre on building**: Louvres installed on balconies serve to control solar penetration, reduce glare, and improve indoor comfort during summer months. They also add a modern architectural feature to the façade. Louvres are typically low to medium in cost and are a cost-effective passive solar control strategy.

**Suitable construction system:** Choosing an appropriate construction system for student housing is crucial to achieving affordability and quick project delivery, which are often key requirements in educational developments. The system must be durable and low maintenance to handle the high turnover and intensive use typical of student residences. Flexibility in layout is also important, allowing for future reconfigurations or changes in housing needs. Additionally, the construction system should support high levels of thermal and acoustic comfort to ensure a healthy and quiet living environment. Finally, sustainable construction choices contribute to lower energy use and align with long-term environmental goals for educational campuses.

**Thermally modified timber wood panel (TMT)**: TMT is solid wood that has been heated to 180–215 °C in an oxygen-free atmosphere (steam, nitrogen or vacuum) for 2–4 days, then slowly cooled and re-humidified. The heat breaks down hemicelluloses (the fungi "food") and chemically sets the cell walls, so the wood takes up far less moisture and becomes more durable[24], [25]. Thermally modified timber panels (TMT) could be suitable for Bologna's climate because of some advantages which are:

- **Humidity tolerance**: huge shrink/swell reduction prevents cupping during Emilia-Romagna's damp winters and hot summers.

- **Fungi / decay resistance**: Class 1–2 durability handles year-round rainfall without biocides.
- **Chemical-free:** only heat and steam; cut-offs can be burned or recycled.
- **Low maintenance façade**: leave to grey naturally or apply a UV oil every 2–3 years to keep color.
- **Fire options**: can be factory-treated to Euro class B-s1, d0 without altering appearance.

| Species | Durability class | Visual character |
|---|---|---|
| Thermo-Spruce | 1,2 | Light knots,Nordic texture |
| Thermo-Pine | 2 | Rustic knots,Golden-brown |
| Thermo-Ash | 1 | Ribbon grain-Hardwood feel |
| Thermo-Tulipwood | 1 | Uniform,Streak-free |

Table 6 – Types of Thermally modified timber

Figure 35– TMT wood panel

| Benefit | Detail |
|---|---|
| Better dimensional stability | Warping compared to thinner boards |
| Improved fixings | Deeper screw embedment, stronger mechanical anchoring |
| Increased impact resistance | Holds up better against hail,debris,vandalism |
| More design freedom | Allows grooving,recesses, or even blind fixings |
| Longer lifespan | Better protection from environment stresses |

Table 7– Benefits of Thermo-Spruce wood

**Reinforced Concrete Frame Structure**: This system uses a skeleton frame of vertical columns and horizontal beams, all made from reinforced concrete, to support the structure. The floor slabs are also cast from concrete, typically forming a monolithic connection with beams and columns.

Also, the typical uses of this system are for apartments, offices, schools, hospitals and the most common system for urban mid-rise construction.

The key points of this system are:

- Reinforced concrete columns can carry vertical loads.
- Beams can support slabs and transfer loads to columns.
- Slabs can act as horizontal surfaces (floors/ceilings).

Monolithic Construction – Often cast together on-site for structural integration.

The Advantages of these systems are:

- Durable and fire-resistant.
- Good sound insulation.
- Strong for multi-story construction.
- Flexible layout (non-load-bearing walls possible).

A **Concrete-Filled Steel Tube (CFST)** system consists of a steel tube, circular, square, or rectangular that is filled internally with concrete. This composite structure combines the high tensile strength and ductility of steel with the excellent compressive strength and fire resistance of concrete[26], [27].

- **High Mechanical Strength**: Naturally, the composite of steel and concrete works together to support high loads.
- **Enhanced Fire Resistance**: The concrete core insulates steel from heat better than hollow steel sections.
- **Improved Durability**: With reduced formwork and integrated confinement, these columns tend to have longer service life.
- **Energy Absorption (Seismic Performance):** CFST columns can absorb and dissipate energy during earthquakes effectively.
- **Formwork Elimination**: The steel tube acts as permanent formwork no need for temporary molds.
- **Structural Efficiency & Cost Savings**: Smaller sectional size and optimized use of materials create economic advantages.

**Steel Frame with Composite Deck System** (Steel-Concrete Composite Structure - Also fits under adaptive reuse + hybrid system): The primary load-bearing structure consists of steel columns and beams. Floors are built using corrugated steel decking, which is then topped with reinforced concrete. The deck acts as formwork and a tension reinforcement for the concrete. This is a composite system, because the steel deck and concrete work together structurally. Also, this system can be accounted for adoptive reuse buildings because Steel is easy to modify, strengthen, or connect, in addition lighter load allows retrofitting on older foundations or frames.

The key points of this system are:

- Steel columns and beams can be the main structure.
- Steel deck could support wet concrete and works in tension.
- Concrete topping slab can work in compression and provide mass.
- Shear Connectors connect the concrete slab to steel beams.

The advantages of this system are:

- Lightweight compared to all-concrete buildings.
- Fast construction (steel and decking prefabricated).
- Allow long spans and open interiors.

# CHAPTER 6. Cost Estimation Analysis

## 6.1 Building phase analysis

Cost estimation is a fundamental element in project development and decision-making throughout the building life cycle. In sustainable construction, cost evaluation is essential not only for financial control but also for comparing technological alternatives according to environmental and performance criteria.

This chapter focuses on the estimation and comparison of construction costs for different technological alternatives for ventilated façade, with the objective of identifying the most appropriate solution through the Analytic Hierarchy Process (AHP). Therefore, the analysis does not aim to determine the total investment cost of the intervention, but specifically the construction cost associated with each option.

**Preliminary and Detailed Cost Estimates**

Cost estimation can be performed at different stages of the design process, depending on the available level of detail: Preliminary estimation which happens at the early design stage, when only schematic or conceptual information is available, the construction cost can be estimated through typological or parametric methods. This involves referring to costs from similar interventions where overall construction values are already known and then adjusting these figures by reference units, such as cost per square meter or cubic meter. These preliminary estimates are suitable for comparing technological alternatives even before detailed construction drawings exist[28].

Detailed or executive estimation happens When a detailed or executive design is available, the construction cost can be calculated by breaking down the project into individual work items and assigning unit costs from regional or national price lists. This method offers higher accuracy and is typically used during the executive design or tendering phase[29].

**From Construction Cost to Total Implementation Cost**

Once the construction cost has been determined using one of the methods above, the total implementation cost can be defined by adding indirect expenses associated with the intervention. These may include administrative costs, insurance, safety management, design fees, testing, and contingencies for unexpected issues. However, since the purpose of this thesis is to compare construction alternatives for ventilated façade rather than to estimate the total investment, the following analysis focuses primarily on construction cost values of ventilated facades.

## 6.2 Selection of Ventilated Façade System (Cost approach)

To evaluate the performance of the proposed ventilated façade system, it is necessary to compare it with alternative solutions that are representative of current practice. For this reason, two benchmark façade systems have been selected:

- Ventilated façade with solid aluminum sheets mounted on a continuous frame
- Ventilated façade with thin fiber-cement boards on continuous metal rails

These systems were chosen because they are both widely used in contemporary construction due to their aesthetic appeal (aluminum) or low initial cost (fiber-cement). However, they also illustrate typical trade-offs, such as increased thermal bridging, higher lifecycle costs, and greater maintenance requirements, which limit their energy performance compared to high-efficiency designs. By including these reference cases, the study can demonstrate, in a structured and objective manner, how the proposed façade achieves a better balance between Cost, energy performance and Installation phase.

### 6.2.1 Ventilated façade with solid aluminum sheets mounted on a continuous frame

A ventilated façade system with solid aluminum panels mounted on a continuous frame is a commonly employed rainscreen cladding. Its main components and characteristics can be summarized as follows:

**Composition:**

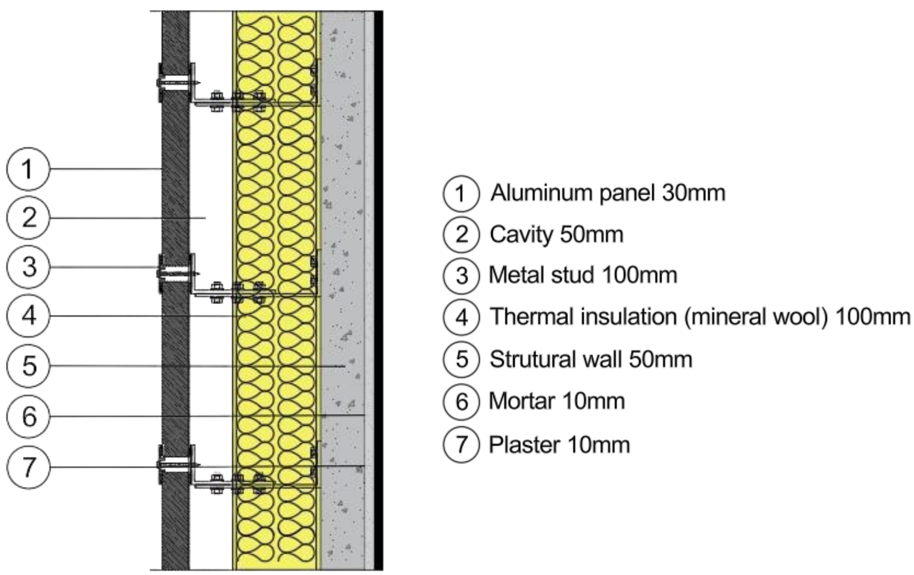



Figure 36– Stratigraphy of ventilated façade (Aluminum solution)

**Advantages:**

- High durability and corrosion resistance.
- Lightweight and visually flexible design.
- Low maintenance requirements for the panels themselves.
- Favorable fire resistance due to non-combustible aluminum.

