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Revitalizing Urban Spaces:
Rooftop Architecture and Its Potential Applications in Turin, Italy

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I also would like to dedicate this thesis to the memory of my late father, who sadly passed away during the course of this project. His strength, wisdom, and presence continue to inspire me every single day. Though he is no longer with me, his influence remains a constant source of motivation.

ABSTRACT

City space now resembles natural resources; it is finite and rare. More than half of people on Earth live in cities nowadays. People are creating cities either vertically, by sacrificing structures, or horizontally, by extending them toward the periphery, to handle this. Still, both options have caused major issues. Luckily, certain parts of cities could help to solve problems. These spaces span abandoned warehouses and vacant lots to a collection of roofs. As a common phenomenon in modern cities, rooftops are seen as lost space when they have built capacity over them. The supporting case is that the economic, urban, and environmental advantages of reusing these areas surpass conventional approaches. The challenge is determining the strategies and architectural elements for vertical extensions. Therefore, the aim of this paper is to evaluate and expose the methods required, based on literature research, documentation, and the examination of case studies and hoping to provide design and construction ideas that improve the acceptance of lost rooftop space and offer homes in locations where land is limited.

A two-step case study approach has been adopted to support this investigation. The first part focuses on a detailed theoretical and contextual analysis of rooftop extensions in dense urban settings, examining the bigger applicability of this approach. The second part applies these principles to a real-world design proposal.

The major conclusions of this research show that while the strategies required are somewhat basic, the difficulty arises in comprehending and coordinating all the required elements in the process. By employing this approach, the thesis shows how sustainable rooftop architecture can provide a solution for both housing and climate issues. It is a replicable design and implementation model that exemplifies the principles and practices of the circular economy within the existing architectural heritage of existing buildings.

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1. INTRODUCTION

Cities throughout the world are facing new and unprecedented issues as a result of the fast rate of urbanization. More than half of the world's population lives in cities now, and experts predict that number will increase by the year 2050. Despite being an indication of economic prosperity, this fast growth has put a tremendous strain on urban areas, prompting two conventional but problematic methods of development: horizontal expansion into the suburbs and vertical expansion via high-density buildings. Despite their success in boosting capacity, both approaches come with drawbacks, such as higher demand on infrastructure, environmental deterioration, and reduced livability. [1]

Even Turin, a city well-known for its historic buildings and urban framework, has similar problems. The city's roofs provide a practical substitute for conventional urban sprawl in light of the scarcity of land and the rising demand for homes. By incorporating ideas like modular stacking, green roofs, and energy-efficient technology, this thesis investigates how rooftop design may turn these unused areas into lively, practical additions to the cityscape.[2] This study seeks to provide options that match with sustainable development objectives while conserving Turin's historical identity by using the city's particular setting, which includes its legal framework, architectural typologies, and cultural attitude.

In reality, as previously said, expanding cities into the suburbs or demolishing old buildings and constructing new, taller ones that occupy the permitted envelope have traditionally been the two main methods for increasing the supply of housing in metropolitan regions. Such methods were popular a century ago because they provided the necessary space for the increasing urban population. Urban planners, legislators, and architects are always attempting to find solutions to the environmental, economic, and urban challenges that they brought with them. However, in order to address these issues, a number of writers have suggested tapping into cities' inventory of vacant places.

In 1986, the phrase "lost space" was invented by Trancik, a renowned architectural theorist. He defined it as all the unused, outmoded, and neglected areas of cities. They are "no-man's-lands" that "nobody cares about maintaining, much less using," as he put it. Additionally, they are often uninvolved and out of place in city life.[3]

Because of rising urbanization, land scarcity, and the need for housing, these areas are becoming more valuable in the city of the 21st century. Some examples of lost places are parks that have long since been abandoned, city lanes, strangely shaped pieces of land, and various types of abandoned warehouses. Roofs are one kind of wasted space that is often disregarded. As is common in modern cities, they are considered to be in Trancik's terminology when there is accessible buildability above them. For a long time, rooftops that were empty were not used because technology wasn't improving, it was too expensive, and both the government and private businesses could easily get to large amounts of land.

Sustaining a secure environment for people to live in while meeting the need for city development is one of the main issues that cities face. Some conventional approaches do address this issue; but, as discussed in this chapter, it is also obvious that they provide a number of challenges. There is a finite quantity of land available, and we are rapidly depleting it. Attempting to address the issue of housing growth using the same antiquated approaches that have been used for many years is where the difficulty resides. Finding new ways to densify existing cities without damaging them requires keeping an eye on emerging technology and putting them to use in previously untapped areas, such as the available rooftop-landscape. If we want our cities to thrive and provide good homes for generations to come, we must make sure they have enough room to expand. Here, the idea of reusing "lost spaces" stands out as a novel and environmentally friendly remedy. Unused lanes, abandoned lots, and roofs are all examples of lost places that have unrealized potential for cities. Rooftops, in particular, provide a lot of potential. These spaces, which are often disregarded, have a lot of untapped structural potential that, with little imagination, might solve important municipal problems including housing shortages, energy waste, and the need for more environmentally friendly metropolitan areas. [4][5]

Rethinking rooftop spaces is more than just an architectural innovation; it's a vital adaptation for the future of urban life. This thesis aims to prove it via literature reviews, case studies, and in-depth research of urban environment. In doing so, these spaces will become dynamic, multipurpose areas. The ultimate goal of this study is to help bring about a change in the way cities are planned and developed so that places like Turin may not only survive but flourish in the modern day. [6]

1.1. Drivers of Change

1.1.1. Urban challenges

All cities encounter significant challenges in ensuring their resilience, requiring the capacity to adapt to future changes. These changes may relate to climate factors, the evolving demographic composition of urban areas due to increased urban migration, the aim for greater inclusivity, and the development of healthier, more livable environments. [7]

Figure 1 Urban Challenges [9]

1.1.2. Functional Benefits

The incorporation of functions or volumes onto rooftops presents numerous functional advantages. Ultimately, an element is introduced that is scarce or requires attention. For instance, in a community characterized by numerous balconies, the integration of gardens on rooftops could be considered. In a community characterized by a limited number of families, the addition of family apartments on rooftops could enhance the diversity of the neighborhood. Incorporating additional functions, such as office spaces, into a residential area can enhance the vibrancy of the neighborhood during daytime hours. The inclusion of a broader array of functions, along with housing and gardens, can positively influence the duration of residents' stay in the neighborhood. [7]

Figure 2 Functional Benefits[9]

1.1.3. Financial benefits

For developers and property owners in metropolitan areas, expanding current structures vertically through rooftop expansions has a number of financial advantages that are quite appealing.

Increasing Property Value:
Adding a extra story or useable space on top of a current construction not only enhances the square footage of the building but also greatly raises its market value. This growth increases the appeal of the property to possible renters or purchasers, therefore influencing the selling or renting rates. Rooftop extensions offer a reasonably priced substitute for conventional horizontal expansions in highly crowded metropolitan areas where land is limited, and property prices are high. Using already existing buildings allows owners to optimize their return on investment without requiring further site purchase.

Revenue Creation:
Extension of rooftops creates fresh money-generating opportunities. Associations of property owners can lease recently constructed space to businesses for uses such event planning, rooftop garden installation, or recreational area establishment. These businesses improve the appearance and usefulness of the building in addition to producing extra money. Furthermore, the higher occupancy brought about by the expansion results in more payments to the treasury of the owners' association, therefore enabling money for more property maintenance or enhancement.

Affordable Construction Techniques:
The chosen building techniques greatly influence the financial viability of rooftop extension projects. The method affects elements like operational expenditures, personnel, supplies, transportation, and maintenance costs. For example, prefabricated modular additions might cut on-site labor and building time, therefore saving money. Choosing light-weight materials can also help to decrease structural reinforcing requirements, hence lowering costs. The most economically feasible building technique for every project depends on a comprehensive study of these elements.

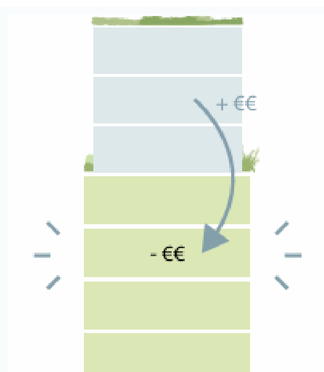
Sustainability and Energy Efficiency:

Including sustainable technology and energy-efficient designs into rooftop additions might result in major long-term savings. Utility expenses can be lowered by features including better insulation, energy-efficient windows, and solar panel integration. These improvements not only cut running costs but also raise the value and attraction of the house to purchasers or renters who care about the environment. Studies have indicated that, particularly for commercial uses, green roofs and energy-efficient additions can pay for themselves fully in a few years.

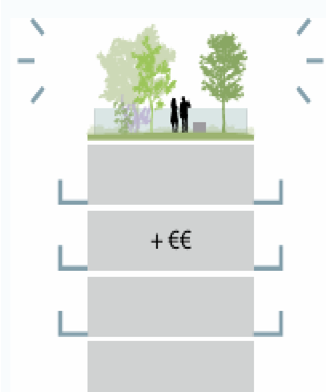
Strategic Financial Planning:

Success of rooftop expansion projects depends on a thorough financial analysis. These covers assessing building expenses, possible rental revenue, and costs of updating extant buildings to satisfy present energy efficiency criteria. By using a market study, one may ascertain the value of air rights and guide talks with interested parties. By use of financial models, we can gain understanding of expected income and create a basis for investment decisions. Sometimes a clever method is to negotiate the cost of air rights in return for hybrid pay schemes or building renovations, therefore benefiting all the participants.[8]

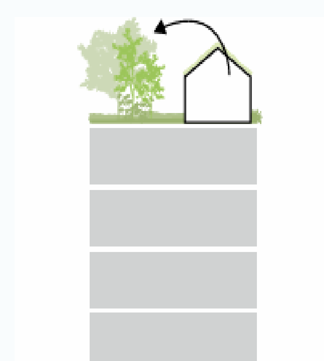
In summary, for developers and property owners rooftop extensions provide a financially favorable possibility. Through careful design and implementation of these initiatives, participants may improve property values, create extra income, and support sustainable urban growth. [9]



Generating income for the Owners Association and making the rooftop more sustainable



Increasing value of building below



Contribution for community functions on the rooftop

Figure 3 Financial Benefits[9]

Environmental benefits	• Enhancing urban density while maintaining green spaces and minimizing urban sprawl • Mitigating the need for demolition of existing structures, thereby lowering embodied carbon emissions • Elevating the performance of the base building through the financial benefits gained from an extension to support a retrofit
Social benefits	• Safeguarding the historical character of cities • Enhancing safety in the city center through increased urban density
Economic benefits	• Boosting the income potential of the base building • Securing funding for the refurbishment of the base building • Decreasing costs associated with land acquisition and new foundations • Accelerating the construction process

Table 1 Benefits of rooftop extensions [7]

1.2. Research Questions

1. What is the effectiveness of rooftop extension in meeting the housing supply requirements?
2. When planning a rooftop extension, what factors and strategies should be taken into account?
3. How can the city's flat roofs be redeveloped to promote sustainability and resilience with significant progress?
4. What are the methods for achieving a sustainable and lightweight rooftop extension project?