**Limitations / Disadvantages:**

- **Thermal performance:** Aluminum is highly conductive, and the continuous metal frame introduces thermal bridges, increasing overall U-value[30], [31].
- **Cost:** Fabrication, precise panel alignment, coatings, and expansion joints lead to high cost.
- **Installation:** Requires precise tolerance and careful detailing to prevent panel warping, noise, or water infiltration[32].

**Performance considerations:**

- Acoustic insulation is generally good, but rain impact noise may be amplified by the metal cladding.
- Fire performance depends on both aluminum panels and compliance of insulation material with fire regulations.
- Lifecycle costs are higher compared to high-performance façades with continuous insulation.

### 6.2.2 Ventilated façade with thin fiber-cement boards on continuous metal rails

A ventilated façade system using thin fiber-cement boards mounted on continuous metal rails represents a widely adopted cost-effective solution in contemporary construction. Its main components and characteristics are summarized below:

**Composition:**

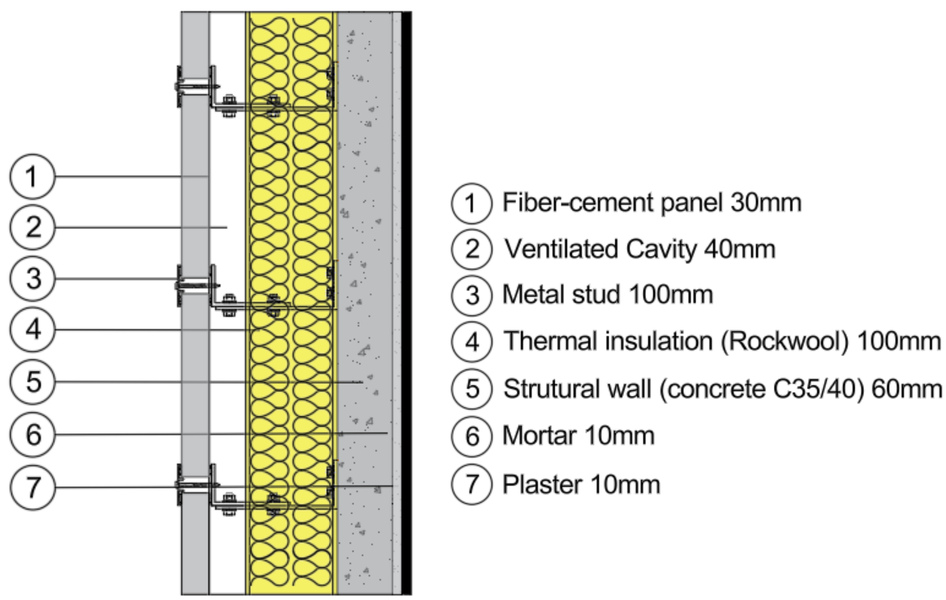



Figure 37– Stratigraphy of ventilated façade (Fiber-cement solution)

**Advantages:**

- Low initial material cost compared to high-end cladding systems.
- Lightweight and relatively easy to transport.
- Resistant to rot and pests due to fiber-cement composition.

- Fire-resistant properties depending on panel type.

**Limitations / Disadvantages:**

- **Thermal performance:** Continuous metal rails in front of the insulation create significant thermal bridges; thin or discontinuous insulation further reduces energy efficiency[30].
- **Durability:** Panels and joints may be prone to cracking, water infiltration, and aesthetic degradation over time.
- **Cost:** Cost may increase due to frequent maintenance, joint repair, repainting, or panel replacement.
- **Installation:** Although seemingly simple, frequent rails and joint detailing require precision; poor detailing can lead to water ingress and additional costs[32].

**Performance considerations:**

- Energy efficiency is generally lower than high-performance systems with continuous insulation.
- Acoustic insulation is moderate; thin panels provide limited sound attenuation.
- Fire performance is typically adequate but depends on compliance of insulation and fixings with regulations.
- Maintenance requirements are higher than more durable façade systems, potentially increasing lifecycle costs.

## 6.3 Cost estimation parameter

As discussed in Section 7.1, the construction cost can be estimated either through typological/parametric methods at a preliminary stage or through detailed work-item analysis at an executive design stage. This section focuses specifically on the application of the regional price list and the parameters used in this thesis for cost estimation.

Construction cost is a key component of real estate investment and must be estimated with reasonable accuracy. In preliminary stages, when detailed designs are unavailable, costs are usually calculated synthetically using physical parameters (€/sqm or €/cbm). This method distinguishes between main functional areas (e.g., residential, offices) and ancillary spaces (e.g., garages, storage) and relies on comparisons with similar properties. To estimate a new unit price for a specific work process, a price analysis can be conducted. This requires breaking down the work process into its elementary components: materials, labor and equipments rental and transportation. Regarding materials, two different approaches can be followed:

- Searching for the necessary items in a Price List (PL, eg. Bologna Regional Price List) to determine the cost of materials[36]
- Averaging at least three quotations from different companies

When following the first appraoch it means using the Bologna Regional Price List, it is possible to find composite items, meaning items that include multiple elementary components (e.g., material + labor for installation). In this case, it is necessary to separate these components by deducting the labor cost from the listed price. (For example, when searching for a specific material in the price list, the found item may also include labor costs for installation; these labor costs should be removed to obtain the material cost alone). Regarding labor costs, two alternative methods can be used:

- Finding the corresponding item in a price list (if one exists);
- Estimating it

If the first method is used, the correct item must be found in the price list, i.e., the one that provides the labor cost for the specific work process under consideration. For second method, the required time (using the time schedule) to complete a certain quantity of the work process (e.g., $1m^3$) must be estimated and multiplied by the hourly cost of a standard team, typically consisting of an unskilled and a skilled worker. For equipments rental and transportation, after identifying the necessary tools and/or vehicles, the corresponding item can be found in the price list, or an average value from at least three quotations can be obtained.

Parametric construction cost estimation is a method that links costs to measurable parameters of building elements (e.g., $m^2$ of floor, $m^2$ of façade, $m^3$ of concrete). This allows costs to be expressed as functions of elemental parameter for façade system (€/$m^3$ -The €/$m^3$ unit was adopted to account for façade thickness variations among alternatives, ensuring comparable volumetric cost analysis.). Also, the (*Prezzario ER 2025)* was chosen because it provides official unit rates for construction materials, systems, and works. However, since the stratigraphy of the building components is already defined in this thesis, the cost estimation can be performed directly using the Bologna Regional Price List (Prezzario ER 2025)[36], ensuring a higher level of accuracy than the purely parametric approach. Using this database ensures:

- **Consistency**: Same reference for all elements.
- **Transparency**: Each parametric element is tied to a standard unit price.
- **Regional validity**: Prices are aligned with Emilia-Romagna's construction market.

Benefits of Parametric Estimation in the Thesis

- Scalable: Can compare design alternatives quickly.
- Transparent: Each element is traceable back to Prezzario ER 2025.
- Integrative: Combines building elements (walls, floors, façade) with external works (fields, landscaping).
- Early accuracy: Provides reliable estimates even before detailed execution planning.