1.3. Methodology

The methodology integrates a series of literature reviews, carefully chosen case studies, and a concluding set of strategies evaluated through the research process. The process begins with an examination of conventional models of urban development. Subsequently, it compares these perspectives within a framework for urban development, focusing the investigation specifically on rooftop lost space.

This paper simultaneously draws conclusions from the principles of adaptable architecture, progressive growth, and advancements in fabrication to outline potential strategies for utilizing rooftop lost space, thereby establishing the conceptual foundation for an alternative model of urban development in the 21st century. The literature sources subsequently identify possibilities and a technical framework. This report subsequently assesses the principles established in the literature review, utilizing selected case studies that offer a solid basis for the proposed guidelines. Ultimately, the theoretical and technical conditions examined form the foundation of the proposed guidelines. This study will lay out particular guidelines for the effective design and construction of rooftop structures. The project will conclude with a summary of the findings.

1.4. Research outline

The study is organized into six distinct sections. Chapter one establishes a rational and broad approach.

The second chapter discusses literature reviews and explores the modern issues and the historical growth of the 21st-century city developments, investigating the pioneers of this industry and also the concepts of adaptive growth in architecture.

Chapter three contains the criteria, rules and principles needed to create such methods.

The evaluation of the case studies comes in chapter four. This includes the necessary documentation, such as photographs and drawings. The study utilizes four case studies that will offer complementary technological insights. The chosen samples provide important data to assess the possibilities, hazards, strengths, and weaknesses of the current state of rooftop extensions in urban environments.

Chapter five investigates the potential of rooftop expansion in Turin, and it will go over a two-step case study from urban scale to building scale.

And finally, chapter six draws the conclusion for the thesis.

2. LITERATURE REVIEW

Urban areas now stand as the key research subject of modern times because the majority of global inhabitants reside within them. Urban conditions in the present day operate as intricate systems which integrate historical elements with modern human goals while their components work together. These layers maintain active contact which fundamentally determines city plans and shapes urban development outcomes. [10][11]

The key obstacle in urban design requires cities to grow for the future while maintaining their livability and public welfare standards. Modern urban practices have intensified debates about traditional planning standards because urbanization continues to rise. Modern cities require new approaches because the industrial-era practices consisting of extensive standardized projects have become inadequate. Urban environments function as living systems that modify their composition and core processes based upon multiple complex organizational and operational relationships.[12]

Figure 4 before and after image of Downtown Cincinnati and The Fort Washington Way Freeway

According to specific scholars urban growth control can be achieved by employing prospective grid development plans. The research shows that areas lacking attention throughout cities contain multiple growth opportunities for development. Flexible urban systems like self-organizing cities require central attention because they enable sustainable growth in expanding cities. [12]

According to Martin in 1972 the efficient use of urban grid space would help reduce spatial constraints. The massive demolition and structural changes Martin prescribed for urban development reduced his approach's effectiveness because he did not grasp the essential value of proportionality together with refined environmentally friendly improvements. Modern urban thought emphasizes the need to unite livability with sustainability in order to satisfy present and upcoming urban dwellers' requirements. [13][14]

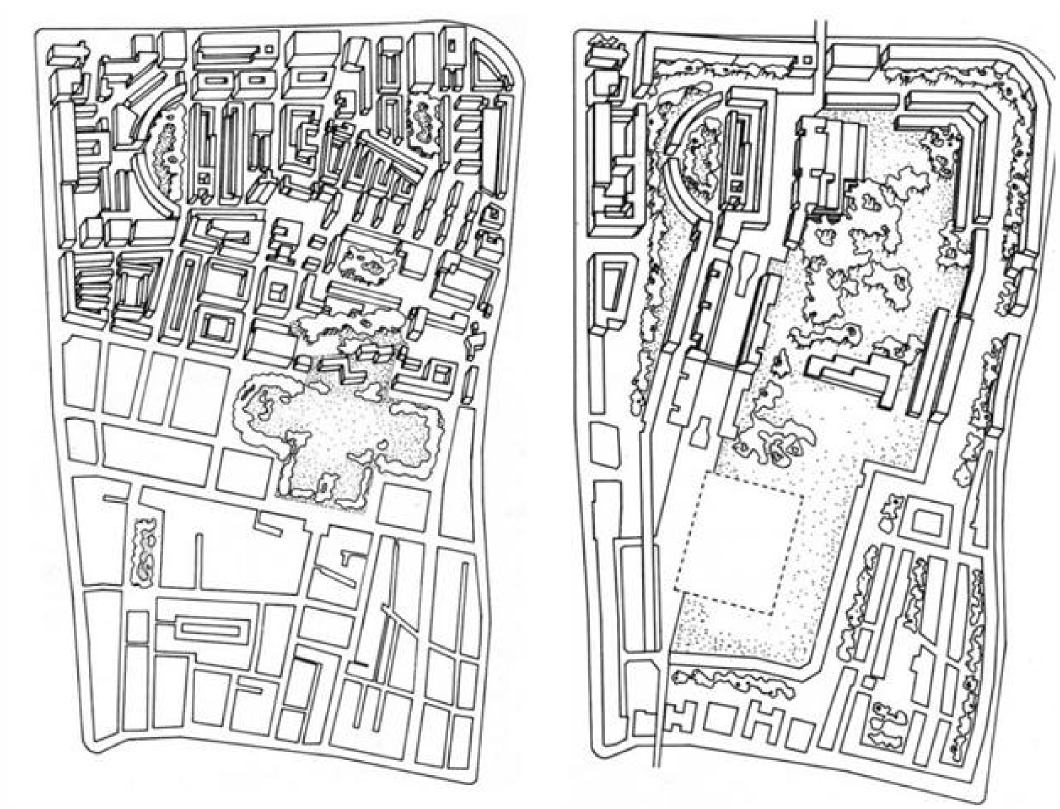


Figure 5 Martin presents an example through illustrations on how the grid can be reshaped to generate more space without altering urban dimensions. Left: Prior to the reorganization. Right: Following the reorganization. The author visualizes the classical urban approach from the twentieth century through this drawing that shows extensive urban development leading to substantial transformations of the original land layout.. [13]

2.1. Urban Densification Methods

There are seven main methods of urban densification to increase building density: [8]

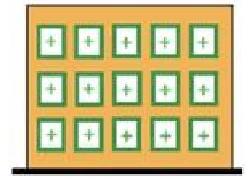
1. **Backyard Infill**: Single-family residential properties use their underutilized backyard areas for constructing new housing units through Backyard Infill. Using this technique creates an affordable and fair urban building solution fitting for expensive metropolitan areas. [15]

2. **Infill Development**: The practice of infill development involves creating new developments by building on available spaces located between existing structures for density expansion. Inhabitants utilize this strategy frequently through urban areas that have multiple disjointed land use patterns.[16]

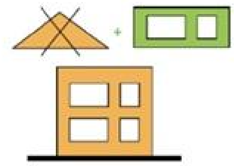
3. **Demolition and Reconstruction**: Existing low-rise buildings undergo destruction followed by building higher-density structures of increased height. This technique needs close planning to minimize displacement and maintain sustainability despite its effectiveness.[17]

4. **Adaptive Reuse – Internal Division**: Multi-family residential complexes undergo internal restructuring when people divide them into numerous small housing units and rentable rooms to boost population density. This method brings high benefits to locations that have sufficient existing buildings.[18]

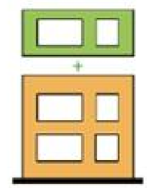
5. **Adaptive Reuse – Functional Conversion**: Old factories along with office buildings are converted into residential spaces through adaptive reuse functional conversion projects. The practice conserves both existing buildings and their history while minimzing the requirement for new construction sites.[19]



6. **Rooftop Conversion**: Existing residential building attics and storage areas undergo conversion into livable spaces which increase dwellings while maintaining the original building dimensions.[6]



7. **Rooftop Extensions (Roof Stacking)**: Rooftop Extensions allows building developers to add stories on top of existing structures which simultaneously enhances sustainable densification of urban areas.[20]



2.2. Lost Space

Urban development has traditionally studied cities through flat two-dimensional views prior to selecting extensive projects that disregarded smaller unused spaces. Cities became neglected for underdeveloped areas which today are classified as "lost spaces." These areas show multiple problems with their connection to urban structures, and they lack clear purpose or beneficial interactions among city life.[3][21]

Modern urban landscapes show less ownership of large continuous properties because smaller distinct lots now occupy this territory. One suggestion would be the impact of promoting small-scale environments specifically located near main roads for developing the city. The technique includes small development projects that connect divided areas with the city master plan to generate sustainable progress possibilities. [22][23]

Urban development generates numerous lost spaces primarily through three factors: zoning law adjustments and urban renewal efforts and the steady increase of car-oriented infrastructure. Trancik establishes five major categories of lost spaces which include automobile dependence and modernist architecture and privatization of public areas and urban zoning regulations and land use changes. The identified areas consist of abandoned parks as well as empty warehouses and forgotten rooftop spaces.