**Ventilated façade (TMT solution)**

| PRICE ANALYSIS | | | | | | | |
|---|---|---|---|---|---|---|---|
| CODE: 01 | Description: Ventilated facade (TMT) | | | | | | 357.75 |
| MATERIALS | DESCRIPTION | | PARAM | UNIT | QUANTITY (m3) | UNIT | TOTAL |
| | Total area | | 494.35 | [€/m2] | 170.2 | [m2] | 84138.37 |
| Plaster | MT01.027.005.a | Plasterboard in type A sheets compliant with EN 520, compliant with CAM (Minimum Environmental Criteria) requirements, measuring 3,000 x 1,200 mm, fire reaction Euroclass A2 - s1, d0 | 3.43 | €/m² | 3.33 | mq | 11.42 |
| Mortar | MT01.014.005.a | Premixed cement-based mortar, additives and aggregates, with a grain size <= 3 mm, for laying load-bearing and infill walls, compliant with the EN 998-2 standard, Euroclass A1 fire reaction, yield 1,500 kg/m3: | 9.77 | per 100 kg | 3 | 100kg | 29.31 |
| Rockwool insulation | MT01.025.035.c | Rock wool in semi-rigid panels without coating, compliant with CAM (Minimum Environmental Criteria) requirements, dimensions 1,200 x 600 mm, fire reaction class A1:spessore 60 mm | 6.80 | €/m² | 3.33 | mq | 22.64 |
| Light weight concrete block | MT01.018.005.b | Hollow concrete blocks, compliant with CAM (Minimum Environmental Criteria)requirements, flat surface:12 x 20 x 50 cm | 1.61 | each | 1 | cad | 1.61 |
| Polystyrene insulation | MT01.025.025.d | White EPS sintered expanded polystyrene, smooth surface or with stiffening ribs, compliant with CAM (Minimum Environmental Criteria) requirements, CE marked according to UNI EN 13163, for external wall insulation and compliant with ETICS standards,spessore 40 mm | 7.92 | €/m² | 3.33 | mq | 26.37 |
| Water proofing insulation | MT01.026.050.a | Prefabricated waterproofing membrane compliant with EN 13707 and/or EN 13969, consisting of a reinforced distilled bitumen-polymer membrane: | 8.03 | €/m² | 3.33 | mq | 26.74 |
| Air cavity | - | - | - | - | - | - | 0.00 |
| Wood panel | A22.028.030.a | Multilayer wood panel made of jointed lamellas of solid spruce boards, glued in orthogonal cross-laminated layers (CLT/X-LAM), then compressed (mechanically or vacuum-pressed). | 126.57 | each | 1 | mq | 126.57 |
| | | | | | | | 244.67 |
| Labor | DESCRIPTION | | PARAM | UNIT | QUANTITY (m3) | UNIT | TOTAL |
| Labor 1 | M01.001.040 | Installer 2th category | 25.50 | hour | 170.2 | 3.6h | 15624.36 |
| Labor 2 | M01.001.015 | Qualified construction worker | 28,36 | hour | 170.2 | 2.4h | 11584.5 |
| | | | | | | | 27208.86 |
| Equipment rental | DESCRIPTION | | PARAM | UNIT | QUANTITY (m3) | UNIT | TOTAL |
| Scaffolding | F01.061.005.b | Rental of basic kit for assembly and dismantling of 21.6 m long scaffolding | 91.92 | €/h | 170.2 | cad | 15644.78 |
| | F01.061.010 | Reinforced synthetic fibre mesh for the protection of exposed construction scaffolding, including dismantling at the end of the works | 3,04 | €/h | 170.2 | mq | 517.4 |
| | F01.055.005.a | for the first 30 days, including all costs and expenses for procurement, assembly, maintenance, dismantling and removal from the construction site at the end of the works | 5,05 | €/h | 170.2 | mq | 859.5 |
| | F01.058.005.a | for the first 30 days, including all costs and expenses for procurement, assembly, maintenance, dismantling and removal from the construction site at the end of the works | 107,52 | €/h | 73.44 | m | 7896.3 |
| | | | | | | | 24917.984 |
| Transport | DESCRIPTION | | PARAM | UNIT | QUANTITY (m3) | UNIT | TOTAL |
| Transport | F01.022.025 | Transport to the construction site, assembly and dismantling of modular huts, including connections to utility networks | 718.35 | € | 1 | € | 718.35 |
| General expences | DESCRIPTION | | PARAM | UNIT | QUANTITY (m3) | UNIT | TOTAL |
| Ex-works | | | 30000 | € | 16% | € | 4800 |
| Profit | DESCRIPTION | | PARAM | UNIT | QUANTITY (m3) | UNIT | TOTAL |
| Ex-works | | | 30000 | € | 10% | € | 3000 |
| Total price | | | | | | | 60889.9 |

Table 8– Price analysis of ventilated facade (TMT)

## Ventilated façade (Aluminum solution)

| PRICE ANALYSIS | | | | | | | |
|---|---|---|---|---|---|---|---|
| CODE: 02 | Description: Ventilated facade (Aluminum) | | | | | | 379.43 |
| MATERIALS | DESCRIPTION | | PARAM | UNIT | QUANTITY (m3) | UNIT | TOTAL |
| | Total area | | 319.00 | [€/m2] | 170.2 | [m2] | 54293.34 |
| Plaster | MT01.027.005.a | Plasterboard in type A sheets compliant with EN 520, compliant with CAM (Minimum Environmental Criteria) requirements, measuring 3,000 x 1,200 mm, fire reaction Euroclass A2 - s1, d0 | 3.43 | €/m² | 3.33 | mq | 11.42 |
| Mortar | MT01.014.005.a | Premixed cement-based mortar, additives and aggregates, with a grain size <= 3 mm, for laying load-bearing and infill walls, compliant with the EN 998-2 standard, Euroclass A1 fire reaction, yield 1,500 kg/m3: | 9.77 | per 100 kg | 3 | 100kg | 29.31 |
| Light weight concrete | A05.028.005.a | Reinforced concrete masonry C 25/30 (Rck 30 N/mm2), consistency class S4 and maximum aggregate diameter of 15 mm, with built-in thermal insulation, constructed using CE-marked formwork panels | 161.95 | €/m² | 1 | mq | 161.95 |
| Polystyrene insulation | MT01.025.025.d | White EPS sintered expanded polystyrene, smooth surface or with stiffening ribs, compliant with CAM (Minimum Environmental Criteria) requirements, CE marked according to UNI EN 13163, for external wall insulation and compliant with ETICS standards,spessore 40 mm | 7.92 | €/m² | 3.33 | mq | 26.37 |
| Air cavity | - | - | - | - | - | - | 0 |
| Aluminium panel | MT01.026.045.a | external cladding in pre-painted aluminium, thickness 30 mm and internal cladding in pre-painted aluminium, thickness 30 mm: | 33.6 | each | 1 | mq | 33.6 |
| | | | | | | | 262.66 |
| Labor | DESCRIPTION | | PARAM | UNIT | QUANTITY (m3) | UNIT | TOTAL |
| Labor 1 | M01.001.030 | Installer 4th category | 29,67 | hour | 170.2 | 3.6h | 18179.4 |
| Labor 2 | M01.001.015 | Qualified construction worker | 28,36 | hour | 170.2 | 2.4h | 11584.5 |
| | | | | | | | 29763.90 |
| Equipment rental | DESCRIPTION | | PARAM | UNIT | QUANTITY (m3) | UNIT | TOTAL |
| Scaffolding | F01.061.005.b | Rental of basic kit for assembly and dismantling of 21.6 m long scaffolding | 91.92 | €/h | 170.2 | cad | 15644.78 |
| | F01.061.010 | Reinforced synthetic fibre mesh for the protection of exposed construction scaffolding, including dismantling at the end of the works | 3,04 | €/h | 170.2 | mq | 517.4 |
| | F01.055.005.a | for the first 30 days, including all costs and expenses for procurement, assembly, maintenance, dismantling and removal from the construction site at the end of the works | 5,05 | €/h | 170.2 | mq | 859.5 |
| | F01.058.005.a | for the first 30 days, including all costs and expenses for procurement, assembly, maintenance, dismantling and removal from the construction site at the end of the works | 107,52 | €/h | 83.44 | m | 8971.5 |
| | | | | | | | 25993.18 |
| Transport | DESCRIPTION | | PARAM | UNIT | QUANTITY (m3) | UNIT | TOTAL |
| Transport | F01.022.025 | Transport to the construction site, assembly and dismantling of modular huts, including connections to utility networks | 718.35 | € | 1 | € | 718.35 |
| | C01.019.030 | Common quarry sand, laid including costs for supply, transport, spreading and compaction as indicated in the c.s.a. and anything else necessary to ensure the work is finished according to the rules of the art. | 41.21 | € | 1 | mq | 41.21 |
| General expences | DESCRIPTION | | PARAM | UNIT | QUANTITY (m3) | UNIT | TOTAL |
| Ex-works | | | 30000 | € | 16% | € | 4800 |
| Profit | DESCRIPTION | | PARAM | UNIT | QUANTITY (m3) | UNIT | TOTAL |
| Ex-works | | | 30000 | € | 10% | € | 3000 |
| Total price | | | | | | | 64579.3 |

Table 9– Price analysis of ventilated facade (Aluminium)