Supercycling represents an innovative approach for transforming abandoned areas according to Coloco Collective urban design company. This approach entails the revitalization of neglected structures and their reintegration into the urban landscape. Competing urban development efforts reveal how unused spaces become valuable components in solving housing problems while enhancing city livability. Rooftop spaces have recently gained recognition as independent lost spaces because they show potential to boost urban density development. The emergence of such spaces results from outdated zoning regulations along with changes in land use direction. Urban rooftop development creates opportunities to recover essential spatial assets because rising residential requirements in densely populated metropolitan areas.[3][23][24]

Lost spaces have proven themselves to be substantial opportunities for urban renewal initiatives. These underutilized areas become sustainable livable spaces by transforming them into functional zones which meet the needs of urban residents.

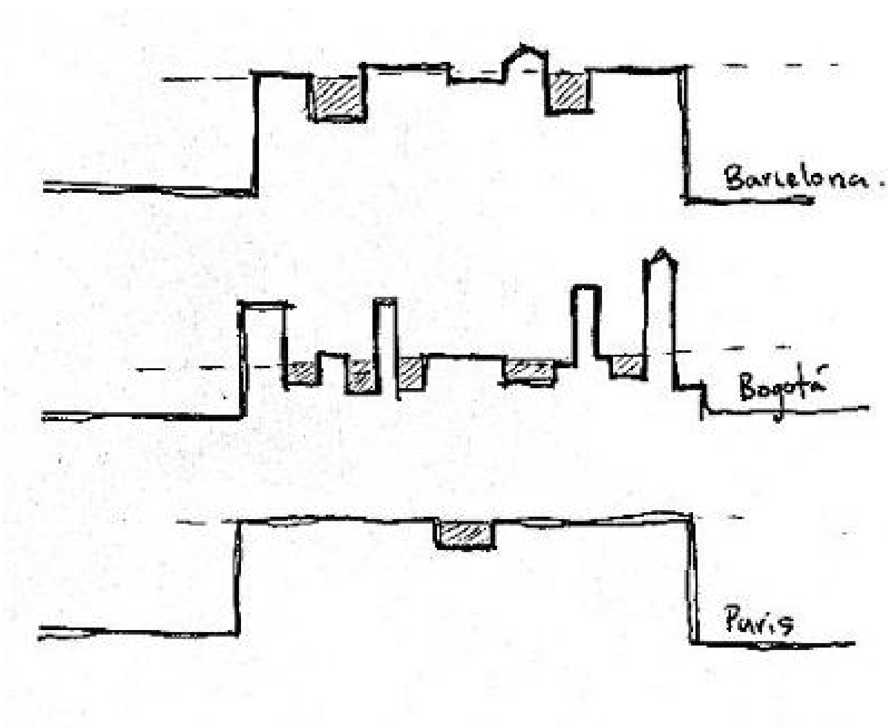


Figure 6 The hatch represents lost space in today's rooftops [8]

2.2.1. The Fifth Facade

The growing land value in cities has led to high-rise construction as an answer for rising space requirements. Rapid urban development created buildings of varying heights and caused an increase in service equipment such as water tanks cooling systems and satellite dishes which have become common rooftop features. Rooftops exist in a forgotten state because throughout history they received no attention as they were only meant to support functional uses other than being decorative spaces. Hence they are now considered "lost space."[3][25]

Researchers have begun studying the "fifth facade" which is a concept developed by Le Corbusier Swiss-French designer and painter because of its sustainability importance. Structure developments on rooftops now serve multiple purposes including farming activities and solar and water management which shows their worth in densifying cities while boosting resource management. Older building structures in urban areas can utilize rooftop spaces for vertical expansion when floor area ratio (FAR) remains vacant. The complete realization of rooftop potential demands overcoming challenges that exist in terms of structural limitations and affordability as well as municipal regulations. Rooftops that fail to reach their full potential can now be repurposed through prefabricated methods developed from emerging technologies. The sustainable urban development goals support this method which offers housing solutions and optimizes resource utilization in cities. [26]

Figure 7 Le Corbusier, Villa Savoye, 1928-1931 [68]

2.3. Pioneers in Rooftop Extension Industry

The growing population needs have driven rooftop extensions to emerge as powerful solutions to address urban housing shortages especially in prominent cities such as Amsterdam, Rotterdam, Barcelona and London. Rooftops across these cities have shown their potential to create profitable sustainable businesses thanks to innovative companies working with progressive policies.

Rooftop innovation dominates Amsterdam and Rotterdam through extensive utilization of flat roof spaces to tackle municipal problems such as residential deficits along with climatic adaptation requirements and energy transformation. Through its Rooftop Catalogue municipality and MVRDV architecture studio identified more than 130 various rooftop applications which demonstrate both sustainability and multiple usage possibilities. The Rooftop Catalogue project acts as an inspirational force that encourages housing corporations together with developers to build rooftop developments thus establishing Rotterdam as an urban densification leader.[9]

La Casa por el Tejado (LCT) architectural company in Barcelona defines new rooftop development concepts through their perspective of buildings as "unfinished artifacts" holding unexplored expansion possibilities. The building solution offered by LCT consists of lightweight prefabricated modular systems which reduce structural requirements as well as shortening construction timelines. Rooftop extension projects of LCT in Barcelona exemplify how original designs can be maintained to construct high-end housing. The business model developed by LCT serves for densifying urban areas while resolving housing scarcity issues.[8]

HTA Design LLP in partnership with Apex Airspace Development has established rooftop housing solutions which address London's critical housing emergency. The Apex Airspace development company provides modular construction units as they build budget-friendly homes by transforming abandoned rooftop areas into residential units. Rooftop development stands as a central strategy of London's planning policies since Apex Airspace Development delivers projects which adhere to these directives. The study by HTA Design shows rooftop spaces have great growth potential because rooftop extensions could build 179,126 new homes across Greater London. [27]

The development of rooftop extensions proves to be both an answer to metropolitan housing scarcity and a rewarding commercial opportunity. By integrating modular construction, sustainability, and innovative design, companies like LCT and Apex Airspace have created scalable models that attract investment and generate significant returns. Their work underscores the untapped potential of rooftops as a resource for urban growth and sustainability.

In conclusion, Amsterdam, Rotterdam, Barcelona, and London have set a benchmark for rooftop extensions, proving that this approach is both economically viable and environmentally sustainable. Their success serves as a blueprint for other cities to follow.

Figure 10 Blue home in Rotterdam (Source: divisare.com)

Figure 9 New Scotland Yard Government Building in London (Source: www.archdaily.com)

2.4. Adaptive Growth

The fast-growing urbanization process caused a major deficit in available land for construction purposes. Traditional architecture follows rigid guidelines for static structure design through controlled planning while viewing buildings as static objects. The built environment remains dynamic by nature since some facilities deteriorate over time while others undergo transformations and numerous facilities keep growing. Design practice needs to implement adaptability functions to allow structures to transform their space requirements over time.[28]

Multitude of cities select standardized designs due to both their fast deployment capabilities and operational effectiveness. Building this way leads people to view buildings as replaceable objects thus creating both regular building demolitions and major resource waste. First-class sustainability standards seek preservation of resources and reuse, but these practices fail to meet such requirements. Adaptive growth brings relief through its approach of treating buildings as dynamic structures instead of fixed constructions. Structures built using this method include future expansion capabilities with adaptable components and empty spaces that allow changes based on user requirements over time.[29][30]

Progressive growth procedures enable urban areas to fulfill their space needs without destroying buildings thus reducing material waste and energy consumption. The approach matches the aspirations of sustainable urban development and allows us to maximize our use of urban resources.

2.5. Conclusion

The author analyzes growth through a complete scope while showing new development prospects along with methods to handle city issues. This paper delivers a summarized presentation of its results. Modern urban development depends on recognizing underutilized spaces, particularly rooftops as essential units during the twenty-first century. These neglected locations will create opportunities to solve metropolitan expansion problems along with the decrease of climate damage and housing cost improvements. The evaluation process of suitable rooftops reveals many unused areas in central housing markets which can fulfill the growing demand for urban living spaces. The research has established that buildings require an organized procedure to make possible their flexible transformation. Present urban areas must integrate current building sites together with digital construction methods and prefabrication to tackle municipal growth problems specifically in housing development.

Two primary actions are suggested: 1. Building developers should identify the many ways rooftop spaces help advance urban development goals. 2. Modern construction methods should be used to develop these areas in order to help developers construct large-scale residential properties.

Through the combination of digital technology and Open Building Principles which are a design approach in which the permanent building is separated from the adaptable interior. Change over time is allowed, hence scalable and user-responsive housing is provided for evolving needs. We can transform the housing production industry because it brings scalable sustainable solutions to urban environment challenges. A comprehensive urban resource management strategy emerges from integrating concepts between lost space research and innovation-based construction approaches. [31][32]

3. PRINCIPLES AND TECHNICAL DESIGN CONSIDERATIONS

3.1. Rooftop Principles

The density overload of cities has turned rooftops into vital resources that drive forward urban developmental progress. Rooftop architecture enables cities to undergo transformation while establishing sustainable practices in addition to resolving residential scarcity. New construction on rooftops generates two distinctive relationship methods between additions and existing structures called parasitic and symbiotic. The two approaches demonstrate contrasting perspectives about how new structures should relate to their surroundings while affecting design, functionality and urban integration aspects. [6]

Topping up refers to putting one or more new floors on top of an existing building, while new function involves putting alternative uses, such as housing or public space, onto underused roofs.

Relationship	Use	Design	Duration
Parasitic	Topping Up (Extending)	Matching	Temporary
Symbiotic	New Function	Contrasting	Permanent

Table 2 Rooftop Architecture Principles

3.1.1. Relationship: Parasitic VS Symbiotic

The operational capabilities and building stability of parasitic architecture exclusively follows the requirements of its host structure. Parasitic architecture showcases three defining features which include adaptability and exploitiveness together with transience while producing significant visual difference between the host building. Within the cityscape of Vienna the Falke Strasse office extension stands prominently on the roof of a conventional structure following its design from Coop Himmelb(I)au, Many critics agree the design demonstrates "chaotic distortion" against the original host building structure because of its revolutionary yet invasive characteristics.