## Ventilated façade (Fiber-cement solution)

| PRICE ANALYSIS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| CODE: 03 | Description: Ventilated facade (Fiber-cement) | | | | | | | 363.37 |
| MATERIALS | DESCRIPTION | | PARAM | UNIT | QUANTITY (m3) | UNIT | TOTAL |
| | Total area | | 319.00 | [€/m2] | 170.2 | [m2] | 54293.34 |
| Plaster | MT01.027.005.a | Plasterboard in type A sheets compliant with EN 520, compliant with CAM (Minimum Environmental Criteria) requirements, measuring 3,000 x 1,200 mm, fire reaction Euroclass A2 - s1, d0 | 3.43 | €/m² | 3.33 | mq | 11.42 |
| Mortar | MT01.014.005.a | Premixed cement-based mortar, additives and aggregates, with a grain size <= 3 mm, for laying load-bearing and infill walls, compliant with the EN 998-2 standard, Euroclass A1 fire reaction, yield 1,500 kg/m3: | 9.77 | per 100 kg | 3 | 100kg | 29.31 |
| Light weight concrete | A05.028.005.a | Reinforced concrete masonry C 25/30 (Rck 30 N/mm2), consistency class S4 and maximum aggregate diameter of 15 mm, with built-in thermal insulation, constructed using CE-marked formwork panels | 161.95 | €/m² | 1 | mq | 161.95 |
| Rockwool insulation | MT01.025.035.c | Rock wool in semi-rigid panels without coating, compliant with CAM (Minimum Environmental Criteria) requirements, dimensions 1,200 x 600 mm, fire reaction class A1:spessore 60 mm | 6.80 | €/m² | 3.33 | mq | 22.64 |
| Air cavity | - | - | - | - | - | - | 0 |
| Fiber-cement panel | A09.031.155.b | Internal partition wall or false wall designed for use in humid environments, consisting of concrete and mineral aggregate panels externally reinforced with fiberglass fabric, Euroclass A1, | 36.99 | each | 1 | mq | 36.99 |
| | | | | | | | 262.32 |
| Labor | DESCRIPTION | | PARAM | UNIT | QUANTITY (m3) | UNIT | TOTAL |
| Labor 1 | M01.001.030 | Installer 4th category | 29,67 | hour | 170.2 | 3.6h | 18179.4 |
| Labor 2 | M01.001.015 | Qualified construction worker | 28,36 | hour | 170.2 | 2.4h | 11584.5 |
| | | | | | | | 29763.90 |
| Equipment rental | DESCRIPTION | | PARAM | UNIT | QUANTITY (m3) | UNIT | TOTAL |
| Scaffolding | F01.061.005.b | Rental of basic kit for assembly and dismantling of 21.6 m long scaffolding | 75.86 | €/h | 170.2 | cad | 12911.37 |
| | F01.061.010 | Reinforced synthetic fibre mesh for the protection of exposed construction scaffolding, including dismantling at the end of the works | 3,04 | €/h | 170.2 | mq | 517.4 |
| | F01.055.005.a | for the first 30 days, including all costs and expenses for procurement, assembly, maintenance, dismantling and removal from the construction site at the end of the works | 5,05 | €/h | 170.2 | mq | 859.5 |
| | F01.058.005.a | for the first 30 days, including all costs and expenses for procurement, assembly, maintenance, dismantling and removal from the construction site at the end of the works | 107,52 | €/h | 83.44 | m | 8971.5 |
| | | | | | | | 23259.772 |
| Transport | DESCRIPTION | | PARAM | UNIT | QUANTITY (m3) | UNIT | TOTAL |
| Transport | F01.022.025 | Transport to the construction site, assembly and dismantling of modular huts, including connections to utility networks | 718.35 | € | 1 | € | 718.35 |
| | C01.019.030 | Common quarry sand, laid including costs for supply, transport, spreading and compaction as indicated in the c.s.a. and anything else necessary to ensure the work is finished according to the rules of the art. | 41.21 | € | 1 | mq | 41.21 |
| General expences | DESCRIPTION | | PARAM | UNIT | QUANTITY (m3) | UNIT | TOTAL |
| Ex-works | | | 30000 | € | 16% | € | 4800 |
| Profit | DESCRIPTION | | PARAM | UNIT | QUANTITY (m3) | UNIT | TOTAL |
| Ex-works | | | 30000 | € | 10% | € | 3000 |
| Total price | | | | | | | 61845.5 |

Table 10– Price analysis of ventilated facade (Fiber-cement)

| Building | Volume (m3) | Cost (m3) | Cost (€) |
|---|---|---|---|
| A | 170.2 | 357.75 | 60,889.05 |
| B | 203.02 | | 72,630.40 |
| C | 0 | | 0 |
| D | 170.2 | | 60,889.05 |
| E | 487.46 | | 174,388.81 |
| F | 487.46 | | 174,388.81 |
| Total | | | 543,186.12 |

Table 11– Total Price of ventilated façade (TMT) per cubic meter

## 6.4 Multi-criteria analysis (AHP)

Decision-making in construction projects often requires evaluating multiple technological or design alternatives under various economic, environmental, and technical criteria. To support this complex process, the Analytic Hierarchy Process (AHP) is adopted in this study as a structured and transparent tool for comparing alternatives and identifying the most suitable solutions for ventilated facade. The cost comparison obtained from the Bologna Price List serves as the quantitative basis for the AHP evaluation, ensuring that each criterion is grounded in real market data.

### 6.4.1 Theoretical Framework of AHP

The Analytic Hierarchy Process (AHP), developed by Thomas L. Saaty in the late 1970s, is one of the most widely used multi-criteria decision-making (MCDM) methods. It provides a systematic approach for solving complex decisions by decomposing them into a hierarchy of interrelated elements. At the top of the hierarchy is the overall goal (e.g., selecting the best technological alternative), followed by criteria and sub-criteria, and finally the alternatives to be evaluated[33].

Main Steps of the AHP Method[34]

- **Hierarchical Decomposition of the Problem**
  The decision problem is broken down into levels: goal, criteria and alternatives. This structure allows each element to be analyzed separately, increasing transparency and logical consistency.
- **Pairwise Comparison of Criteria and Alternatives**
  Each element in a given level is compared pairwise with the others in terms of their relative importance to an element in the level above. These judgments are expressed using Saaty's 1–9 scale, where 1 indicates equal importance and 9 indicates extreme importance of one element over another. The results are organized into pairwise comparison matrices.
- **Weight Calculation (Priority Vectors)**
  From each comparison matrix, the relative weights (priorities) of the elements are derived by calculating the principal eigenvector. This process reflects the degree of importance assigned to each criterion or alternative[35].

**Synthesis of Priorities and Consistency Check**

The data from the pairwise comparison matrices are used to determine the relative importance of the elements within each matrix. This produces a hierarchy of weights representing the overall preference of one element compared to another.Mathematically, these priorities are represented as a vector of cardinal values, corresponding to the principal eigenvector of the pairwise comparison matrix[35]:

$$AX = \lambda_{\max} X$$

Where:

- $A$= pairwise comparison matrix
- $X = (x_1, x_2, \ldots, x_n)^T$= eigenvector
- $\lambda_{\max}$= maximum eigenvalue

Once the largest eigenvalue of the matrix ($\lambda_{\max}$) is determined, consistency is checked to ensure that the expert judgments are logically coherent. The Consistency Index (CI) and Consistency Ratio (CR) are calculated as follows:

$$CI = \frac{\lambda_{\max} - n}{n - 1}$$

$$CR = \frac{CI}{RI}$$

Where $RI$is the Random Index, depending on the matrix size. If $CR < 0.10$, the level of inconsistency is acceptable, and the results are considered valid. Otherwise, the pairwise comparison matrix should be revised. This consistency verification ensures that the decision-making process is objective, repeatable, and statistically sound, avoiding contradictions in expert judgments.

### 6.4.2 Application of AHP to the Case Study

The theoretical framework described above was applied to the adaptive reuse and new buildings of Ex Caserma Perotti, located in Bologna. The objective was to identify the most suitable technological alternative that balances energy performance, cost, and installation.

**1. Definition of the Goal**

To select the optimal construction technology for the building's ventilated facade, ensuring both economic feasibility and environmental performance.

**2. Identification of Criteria**

Based on the thesis's objectives and sustainability principles, three main evaluation criteria were defined:

- **Cost:** This criterion represents the economic aspect of each solution and is the primary focus of this study. It is derived from the cost estimation analysis presented in Section 6.1, which includes material, labor, equipment, and transportation expenses as well as indicative maintenance costs. The objective is to identify the most cost-efficient façade technology that maintains acceptable performance levels.
- **Energy Performance:** This criterion reflects the thermal behavior of the façade systems, considering insulation continuity, material conductivity, and the expected impact on overall building energy demand. Although secondary to cost in weighting, it ensures that economic choices do not compromise environmental efficiency.

- **Installation:** This criterion evaluates the practical feasibility of each system, including assembly complexity, construction time, accessibility for maintenance, and the potential need for replacement over the building's life cycle. It highlights the balance between simplicity of construction and long-term durability.

Among the three criteria, Cost was assessed through direct quantitative estimation (€/m³) using the Bologna Regional Price List. Energy Performance and Installation were instead evaluated qualitatively, based on material properties, façade composition, and literature benchmarks. Each was assigned a relative importance through the AHP pairwise comparison, allowing qualitative assessments to be integrated with the quantitative cost data in a coherent decision-making framework.

### 3. Definition of Alternatives

Three technological alternatives were compared with different façade systems. Each option was modeled to obtain quantitative and qualitative performance indicators for the defined criteria.

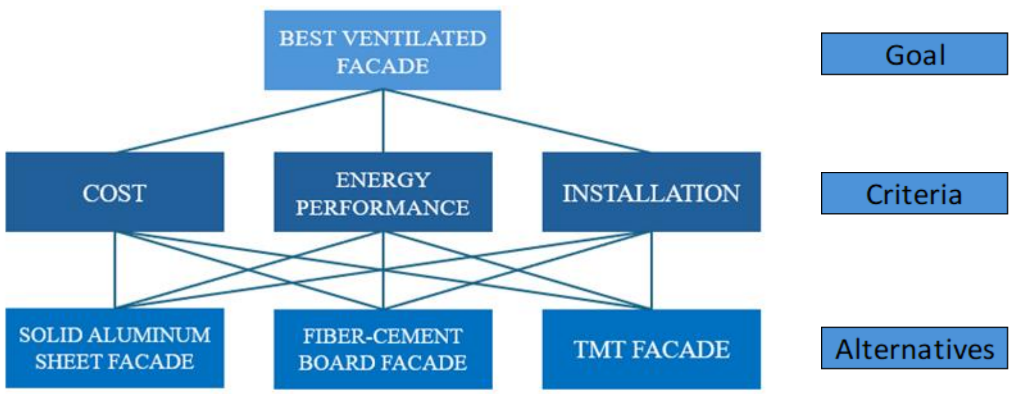



Figure 38 – Diagram of best ventilated façade

### 4. Pairwise Comparison and Weight Assignment

Pairwise comparison matrices were established for both the criteria and the alternatives, using Saaty's 1–9 scale. Expert judgments were collected and inserted into the matrices, and the corresponding priority vectors were calculated.

| Numerical value | Description |
|---|---|
| 1 | Equal importance |
| 3 | Slight importance of one over another |
| 5 | Moderate importance of one over another |
| 7 | Very strong importance |
| 9 | Extreme importance of one over another |
| 2,4,6,8 | Intermediate values between two adjacent values |

Table 12– 9-point rating scale for Comparative judgment method

"For each level, it is necessary to build as many square matrices of pairwise comparison between elements as there are elements ordered above.

### 5. Result Synthesis and Ranking

After computing the local and global weights, the overall priorities of the three alternatives were obtained. The alternative with the highest global priority value was identified as the most suitable technological solution for the adaptive reuse of Ex Caserma Perotti.

### Calculation of the eigenvector

| Goal | Cost | Energy performance | Installation |
|---|---|---|---|
| Cost | 1 | 3 | 4 |
| Energy performance | 0.33 | 1 | 3 |
| Installation | 0.25 | 0.33 | 1 |

| Priority vector goal | |
|---|---|
| $v1$ =2.28 | 61.62% |
| $v2$ =0.99 | 26.76% |
| $v3$ =0.43 | 11.62% |
| Total=3.70 | 100% |

| |
|---|
| Cost |
| Energy performance |
| Installation |

| X goal | Y | Z | n | λmax | IC | IR | RC |
|---|---|---|---|---|---|---|---|
| 0.6162 | 1.8838 | 3.0571 | 3 | 3.0685 | 0.0342 | 0.52 | 0.06 |
| 0.2676 | 0.8195 | 3.0626 | | | | | |
| 0.1162 | 0.3586 | 3.0857 | | | | | |

Table 13– Calculation of the eigenvector and Internal consistency of the pairwise comparison matrix for goal

| Cost | TMT façade | Fiber-cement board façade | Solid aluminum sheet façade |
|---|---|---|---|
| TMT façade | 1 | 3 | 4 |
| Fiber-cement board façade | 0.33 | 1 | 3 |
| Solid aluminum sheet façade | 0.25 | 0.33 | 1 |

| Priority vector Cost | |
|---|---|
| $v1$ =2.27 | 61.35% |
| $v2$ =0.99 | 26.75% |
| $v3$ =0.44 | 11.90% |
| Total=3.70 | 100% |

| |
|---|
| TMT façade |
| Fiber-cement board façade |
| Solid aluminum sheet façade |

| X1 | Y | Z | n | λmax | IC | IR | RC |
|---|---|---|---|---|---|---|---|
| 0.6135 | 1.8920 | 3.0839 | 3 | 3.0687 | 0.0343 | 0.52 | 0.066 |
| 0.2675 | 0.8270 | 3.0914 | | | | | |
| 0.1190 | 0.3607 | 3.0307 | | | | | |

Table 14– Calculation of the eigenvector and Internal consistency of the pairwise comparison matrix for cost

| Energy performance | TMT façade | Fiber-cement board façade | Solid aluminum sheet façade |
|---|---|---|---|
| TMT façade | 1 | 2 | 3 |
| Fiber-cement board façade | 0.5 | 1 | 3 |
| Solid aluminum sheet façade | 0.33 | 0.33 | 1 |

| Priority vector Energy performance | |
|---|---|
| $v1$ =1.80 | 52.63% |
| $v2$ =1.14 | 33.33% |
| $v3$ =0.48 | 14.03% |
| Total=3.42 | 100% |

| |
|---|
| TMT façade |
| Fiber-cement board façade |
| Solid aluminum sheet façade |

| X2 | Y | Z | n | λmax | IC | IR | RC |
|---|---|---|---|---|---|---|---|
| 0.5263 | 1.6138 | 3.0663 | 3 | 3.0468 | 0.0234 | 0.52 | 0.045 |
| 0.3333 | 1.0174 | 3.0524 | | | | | |
| 0.1403 | 0.4240 | 3.0219 | | | | | |

Table 15– Calculation of the eigenvector and Internal consistency of the pairwise comparison matrix for energy

| Installation | TMT façade | Fiber-cement board façade | Solid aluminum sheet façade |
|---|---|---|---|
| TMT façade | 1 | 3 | 4 |
| Fiber-cement board façade | 0.33 | 1 | 2 |
| Solid aluminum sheet façade | 0.25 | 0.5 | 1 |

| Priority vector Installation | |
|---|---|
| $v1$ =2.27 | 62.36% |
| $v2$ =0.87 | 23.90% |
| $v3$ =0.50 | 13.73% |
| Total=3.64 | 100% |

| |
|---|
| TMT façade |
| Fiber-cement board façade |
| Solid aluminum sheet façade |

| X3 | Y | Z | n | λmax | IC | IR | RC |
|---|---|---|---|---|---|---|---|
| 0.6236 | 1.8898 | 3.0305 | 3 | 3.0154 | 0.0077 | 0.52 | 0.015 |
| 0.239 | 0.7194 | 3.0100 | | | | | |
| 0.1373 | 0.4127 | 3.0058 | | | | | |

Tables 16– Calculation of the eigenvector and Internal consistency of the pairwise comparison matrix for installation

**Result**

According to the result of analytic hierarchy process for different types of façades, thermally modified timber facade is the best solution by considering 3 parameters (coat, energy performance, installation) among other facades.

| X1 | X2 | X3 | X goal | Result |
|---|---|---|---|---|
| 0.6135 | 0.5263 | 0.6236 | 0.6162 | 59.13% |
| 0.2675 | 0.3333 | 0.239 | 0.2676 | 28.18% |
| 0.119 | 0.1403 | 0.1373 | 0.1162 | 12.68% |

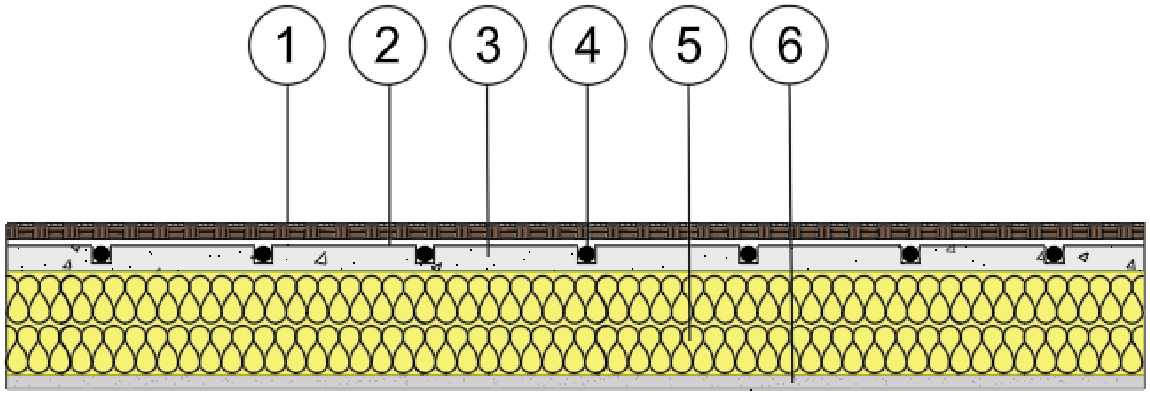
| |
|---|
| TMT façade |
| Fiber-cement board façade |
| Solid aluminum sheet façade |

Tables 17– Result of best ventilated façade

# CHAPTER 7. CONSTRUCTION DETAILING

## 7.1 Opaque and transparent elements

### Interior floor (Adoptive reuse and New)



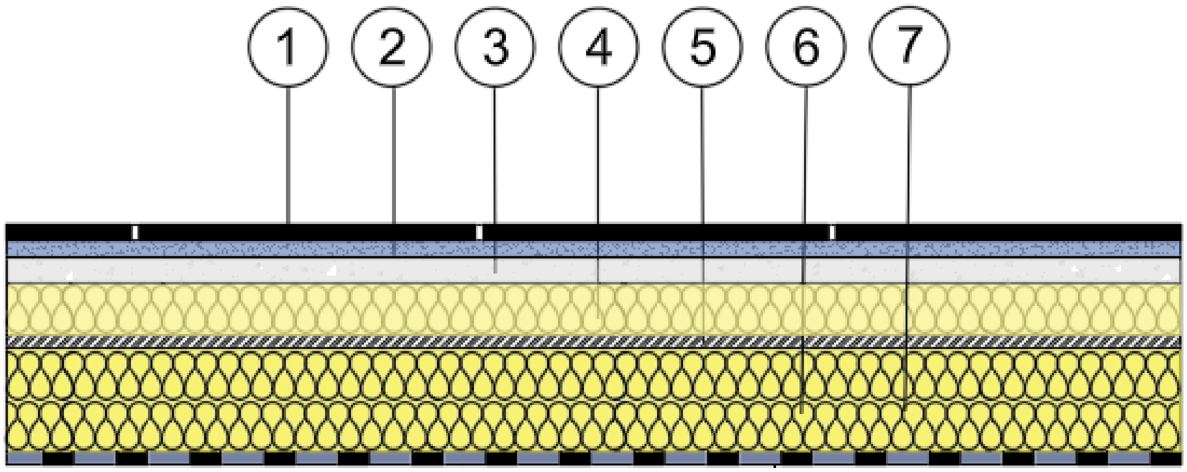

1 Wooden parquet 100*20*20 (mm)
2 Sepration layer 10mm
3 Light concrete (C10/15) 20mm
4 Heating pipe 20mm
5 Thermal insulation (XPS) 80mm
6 Waterproofing membrane 10mm