The potential dynamic elements that parasitic designs introduce during their relationship with hosts may question established design aesthetics while elevating the building's significance. Through symbiotic architecture two entities develop a beneficial relationship which benefits both additions and their host structures. The method integrates a new structural design with original buildings to enhance operational effectiveness and landmark status of both structures. Symbiotic designs serve dual objectives of sustainable urban development while they integrate environment-friendly function with social interaction goals. Rooftop greenhouses and gardens establish a symbiotic connection between structures through energy efficiency benefits for the main building combined with nature appreciation by residents across communities.[33]

Figure 11 Coop Himmelb(l)au firm in Vienna (Source: Google.com)

3.1.1.1. Design Considerations and Urban Implications

Rooftop intervention designs that use parasitic or symbiotic methods perform effectively based on three main factors: building structural strength, social and environmental value of the location, and user needs. Visual impact forms the central focus of parasitic designs yet symbiotic designs emphasize how integration with their surroundings creates concepts that work together.

The combination of rooftop gardens increases biodiversity in cities while creating spaces for human socializing thus creating beneficial outcomes for the entire community. Symbiotic designs maintain substantial value for sustainable urban development projects. Green infrastructure components such as rooftop gardens together with solar panels help cities manage heat islands and improve air quality and cut down on energy usage. Systems that implement rainwater harvesting with renewable energy installations create substantial environmental benefits in roof-based architectural designs.[34]

3.1.1.2. Broader Urban Potential

Rooftops demonstrate their substantial transforming abilities through parasitic together with symbiotic approaches within urban design. Parasitic designs push boundaries of traditional design principles to foster architectural discussion about creativity but symbiotic designs support communal sustainability goals. These approaches establish the necessary framework to analyze city revitalization together with housing challenges while developing sustainable urban areas. Urban developers can bring about an inclusive sustainable future through proper rooftop architectural applications that change how cities look from above.[6]

	Symbiotic	**Parasitic**
Relationship	Mutual benefit and coexistence	Dependency, often one-sided
Impact on Host	Enhances the host structure	May strain or alter the host structure
Aesthetic Approach	Harmonious integration	Often contrasting or disruptive
Examples in Practice	Green roofs, sustainable retrofitting	Pods, cantilevered extensions
Sustainability	High	Variable, sometimes temporary

Table 3 Parasitic vs Symbiotic Comparison Table (Author)

3.1.2. Use: Topping Up VS New Function

Rooftop architecture allows architects to recreate the destiny of vertical spaces by integrating contemporary urban demands through a variety of suitable functions. Site-specific characteristics together with appropriate solution choices determine the success of interventions which pursue renovation and revitalization as well as regeneration objectives. The two separate strategies used in rooftop development involve both "Topping Up" approaches and functional incorporation. The implementation methods for rooftop development generate unique consequences regarding social living and functional purposes along with architectural outcomes.[7]

3.1.2.1. Topping Up: Expanding Existing Functions

According to Melet and Vreedenburgh "Topping Up" refers to a procedure which adds new floors onto existing buildings while maintaining their operational function. The building expansion process mainly adds new levels which duplicate the existing building functions. The practice of floor space addition improves property market values but generally fails to address urban social or community needs.

According to Melet and Vreedenburgh the social structural and architectural value remains unchanged by such an approach because this method serves the very same target audience. The focus of present-day rooftop development primarily concentrates on maximizing economic value by sacrificing opportunities for enhancing social relations between communities. The addition of extra workspace occurs in office buildings while residential buildings extend to include further apartments. The density-increasing initiatives usually fail to examine potential future purposes and essential urban solutions like inadequate public spaces along with minimal local involvement.[7]

3.1.2.2. Adding New Functions: Unlocking Social and Urban Potential

When new functions integrate with rooftop spaces the result is active social and architectural centers that fulfill economic needs along with urban social roles. The technique demonstrates modern uses for rooftop locations through the development of sports venues and community areas together with public facilities. Such design approach creates space for social networking and cultural programming and community involvement which addresses important requirements in crowded urban districts.

Green spaces on rooftops with recreational areas function as critical urban elements which simultaneously improve residential standards together with preserving biodiversity in metropolitan landscapes. Rooftop cultural spaces which include theaters and art installations possess the ability to create new social opportunities that enhance creativity across the community while fostering inclusivity. The interventions exist to meet various goals including architectural development and social improvements or economic opportunities and these approaches operate specifically for neighborhood needs.

3.1.2.3. Implications for Urban Development

There's a lot to be said when it concerns urban development for "Topping Up" and new functions. New functions are primarily social and environmental advantages, while "Topping Up" is usually more oriented toward economic efficiency and densification. Integrating new functions would be more aligned with the avowed objectives of sustainable urban development: it is intended to create multifunctional spaces intended to promote community well-being and the urban resilience into which they are integrated.

With new function rooftops, urban environments can begin to tackle the deficit in housing available, lack of enough public spaces, and the need for sustainability in infrastructure.

The bottom line would state that rooftop interventions achieve their effectiveness at a primary locus-the ground-contact surface of economic, social, and environmental parameters with the effectiveness of intervention.

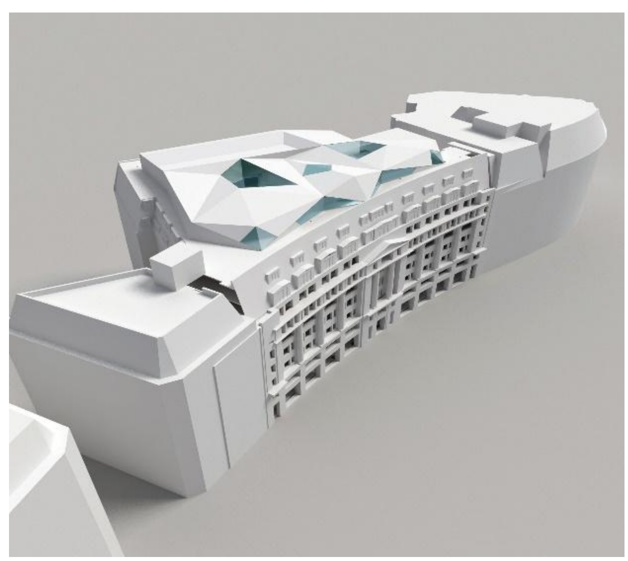
3.1.3. Design: Matching VS Contrasting

Roof additions, like any other extensions to buildings, almost always connect themselves to the architecture below. One therefore subjects the extra design resolution to critical assessment to establish whether the addition acts in concert with the old structure or offers something contrasting.

The design of a vertical addition to the host building, from the structural perspective, warrants thorough analysis, as this may be the very key to the success of an addition. There are several methods in which a match may be forged. For example, the physical properties of the host could be interpreted either literally or compositional and materially.

This includes imitating window openings and trim details for seamless integration and, thus, minimizing any differences between the new and existing structures. Following a similar context, some extensions can unfold as traditional mansard roofs by utilizing the entire area of the roof plane, thereby establishing an age-old yet harmonious relationship with the structure beneath. Zamperini argues that rooftop development should have regard for the environment; that is, rooftop design should relate to the building directly below it. This usually applies to the discussion of extensions that utilize the existing structure. [35]

To act in contrast to the present building is thereby a major design option, seeing the rooftop as an experimental platform for new ideas. The rooftop extension by Sheppard Robson at Aldwych House in London introduces a different entity with a personality standing in contrast with the historic structure set within a conservation area. The uniquely formed structure is a contrasting interpretation of the conventional mansard roofs being built in its vicinity, thus making an architectural statement whose importance in the weighing of the arguments presented aided its ascent through the process for planning approval. The addition relates differently to the existing building in terms of materials and form while remaining respectful of the symmetry of the existing structure and framing views towards the Southbank and the City as well as mediating solar gain. [36]



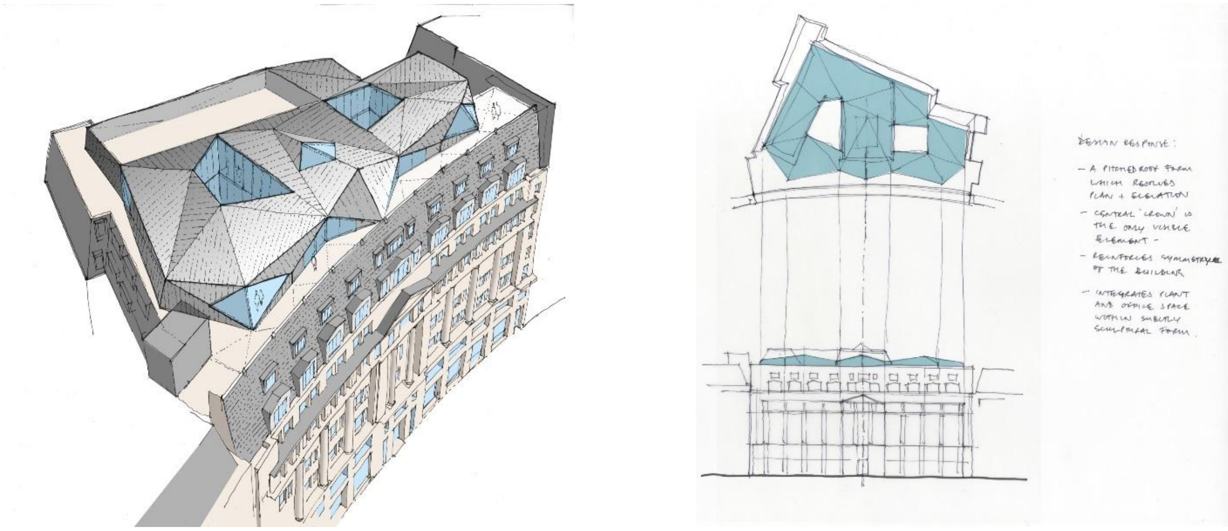


Figure 12 Images of proposed addition to Aldwych House by Sheppard Robson Source: www.sheppardrobson.com

3.1.4. Duration: Temporary VS Permanent

Rooftop additions really offer interesting solutions to urban issues, which are designed and constructed according to different needs of cities. There has been a greater interest in temporary rooftop installations because they make it possible to use what are otherwise underused spaces without the difficulties of long-term planning and regulations. The above-mentioned structures-pop-up cinemas, restaurants, and event spaces-have proven to be really effective in rapidly transforming cities because of their flexible and adaptive contribution to the pace of urban change. Take, for example, the pop-up restaurant by Park Associate in Milan Pop up Restaurant in Milan, set on top of the late 19th-century Palazzo Beltrami. This very readily illustrates that trend. The installation is designed to be clearly mobile, so that it adapts very well to different urban environments as well as giving people an experience on top of the roof.