Figure 39– Diagram of interior floor

| Interior floor | | | | | |
|---|---|---|---|---|---|
| **Material** | **γ [kN/m3]** | **Thickness [m]** | **λ [w/m.k]** | **Load per unit area [kN/m2]** | **U-value (W/m²K)** |
| Water proofing insulation | 0.45 | 0.01 | 0.035 | 0.005 | 0.30 |
| Thermal insulation (XPS) | 0.45 | 0.08 | 0.035 | 0.036 | |
| Light concrete | 18 | 0.02 | 0.75 | 0.36 | |
| Heating pipe | 9.6 | 0.02 | 0.4 | 0.192 | |
| Sepration layer | 9.2 | 0.01 | 0.40 | 0.092 | |
| Parquet | 9 | 0.02 | 0.18 | 0.18 | |
| Total | | | | 0.86 | |

Table 18– Physical characteristics of the interior floor

## Roof (Adoptive reuse and New)




1 Ceramic tile 20mm
2 Mortar 15mm
3 Light concrete (C10/15) 20mm
4 Insulation (Rockwool) 40mm
5 Sepration layer 10mm
6 Vapour insulation (PVC) 80mm
7 Waterproofing membrane 10mm

Figure 40– Diagram of roof

| Roof | | | | | |
|---|---|---|---|---|---|
| **Material** | **γ [kN/m3]** | **Thickness [m]** | **λ [w/m.k]** | **Load per unit area [kN/m2]** | **U-value (W/m²K)** |
| Water proofing insulation | 0.45 | 0.01 | 0.035 | 0.0045 | |
| Vapour insulation (PVC) | 0.45 | 0.08 | 0.035 | 0.036 | |
| Light concrete | 18 | 0.02 | 0.75 | 0.36 | |
| Insulation (Rockwool) | 0.1 | 0.04 | 0.035 | 1.66 | 0.24 |
| Sepration layer | 9.2 | 0.01 | 0.40 | 0.092 | |
| Mortar | 20 | 0.015 | 0.1 | 0.30 | |
| Ceramic tile (Light composite stone) | 20 | 0.02 | 2 | 0.40 | |
| Total | | | | 2.85 | |

Table 19– Physical characteristics of the roof

Exterior floor (Green roof) (Adoptive reuse and New)

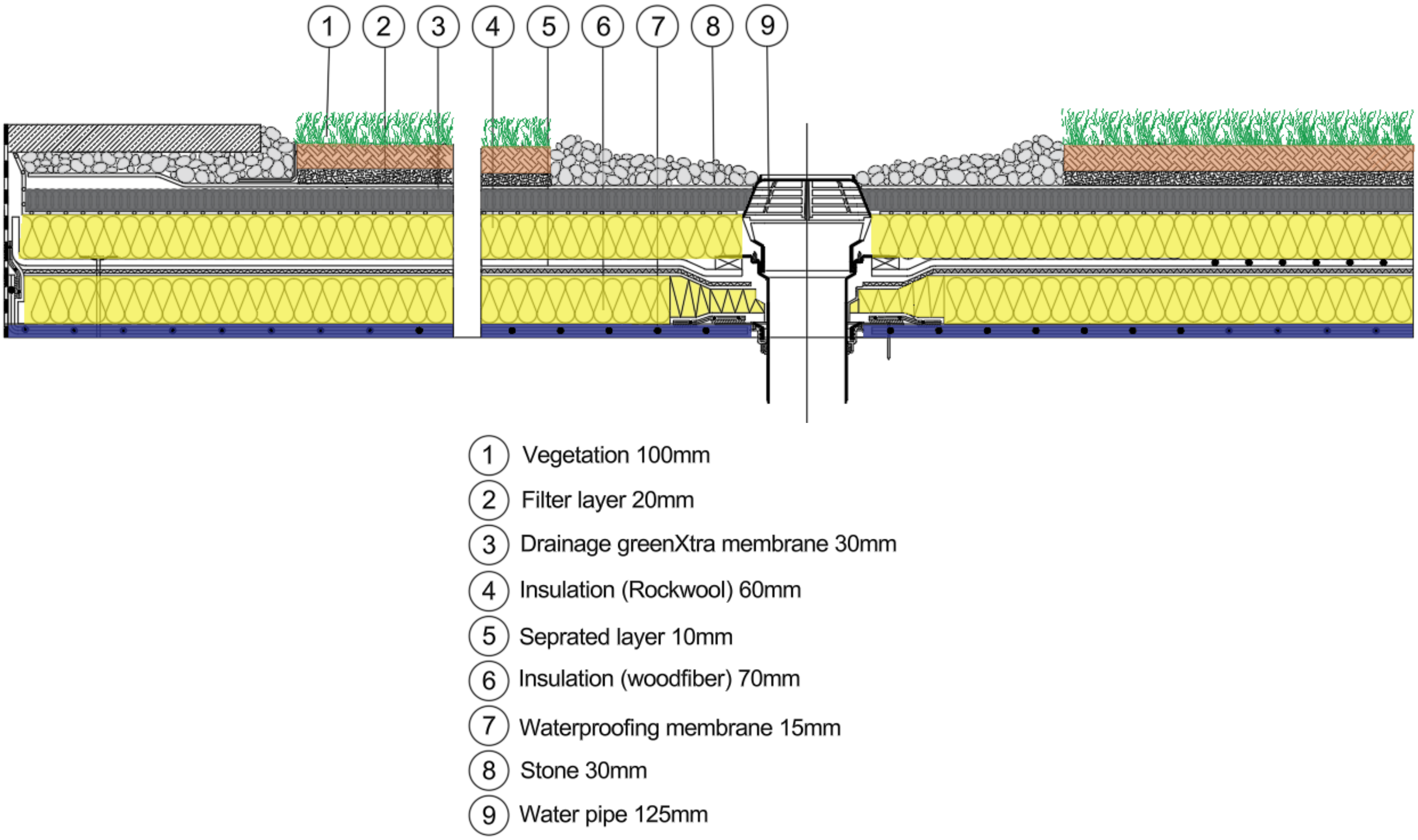



Figure 41– Diagram of green roof

| Green roof | | | | | |
|---|---|---|---|---|---|
| **Material** | **γ [kN/m3]** | **Thickness [m]** | **λ [w/m.k]** | **Load per unit area [kN/m2]** | **U-value (W/m²K)** |
| Water proofing Membrane | 0.45 | 0.015 | 0.25 | 0.0068 | 0.21 |
| Rigid insulation (wood fiber) | 2 | 0.07 | 0.045 | 0.14 | |
| Sepration layer | 1.2 | 0.01 | 0.50 | 0.012 | |
| Root barrier | 1.2 | 0.003 | 0.35 | 0.004 | |
| Insulation (Rockwool) | 0.1 | 0.06 | 0.035 | 1.66 | |
| Drainage membrane | 1 | 0.03 | 0.35 | 0.03 | |
| Filter layer | 16 | 0.02 | 0.35 | 0.32 | |
| Vegetation | 1 | 0.10 | 0.35 | 0.10 | |
| Total | | | | 2.27 | |

Table 20 – Physical characteristics of the green roof

Exterior wall (1) (Adoptive reuse and New)