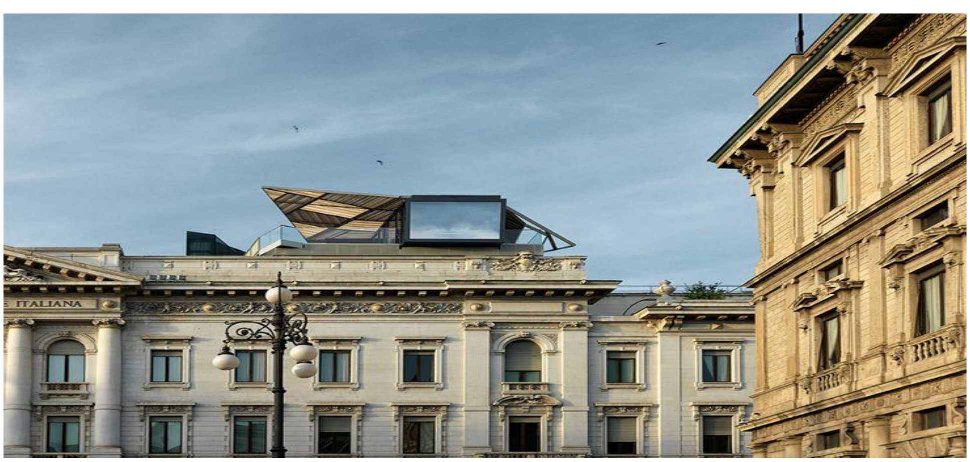


Figure 13 Pop up Restaurant in Milan (Source: Google.com)

Temporary rooftop additions have become an essential tool for fulfilling urban needs such as associating places or theaters into the city. Such additions, however minor, are normally lightweight, modularly designed, and easily assembled/dismantled. Such projects are often an opportunity or a field for experimentation-invention, with which designers come up with novel solutions that do not require comprehensive planning approval for permission. Hence, documentational obstacles are brought down while encouraging creativity and innovation in urban design.

Permanent rooftop design responds to needs ranging from housing to commercial growth in the cities. Such structures must be evaluated concerning materials, structural integrity, and design so as to yield durability and integration into the host building. Permanent buildings like homes or businesses have higher economic returns and aim toward long-lasting usage.[35] These have green roofs and rooftop gardens that become permanent elements of cities to encourage urban biodiversity and address environmental challenges.[37]

According to the urban context and objective, rooftop solutions can be either temporary or permanent. Temporary installations inspire innovation and experimentation while permanent solutions strengthen urban resilience and relevance. Social spaces can integrate both methods for flexibility to address emerging community needs.

3.2. Building Typologies

Various historical, cultural, and functional factors influence urban building typologies. They can be classified on the basis of various criteria: form, function, construction materials, climatic conditions and arrangements in space. Building typologies in European cities often exhibit features of both historical and modern origin. In older neighborhoods, traditional unreinforced masonry is the standard material for construction, while reinforced concrete and composite buildings predominate in present developments. Typologies depend on urban planning practices concerning plot density, street configurations, and open space provisions. [39]

Building typologies are essential to understanding structural characteristics and energy performance for urban settings. In Italy, the building stock shows plenty of variation with each typology stemming from different historical ways of building, climatic policies, and urban planning designs. Professors Ilaria Ballarini and Vincenzo Corrado have been active in constructing a scientific basis for Italian building typologies, making important contributions through their work in the IEE-TABULA project. The project sought to establish an integrated framework on energy performance and refurbishment capacity. The "Building Typology Matrix," classifies buildings according to climatic zones, construction periods, and sizes and represents a useful working tool for energy assessments. [40][41]

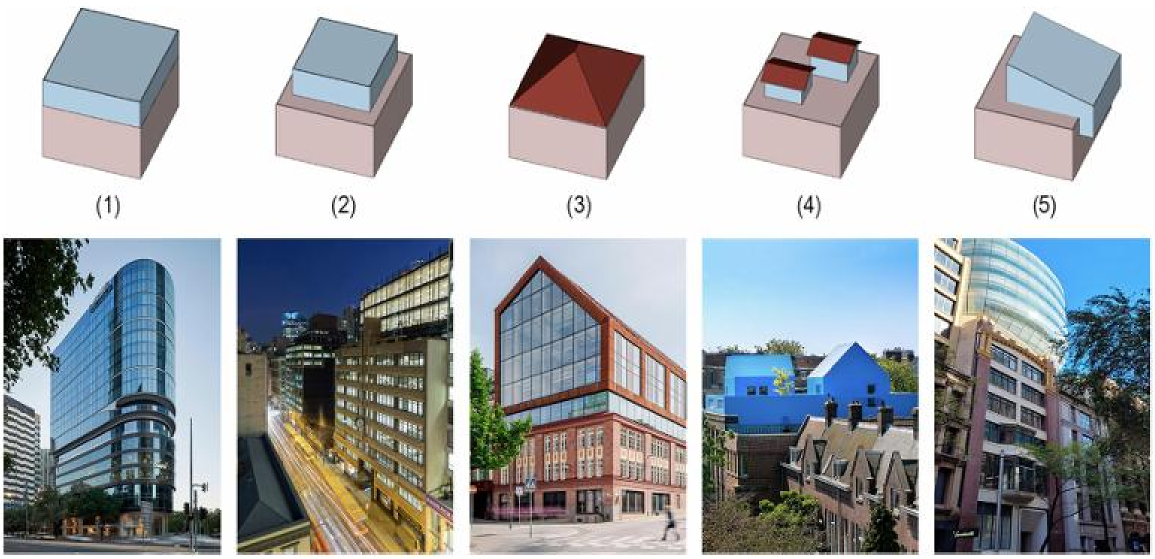


Figure 14 Five forms of Vertical Expansion projects: (1) extruded - Adina Apartment Hotel, Melbourne; (2) setback - Deco Building, Sydney; (3) roof - Trikafabriken 9, Hammarby Sjostad; (4) rooftop village - Didden Village, Rotterdam; (5) freeform - Substation 164, Sydney. [38]

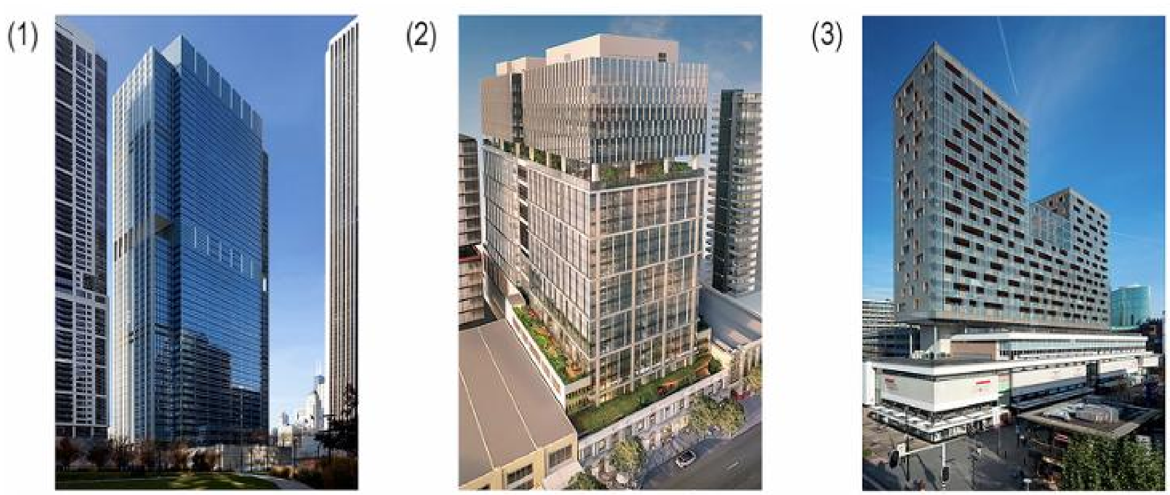


Figure 15 Examples of Vertical Expansion projects and their facade strategies: (1) unified facade at Blue Cross Blue Shield; Chicago; (2) similar facade at Midtown Centre, Brisbane; (3) distinct facade at De Karel Doorman; Rotterdam. [38]

3.2.1. Potential for Rooftop Expansions

The architectural variety brings different noise levels in types of Italian buildings in regard to suitability for rooftop additions. Flat roofs on post-war and modern buildings should be considered for future vertical expansion, especially for housing units and green roofing systems above them. On the contrary, pitching roofs that have been mostly preserved in older buildings may require extensive structural modifications. The Centro and Vanchiglietta neighborhoods of Turin, which were also shortlisted for further study in this document, offer many possibilities for rooftop construction due to the mix of historical and contemporary typologies. Flat roofs in these areas may be configured as tools for efficient improvements, such as photovoltaic panels or lightweight modular constructions, consistent with the overarching objectives of urban densification and sustainability.

The rooftop extensions and energy refurbishments can be determined best from the building typologies by policy makers and urban planners. This contribution will make urban areas less functional but more sustainable and boost the attainment of national and European energy efficiency targets.