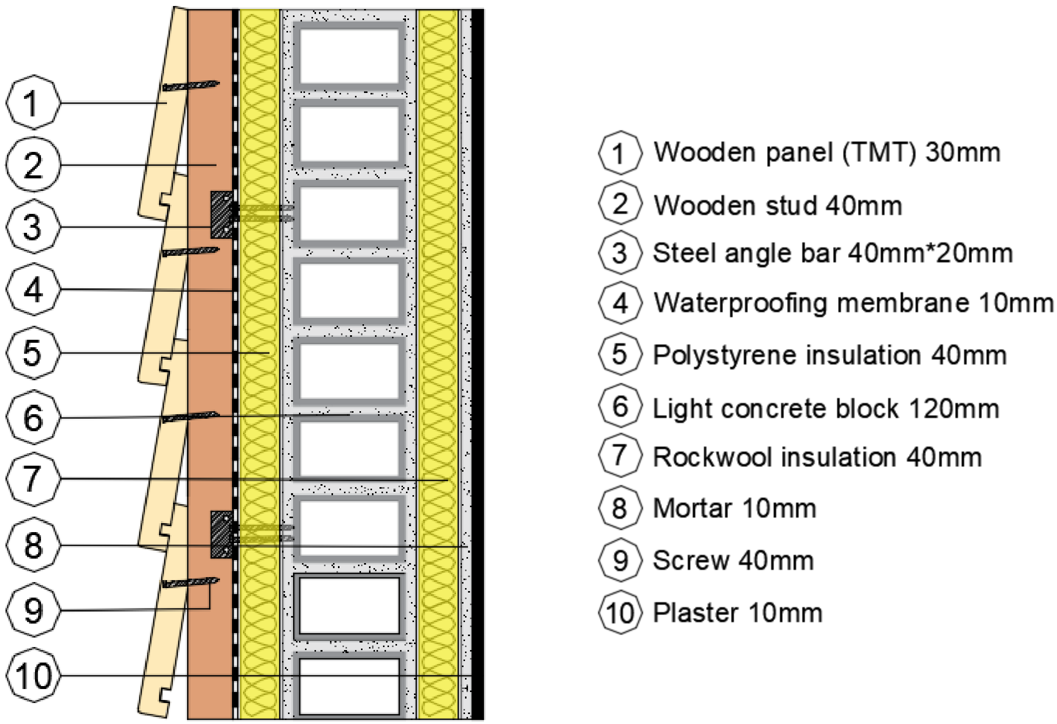



Figure 42– Diagram of exterior wall (1)

| Exterior Wall 1 (300mm) | | | | | |
|---|---|---|---|---|---|
| **Material** | **γ [kN/m3]** | **Thickness [m]** | **λ [w/m.k]** | **Load per unit area [kN/m2]** | **U-value (W/m²K)** |
| Plaster (gypsum) | 20 | 0.01 | 0.35 | 0.20 | 0.22 |
| Mortar | 20 | 0.01 | 0.1 | 0.20 | |
| Rokwool insulation | 0.3 | 0.06 | 0.045 | 0.018 | |
| Light weight block | 12 | 0.12 | 0.4 | 1.44 | |
| Polystyrene insulation | 0.2 | 0.04 | 0.04 | 0.008 | |
| Water proofing insulation | 0.45 | 0.01 | 0.035 | 0.004 | |
| Cavity | 0.01 | 0.02 | 0.025 | 0.00 | |
| Wood panel (TMT) | 4.75 | 0.05 | 0.09 | 0.17 | |
| Total | | | | 2.04 | |

Table 21– Physical characteristics of the exterior wall (1)

## Exterior wall (2) (New building)

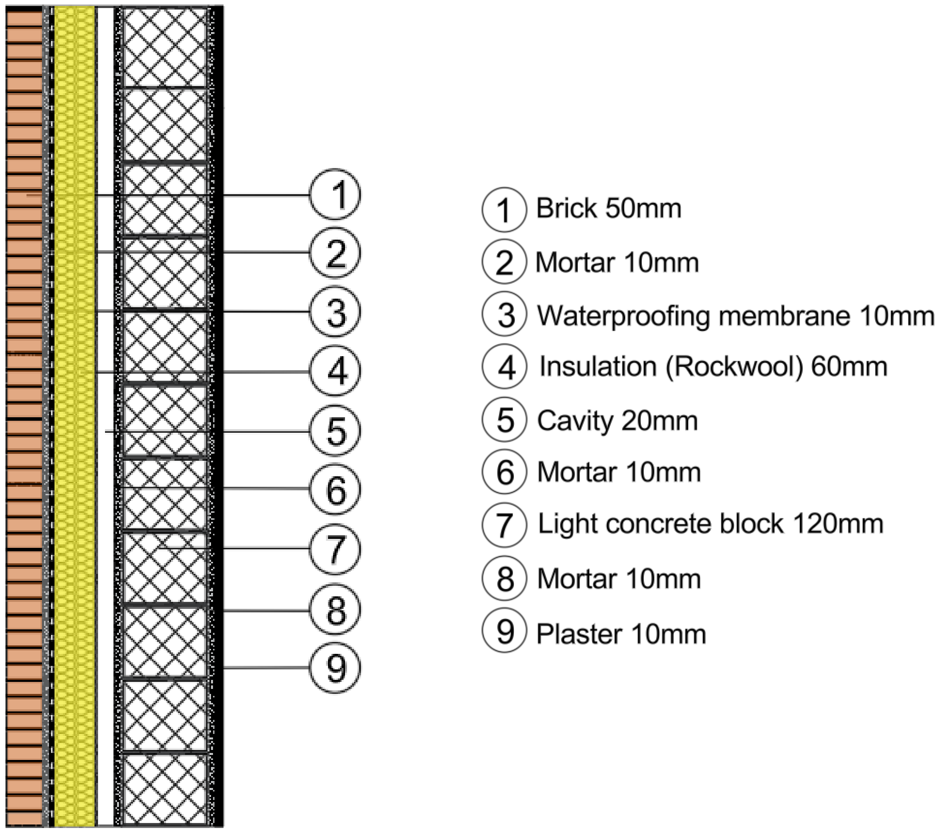



Figure 43– Diagram of exterior wall (2)

| Exterior Wall 2 (300mm) | | | | | |
|---|---|---|---|---|---|
| **Material** | **γ [kN/m3]** | **Thickness [m]** | **λ [w/m.k]** | **Load per unit area [kN/m2]** | **U-value (W/m²K)** |
| Plaster (gypsum) | 20 | 0.01 | 0.35 | 0.20 | 0.30 |
| Mortar | 20 | 0.01 | 0.1 | 0.20 | |
| Light weight block | 12 | 0.12 | 0.4 | 1.44 | |
| Mortar | 20 | 0.01 | 0.1 | 0.20 | |
| Cavity | 0.01 | 0.02 | 0.025 | 0.00 | |
| Rokwool insulation | 0.3 | 0.06 | 0.045 | 0.018 | |
| Water proofing insulation | 0.45 | 0.01 | 0.035 | 0.004 | |
| Mortar | 20 | 0.01 | 0.1 | 0.20 | |
| Brick | 20 | 0.05 | 1 | 1.00 | |
| Total | | | | 3.26 | |

Table 22– Physical characteristics of the exterior wall (2)

## Exterior wall (3) (Adoptive reuse and New)

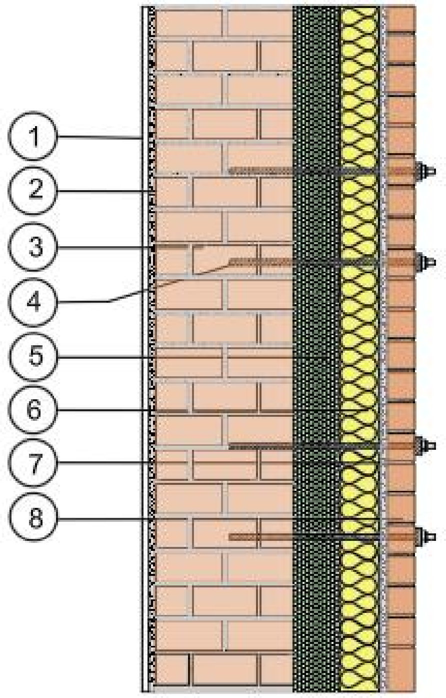



Figure 44– Diagram of exterior wall (3)

| Exterior Wall 3 (400mm) | | | | | |
|---|---|---|---|---|---|
| **Material** | **γ [kN/m3]** | **Thickness [m]** | **λ [w/m.k]** | **Load per unit area [kN/m2]** | **U-value (W/m²K)** |
| Plaster (gypsum) | 20 | 0.01 | 0.35 | 0.20 | 0.27 |
| Mortar | 20 | 0.01 | 0.1 | 0.20 | |
| Brick | 20 | 0.20 | 1 | 1.00 | |
| Rokwool insulation | 0.3 | 0.065 | 0.045 | 0.018 | |
| Polystyrene insulation | 0.2 | 0.065 | 0.04 | 0.008 | |
| Mortar | 20 | 0.01 | 0.1 | 0.20 | |
| Interior brick | 20 | 0.04 | 1 | 1.00 | |
| Total | | | | 2.63 | |

Table 23– Physical characteristics of the exterior wall (3)

## Interior wall (Adoptive reuse and New)

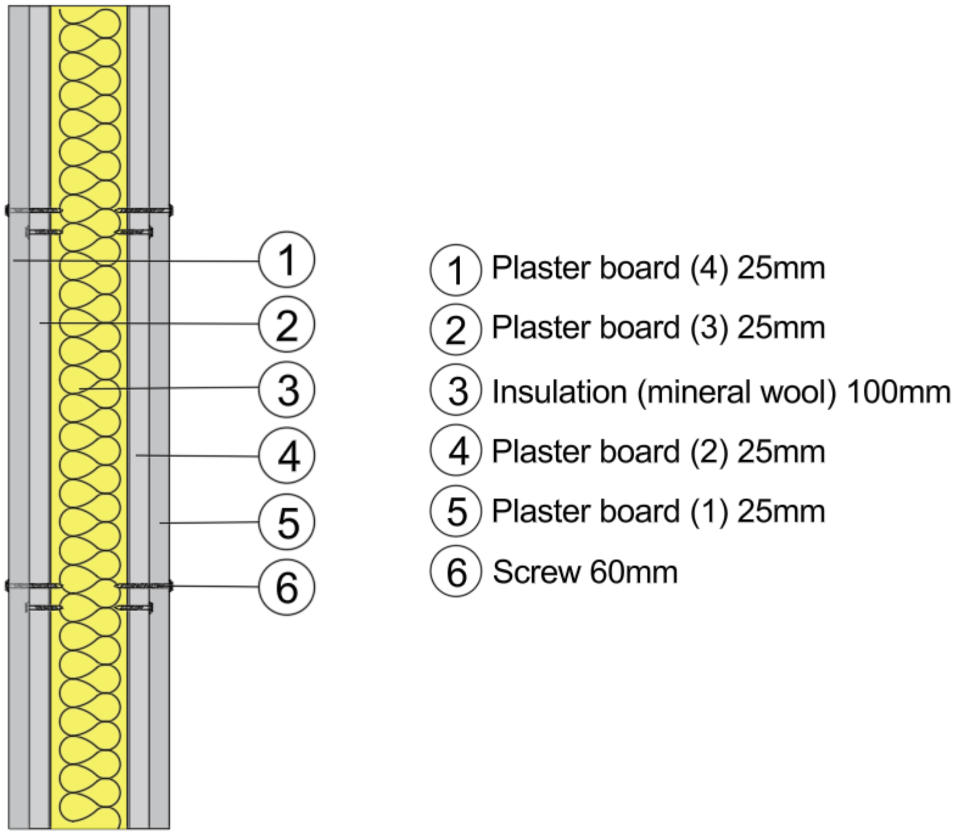



Figure 45– Diagram of interior wall

| Interior Wall (200mm) | | | | | |
|---|---|---|---|---|---|
| **Material** | **γ [kN/m3]** | **Thickness [m]** | **λ [w/m.k]** | **Load per unit area [kN/m2]** | **U-value (W/m²K)** |
| Plaster board 4 (Fermacell Powerpanel | 12 | 0.025 | 0.25 | 0.30 | 0.29 |
| Plaster board 3 (Fermacell Powerpanel | 12 | 0.025 | 0.32 | 0.30 | |
| Profile C (metal) | 78.5 | 0.025 | 0.50 | 1.96 | |
| Mineral wool insulation | 0.1 | 0.10 | 0.035 | 0.01 | |
| Profile C (metal) | 78.5 | 0.025 | 0.50 | 1.96 | |
| Plaster board 2 (fibre-gypsum/Fermacell) | 11 | 0.025 | 0.35 | 0.27 | |
| Plaster board 1(gypsum) | 11 | 0.025 | 0.35 | 0.27 | |
| Total | | | | 5.07 | |

Table 24– Physical characteristics of the interior wall

Bathroom wall (Adoptive reuse and New)

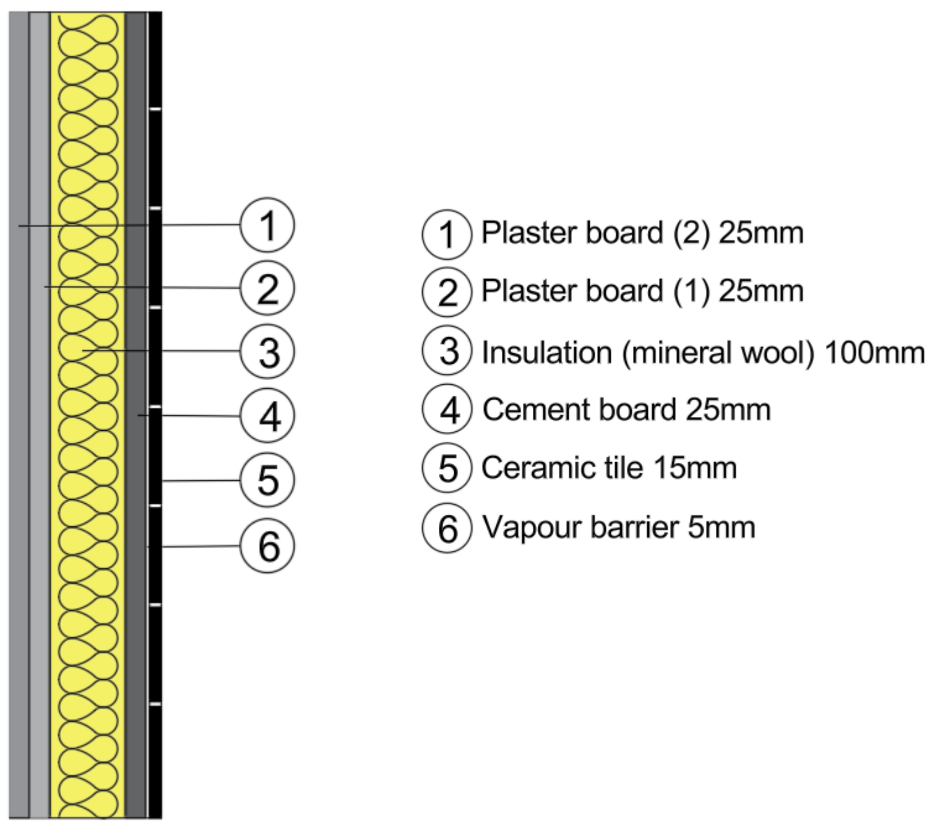



Figure 46– Diagram of bathroom wall

| Bathroom Wall (150mm) | | | | | |
|---|---|---|---|---|---|
| **Material** | **γ [kN/m3]** | **Thickness [m]** | **λ [w/m.k]** | **Load per unit area [kN/m2]** | **U-value (W/m²K)** |
| Ceramic tile | 20 | 0.015 | 0.80 | 0.30 | 0.29 |
| Vapour barrier | 9.2 | 0.001 | 0.50 | 0.01 | |
| Cement board | 0.35 | 0.025 | 0.32 | 0.009 | |
| Profile C (metal) | 78.5 | 0.025 | 0.50 | 1.96 | |
| Mineral wool insulation | 0.1 | 0.1 | 0.035 | 0.01 | |
| Profile C (metal) | 78.5 | 0.025 | 0.50 | 1.96 | |
| Plaster board 2 (fibre-gypsum/Fermacell) | 11 | 0.025 | 0.35 | 0.27 | |
| Plaster board 1(gypsum) | 11 | 0.025 | 0.35 | 0.27 | |
| Total | | | | 4.79 | |

Table 25– Physical characteristics of the bathroom wall

## 7.2 Construction nodes

Refer to paper of construction detail on the below.

# CONCLUSION

This thesis demonstrates that sustainable urban regeneration can be effectively achieved through the integration of architectural design, cost analysis, and technological evaluation. By focusing on the adaptive reuse and partial reconstruction of the Ex caserma Perotti in Bologna, the research bridges the gap between theoretical frameworks of sustainability and the practical challenges of implementation. The study draws upon the C40 competition's principles of affordability, inclusivity, and environmental responsibility, translating them into a context-specific architectural proposal that promotes energy efficiency, social well-being, and economic feasibility.

The design process adopted an integrated methodology combining analytical, creative, and technical dimensions. The adaptive reuse of existing structures preserved the cultural and material identity of the site, while the introduction of modular new buildings ensured functional flexibility and spatial efficiency. The project's urban strategy emphasized connectivity, social interaction, and micro-climatic comfort through the introduction of courtyards, green roofs, and pedestrian pathways. Collectively, these interventions transformed the former military site into a sustainable and socially vibrant student housing complex embedded within Bologna's urban fabric.

The cost estimation analysis and the application of the Analytic Hierarchy Process (AHP) played a pivotal role in linking design intentions to economic feasibility. By comparing different ventilated façade systems, solid aluminum, fiber-cement, and thermally modified timber (TMT), the research identified TMT as the optimal solution, offering the best balance between cost, energy efficiency, and ease of installation. This analytical framework not only informed material selection but also provided a replicable method for evaluating technological alternatives in early design stages. The findings confirm that sustainable design must be understood as a multidisciplinary process in which environmental performance, life-cycle cost, and constructability are evaluated together rather than in isolation.

However, some limitations should be acknowledged. The AHP evaluation involved a limited number of expert inputs and criteria, which could be expanded in future studies to include contractors, sustainability consultants, and public stakeholders for a more comprehensive perspective. Similarly, environmental performance was evaluated at a conceptual level; more advanced energy simulations or life-cycle assessments (LCA) could yield greater precision in quantifying long-term sustainability outcomes. Moreover, since the research focused exclusively on the Ex caserma Perotti results should be interpreted within its specific climatic and cultural context, and post-occupancy data were unavailable because the project remains unbuilt.

These limitations also outline potential directions for future development. Further research could integrate cost estimation with life-cycle carbon assessment to evaluate both financial and environmental impacts throughout the building's lifespan. The use of Building Information Modeling (BIM) and parametric tools could automate the AHP process, enabling dynamic cost-performance optimization during design. Finally, once implemented, the Ex-Perotti project could serve as a living laboratory for post-occupancy evaluation, providing empirical data on energy consumption, user comfort, and community engagement thereby closing the feedback loop between design intent and real-world performance.

Ultimately, this thesis contributes to the broader discourse on sustainable architecture by illustrating how adaptive reuse, modularity, and cost-informed design can collectively transform obsolete urban sites into resilient, energy-efficient, and socially cohesive environments. The Ex caserma Perotti project exemplifies how the integration of design innovation and economic analysis can guide the creation of sustainable student housing and, more broadly, support the development of inclusive, low-carbon cities for the future.

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