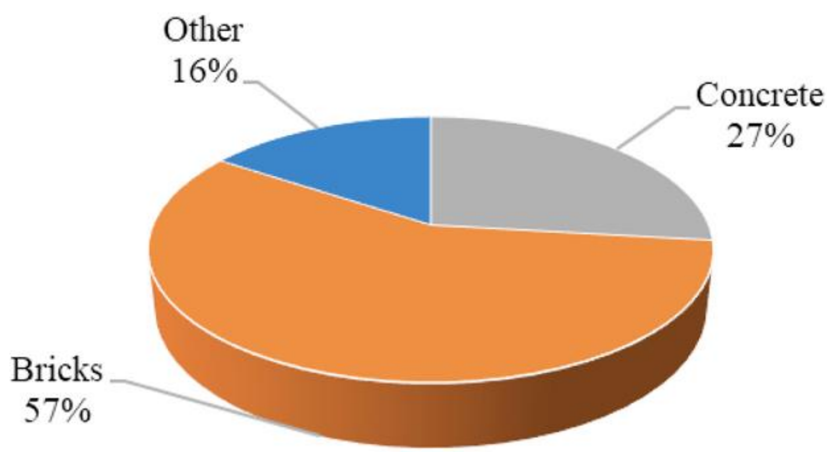
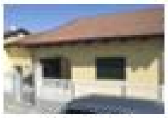
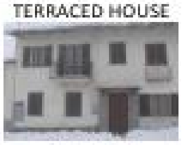
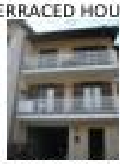
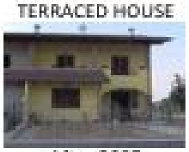


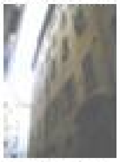
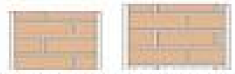
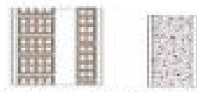
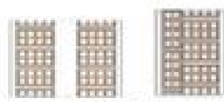
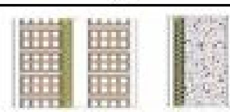
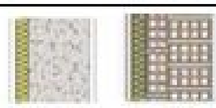
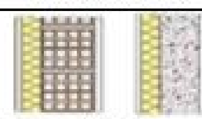
Figure 16 Types of construction materials used in Northern Italy [69]

Figure 17 Construction elements of different building types [41]

Building-type	ROOFS/CEILINGS[(1)]	FLOORS	WALLS	WINDOWS	DOORS
SINGLE-FAMILY HOUSE  up to 1900	Pitched roof with wood structure and planking	Concrete floor on soil	Masonry with lists of stones and bricks (40 cm)	Single glass, metal frame without thermal break	Wooden door
SINGLE-FAMILY HOUSE  1901-1920	Pitched roof with wood structure and planking	Concrete floor on soil	Masonry with lists of stones and bricks (40 cm)	Single glass, metal frame without thermal break	Wooden door
SINGLE-FAMILY HOUSE  1921-1945	Pitched roof with wood structure and planking	Concrete floor on soil	Solid brick masonry (38 cm)	Single glass, wood frame	Wooden door
SINGLE-FAMILY HOUSE  1946-1960	Pitched roof with brick-concrete slab	Concrete floor on soil	Solid brick masonry (38 cm)	Single glass, wood frame	Wooden door
SINGLE-FAMILY HOUSE  1961-1975	Pitched roof with brick-concrete slab	Concrete floor on soil	Hollow brick masonry (40 cm)	Single glass, wood frame	Wooden door
SINGLE-FAMILY HOUSE  1976-1990	Pitched roof with brick-concrete slab, low insulation	Floor with reinforced brick-concrete slab, low insulation	Hollow wall brick masonry (40 cm), low insulation	Double glass, air filled, wood frame	Double panel wooden door
SINGLE-FAMILY HOUSE  1991-2005	Ceiling with reinforced brick-concrete slab, medium insulation	Floor with reinforced brick-concrete slab, medium insulation	Hollow brick masonry (40 cm), medium insulation	Double glass, air filled, wood frame	Double panel wooden door

Building-type	ROOFS/CEILINGS[1]	FLOORS	WALLS	WINDOWS	DOORS
SINGLE-FAMILY HOUSE  After 2005	Ceiling with reinforced brick-concrete slab, high insulation	Concrete floor on soil, high insulation	Honeycomb bricks masonry (high thermal resistance), high insulation	Low-e double glass, air or other gas filled, wood frame	Double panel wooden door
TERRACED HOUSE  Up to 1900	Pitched roof with wood structure and planking	Vault floor with solid bricks	Masonry with lists of stones and bricks (40 cm)	Single glass, wood frame	Wooden door
TERRACED HOUSE  1901-1920	Pitched roof with wood structure and planking	Concrete floor on soil	Masonry with lists of stones and bricks (40 cm)	Single glass, wood frame	Wooden door
TERRACED HOUSE  1921-1945	Flat ceiling with hollow bricks and steel beams	Concrete floor on soil	Solid brick masonry (25 cm)	Single glass, wood frame	Wooden door
TERRACED HOUSE  1946-1960	Pitched roof with brick-concrete slab	Floor with reinforced brick-concrete slab	Hollow wall brick masonry (30 cm)	Single glass, wood frame	Wooden door
TERRACED HOUSE  1961-1975	Flat roof with reinforced brick-concrete slab	Concrete floor on soil	Hollow brick masonry (40 cm)	Single glass, wood frame	Wooden door
TERRACED HOUSE  1976-1990	Pitched roof with wood structure and planking, low insulation	Floor with reinforced brick-concrete slab, low insulation	Hollow wall brick masonry (40 cm), low insulation	Double glass, air filled, wood frame	Double panel wooden door
TERRACED HOUSE  1991-2005	Ceiling with reinforced brick-concrete slab, medium insulation	Floor with reinforced brick-concrete slab, medium insulation	Hollow brick masonry (40 cm), medium insulation	Double glass, air filled, wood frame	Double panel wooden door
TERRACED HOUSE  After 2005	Ceiling with reinforced brick-concrete slab, high insulation	Concrete floor on soil, high insulation	Honeycomb bricks masonry (high thermal resistance), high insulation	Low-e double glass, air or other gas filled, wood frame	Double panel wooden door

Building-type	ROOFS/CEILINGS[1]	FLOORS	WALLS	WINDOWS	DOORS
MULTI-FAMILY HOUSE  Up to 1900	Vault ceiling with solid bricks	Vault floor with solid bricks	Masonry with lists of stones and bricks (60 cm)	Single glass, wood frame	Wooden door
MULTI-FAMILY HOUSE  1901-1920	Ceiling with wood beams and hollow bricks	Vault floor with bricks and steel beams	Masonry with lists of stones and bricks (60 cm). Solid brick masonry (38 cm)	Single glass, wood frame	-
MULTI-FAMILY HOUSE  1921-1945	Ceiling with reinforced concrete	Floor with reinforced concrete	Solid brick masonry (38 cm). Hollow wall brick masonry (30 cm)	Single glass, wood frame	-
MULTI-FAMILY HOUSE  1946-1960	Ceiling with reinforced brick-concrete slab	Floor with reinforced brick-concrete slab	Solid brick masonry (38 cm). Solid brick masonry (25 cm)	Single glass, wood frame	-
MULTI-FAMILY HOUSE  1961-1975	Ceiling with reinforced brick-concrete slab	Floor with reinforced brick-concrete slab	Hollow wall brick masonry (30 cm). Hollow brick masonry (25 cm)	Single glass, wood frame	-
MULTI-FAMILY HOUSE  1976-1990	Ceiling with reinforced brick-concrete slab, low insulation	Floor with reinforced brick-concrete slab, low insulation	Hollow brick masonry (25 cm), low insulation	Double glass, air filled, metal frame without thermal break	-
MULTI-FAMILY HOUSE  1991-2005	Ceiling with reinforced brick-concrete slab, medium insulation	Floor with reinforced brick-concrete slab, medium insulation	Hollow wall brick masonry (30 and more), medium insulation. Concrete masonry (also prefabricated, 30 cm), medium insulation	Low-e double glass, air or other gas filled, wood frame	-
MULTI-FAMILY HOUSE  After 2005	Ceiling with reinforced brick-concrete slab, high insulation	Floor with reinforced brick-concrete slab, high insulation	Honeycomb bricks masonry (high thermal resistance), high insulation. Concrete masonry (also prefabricated), high insulation	Low-e double glass, air or other gas filled, wood frame	-

Building-type	ROOFS/CEILINGS[1]	FLOORS	WALLS	WINDOWS	DOORS
APARTMENT BLOCK  Up to 1900	 Ceiling with wood beams and hollow bricks	 Vault floor with solid bricks	 Masonry with lists of stones and bricks (60 cm). Solid brick masonry (50 cm)	 Single glass, wood frame	-
APARTMENT BLOCK  1901-1920	 Vault ceiling with bricks and steel beams	 Vault floor with bricks and steel beams	 Solid brick masonry (38 cm). Solid brick masonry (50 cm)	 Single glass, wood frame	-
APARTMENT BLOCK  1921-1945	 Flat ceiling with hollow bricks and steel beams	 Floor with hollow bricks and steel beams	 Solid brick masonry (50 cm). Solid brick masonry (25 cm)	 Single glass, metal frame without thermal break	-
APARTMENT BLOCK  1946-1960	 Ceiling with reinforced brick-concrete slab	 Floor with reinforced brick-concrete slab	 Hollow wall brick masonry (30 cm). Concrete masonry (18 cm)	 Single glass, wood frame	-
APARTMENT BLOCK  1961-1975	 Ceiling with reinforced brick-concrete slab	 Floor with reinforced brick-concrete slab	 Hollow wall brick masonry (40 cm). Hollow brick masonry (40 cm)	 Single glass, wood frame	-
APARTMENT BLOCK  1976-1990	 Ceiling with reinforced brick-concrete slab, low insulation	 Floor with reinforced brick-concrete slab, low insulation	 Hollow wall brick masonry (40 cm), low insulation. Concrete masonry (also prefabricated, 18 cm), low insulation	 Double glass, air filled, metal frame without thermal break	-
APARTMENT BLOCK  1991-2005	 Ceiling with reinforced brick-concrete slab, medium insulation	 Floor with reinforced brick-concrete slab, medium insulation	 Concrete masonry (also prefabricated, 30 cm), medium insulation. Hollow brick masonry (40 cm), medium insulation	 Double glass, air filled, metal frame with thermal break	-
APARTMENT BLOCK  After 2005	 Ceiling with reinforced brick-concrete slab, high insulation	 Floor with reinforced brick-concrete slab, high insulation	 Honeycomb bricks masonry (high thermal resistance), high insulation. Concrete masonry (also prefabricated), high insulation	 Low-e double glass, air or other gas filled, wood frame	-

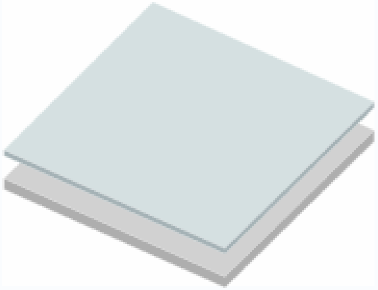
3.3. Sustainability

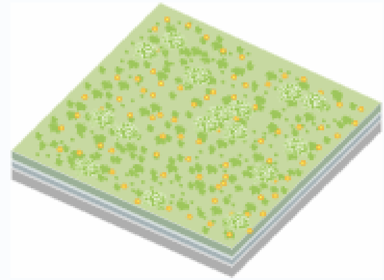
The existence of sustainability in rooftop development is verifiable, Rooftop development supports sustainability by enabling urban densification, energy efficiency, and reuse of existing structures. Albeit urban development must accommodate environmental purposes. With issues relating to energy efficiency and conserving our resources, the Rooftop-Catalogue in Rotterdam states that every rooftop intervention must promote the sustainability of urban settings. Insulation and limited vegetation are considered vital basic strategies, while other sustainable features-directly recommended-are water storage systems, renewable energy technologies, or sustainable urban densification. Sustainability standards are therefore mandatory for any new rooftop structure in terms of materials and techniques that maximize energy efficiency.[9]

In particular, lightweight modular systems are eminently suitable for sustainable rooftop densification. Considerable eco-advantages arise through the employment of cross-laminated timber, recycled aluminum, or lightweight steel as materials in such a structure. With respect to modular construction, material wastage is reduced by a remarkable 60-90% through precision manufacturing processes in controlled environments. The reduced timeframe for construction processes under this system minimizes disturbances on-site. In addition, modular systems, featuring high flexibility, allow for easy integration with renewable energy, rainwater harvesting, and various other sustainable technologies.[42][43]

With much attention drawn to embodied carbon reduction for rooftop structures, lightweight materials like cold-formed steel or timber contribute notably toward sustainability. Modular timber systems are both carbon-negative and flexible, which makes them amenable to disassembly and reuse, that is, according to circular economies. Lightweight steel systems reduce environmental impacts during construction and deconstruction alike in a very similar fashion, thus giving them a strong advantage for sustainable urban development.[43][44]

The integration of lightweight modular structures with various sustainable components allows for the transformation of underutilized rooftop spaces into multifunctional assets. These interventions address urban challenges such as energy demand and resource efficiency while also contributing to the development of vibrant, resilient, and sustainable cities.

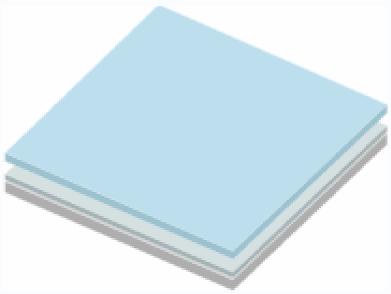




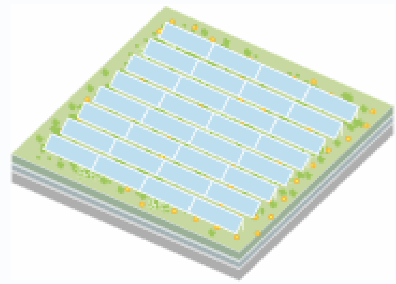
Minimum (and always):
Insulation of existing rooftop

and

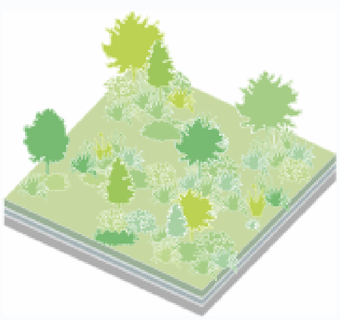
extensive greenery



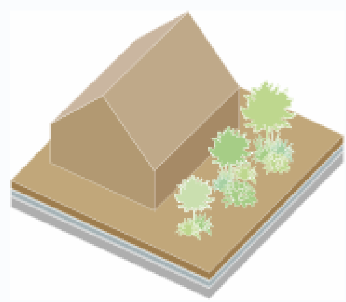
+ either water collection



+ or energy



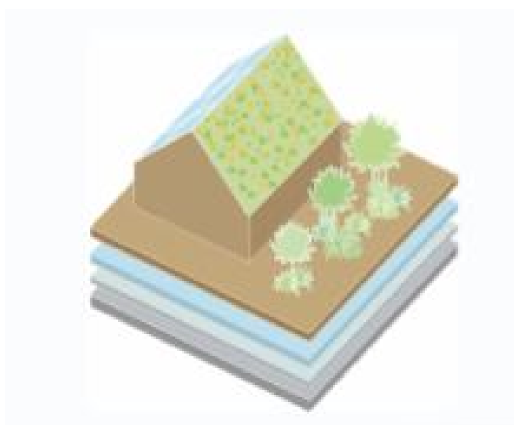
+ either additional greenery



+ or densification [always with a sustainable construction and sustainable materials]

- Insulation
- Greenery
- Energy

- Insulation
- Water Buffer
- Greenery
- Energy



- Insulation
- Water Buffer
- Densification
- Greenery
- Energy

Figure 18 Sustainable rooftop principles [9]

3.3.1. UN Sustainable Development Goals (SDG's)

Among the seventeen Sustainable Development Goals established by the United Nations, seven are particularly relevant to rooftops:

Number 3 ('good health and well-being'), number 6 ('clean water and sanitation'), number 7 ('affordable and clean energy'), number 11 ('sustainable cities and communities'), number 12 ('responsible consumption and production'), number 13 ('climate action') and finally number 15 ('life on land').

Figure 19 Applicable UN SDGs to rooftops[9]

3.4. Constraints and Technical Design Considerations

In this section, the major limitations and technical design considerations related to rooftop extensions are presented, comprising structural capacity to resist loads, foundation strength and soil bearing limits, seismic behavior and center of gravity, means of access and fire protection, integration of building services and utilities, urban regulations, and selection of materials.

3.4.1. Structure

The structural capacity of a building serves as the starting point for assessing the possibility of implementing rooftop development. In the initial stages of the viability assessment, it is essential to conduct studies regarding the capacity of the existing structure to accommodate a rooftop development. It is plausible that buildings can accommodate smaller scale vertical extensions, as these typically utilize the existing foundations of the primary structure, which can bear additional gravity loads of up to 5%. [45].

Nonetheless, more extensive rooftop developments would necessitate the implementation of new systems that integrate with the structural framework of the existing buildings to adequately support any additions. The Hearst Tower, designed by Norman Foster in 2003, features 46 stories constructed atop a historic six-story building in New York (

Figure 20). The structural addition established a distinctive relationship between the existing and the new elements, facilitating the integration of a new steel frame system that was supported by existing foundations necessitating underpinning.

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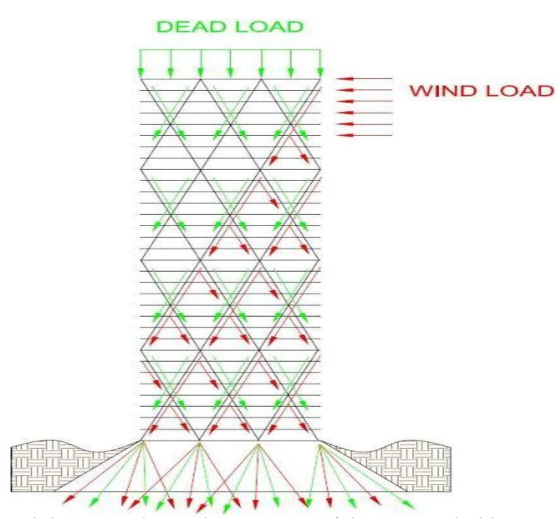


Figure 20 (a) The Hearst Tower in New York (b) Dead Load and Wind Load diagram shows the integrity of the new and old structures

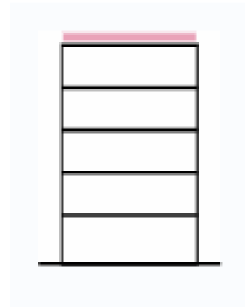
To assess the capacity of the existing building to support additional structures, one can evaluate its strength through theoretical calculations or comprehensive investigations. Theoretical calculations necessitate the acquisition of technical data pertaining to the building, encompassing the specifications of the materials utilized, as well as the type of foundation and soil involved. The second method involves examining the existing structure using various techniques employed by specialized civil engineers. Included among these techniques are visual inspections utilizing thermal cameras and Geo-radar instruments.[46][47]Alternative methods involve conducting destructive examinations that necessitate the collection of samples from the current structure for analysis. But generally it is better to consider the two approaches together. This form of inquiry is essential for older structures, as the characteristics of these buildings often evolve over time. For example, certain walls that were not originally intended to function as shear walls may ultimately support weight as a result of the inherent movements occurring in the soil and throughout the building structure. Through thorough examination, such alterations can be identified, and additional internal reinforcements may be implemented as necessary. Structural solutions are generally formulated with consideration for the existing building, ensuring that weight is appropriately distributed onto load-bearing elements and secured to lift shafts to enhance rigidity. Addressing significant wind loads on these often exposed elevated locations necessitate further attention, as structural designs must be proportionately more robust than those for comparable ground floor projects.

3.4.1.1. Load Bearing Capacity

Building structure load bearing is one of the critical determinants for accommodating rooftop extension. It is derived from material characteristics, structural configuration, and load distribution across the entire framework of the building. Rooftop initiatives-the green roof, modular housing, etc-will have to address and upgrade the structural capacity for safety and functionality.

There are four basic principles fundamentally used to determine rooftop load-bearing capacity:

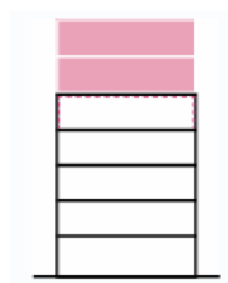
1. Existing Roof Reserve Capacity:



The core reserve capacity seen in various old buildings has its roots in the over-dimensioning of materials and the continuous improvement in the strength of concrete and steel with time. According to certain studies, the improved understanding of material behavior and stress analysis has enhanced the reliability of structural retrofits; older concrete can now carry loads much heavier than indicated in its original design specifications. [48]

Figure 21 Peperklip, Rotterdam[9]

2. Load-Bearing Lines of the Existing Structure:



In general, structural elements like beams and columns are more capable of carrying loads than the roof deck itself. These lines are used strategically to carry additional loads, providing a reserve capacity of 15-25%. This is similar to the way load distribution for rooftop installations has been enhanced in reinforced concrete and steel structures.[49]

Figure 22 Pakhuis Meesteren, Rotterdam[9]

3. Hybrid Structural Systems:

Hybridization becomes a possible measure to increase overall load-bearing capacity through an integration of existing structural components with added support members, such as steel frames or cross-laminated timber. In large rooftop ventures where the load requirements exceed the original structure's reserve capacity, hybrid systems represent a considerable advantage for residential extensions or communal areas.[48], [49]

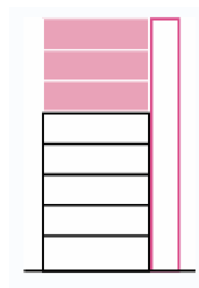
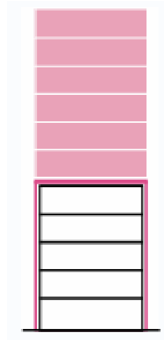


Figure 23 Karel Doorman, Rotterdam[9]

4. Secondary Structures:



Independent frameworks, like steel trusses, modular systems, or any combination thereof, can be installed to serve rooftop loads without dependent attachments to the existing structure. This is necessary for projects requiring minimum disruption to the existing structure while carrying huge rooftop elements.

Figure 24 Fenix Lofts, Rotterdam[9]

Structural load-bearing capacity may thus be assessed with this list input: [9]

• New understanding of strength calculation in the last century.

• Development of structural modeling.

• Upgraded understanding of materials-and-their-construction dynamics.

• Real gains in concrete strength due to ongoing hardening processes.

• Comparison of regulatory compliance on current construction practice versus design standards for new construction.

• Practical dimensioning considered vis-à-vis theoretically required construction.

• Reserve on account of decisions made by the structural engineer regarding `overdimensioning.'

Together all these reserves may comprise 15-50% or more of the overall reserves.

The existing reserves can assess and improve the structural capacity of the buildings for rooftop extensions by optimizing load-bearing lines and using hybrid or secondary structures. Therefore, advanced material applications with the principles of modern engineering assure roofs for various urban initiatives. According to these principles, cities such as Turin will be able to benefit from their underused rooftops to address some of the issues caused by housing, sustainability, and urban resilience.

3.4.1.2 Foundation strength and soil allowable bearing capacity

The second challenge relates to the characteristics of the foundations and their sufficiency in supporting a new structure. The techniques employed to determine the actual durability of the current structure can also be applied to the foundations. It is essential to note that the ability of the soil and foundation to support increased weight varies as a result of earth movements and the effects of soil compression over time. In practical scenarios, the soil adjacent to the foundation is excavated for inspection alongside the foundations, and additional reinforcement is incorporated into the existing foundations as necessary. [50]

3.4.1.3 Earthquakes and center of gravity

Two primary factors associated with earthquakes must be considered when increasing the number of floors on rooftops. The initial aspect pertains to the center of gravity (CG) of the existing building. As the elevation of an existing structure rises, its center of gravity correspondingly ascends, as illustrated in Figure 25. Therefore, it is essential to reassess the entire building's structure and incorporate safety factors into the evaluation. The second aspect pertains to the structural configurations of older buildings. Most buildings constructed prior to the First World War were not engineered to withstand seismic activity. Introducing an extra weight to an existing structure increases its susceptibility to seismic forces. [8]

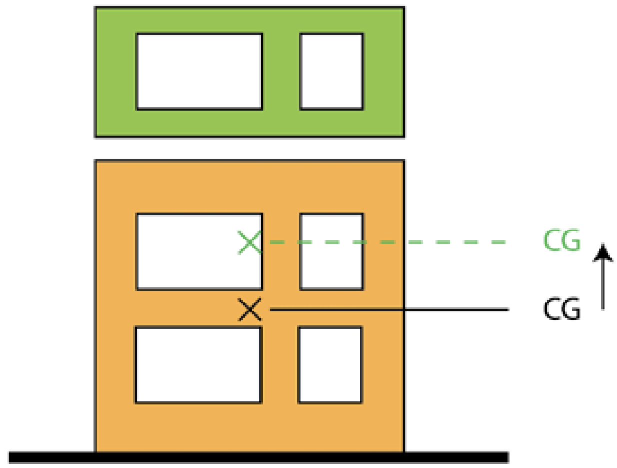


Figure 25 Centre of Gravity (CG) goes higher as buildings get higher[8]

Various techniques are employed to enhance the seismic resilience of current structures. A practical approach involves the addition of a ring beam, as illustrated in Figure 26. Ring beams serve as horizontal structural components that encircle a building or particular sections, offering essential reinforcement and stability. These methods are extensively employed in both new construction and seismic retrofitting to improve the structural integrity of buildings.

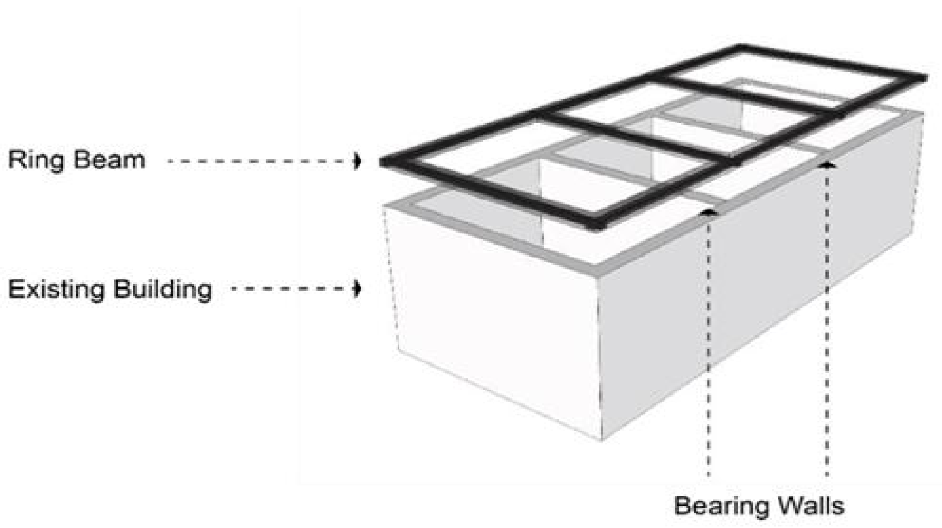


Figure 26 Ring beam / RC Platform connecting all bearing walls of the existing building[8]

The greatest advantage of ring beams is that they enhance the structural "box behavior," which assures that walls and roofs function together as a cohesive system during any seismic event. This, in turn, minimizes the chances for wall separation and structural collapse under lateral loads. Reinforced concrete ring beams are extremely important in tying the masonry walls and providing a level distribution of seismic loads, thus dramatically improving earthquake resistance.[51]

In addition, ring beams may serve as a base for roof extensions, redistributing additional load and relieving the effects of an increased center of gravity. Thus, they become a very flexible solution for all retrofitting jobs and new construction, assuring stability and performance across a broad spectrum of structural situations.[52]

Reinforced concrete ring beams are recognized to be effective because of their ability to withstand seismic loads and increasing the tensile strength of masonry walls. This applies to both existing buildings as well as these floors, wherein the ring beam serves to tie down the roof with a new extension. In some instances, if the current structure can carry extra weight, a raft or reinforced concrete platform is put within the ring beams.

3.4.2. Access & Fire Safety

Access to rooftops is essential for realizing the potential of elevated spaces, typically accomplished by extending the current stair or lift core, which is regarded as the most economical solution. Circulation cores generally function as shear bracing components in structures, extending above the roof level to facilitate maintenance access.[27] In contrast, rooftops can be accessed via independent pathways, which often segregate visitors. This arrangement provides a direct route to the addition and is commonly integrated into rooftop construction, particularly when the host and the extensions are utilized differently. MVRDV designed an architectural installation in Rotterdam aimed at promoting interaction among residents and visitors with the roofscape. This temporary structure, resembling a scaffolding staircase, provides users with access to the roof of Groot Handelsgebouw. The 180-step pathway provided an opportunity for visitors to pause and appreciate the extensive views of the city, while also serving as a venue for discussions and musical performances.

Figure 27 Temporary scaffolding staircase – Rotterdam [9]

The accessibility of rooftop development is not solely for the benefit of users; rather, it is a fundamental requirement across all buildings to ensure compliance with fire safety standards. Rooftop additions are classified as new build developments, which entails that significantly more stringent building regulations are applicable to this section compared to the structure beneath it.[53] The potential for incorporating additional accommodation atop existing structures may be influenced by the height of the building, as various classifications of building height are subject to distinct Building Regulation requirements. The incorporation of rooftop accommodation may elevate a building to a different classification, necessitating new considerations regarding means of escape, smoke ventilation, fire-fighting provisions, the requirement for dry or wet risers, the fire resistance of structural elements and other building components, as well as the potential necessity for sprinklers.

3.4.3. Building Services and Utilities

It is essential to examine the capability of the current service infrastructure to meet increased demand, and to establish plans for additional capacity, if necessary, at the early stages of the development process. Also creation of cavities for ducts and integration of every external unit carefully is very important.

3.4.3.1. HVAC – Heating ventilation and air conditioning

Multiple challenges are included when it comes to Integrating active systems in both the new extension and the old building. In most cases with old buildings, existing HVAC systems do not function efficiently. By adding more stories, it makes it nearly impossible for the existing HVAC system to cover the newly required capacity of the whole building. In this case, either a total renovation has to be carried out for the whole system to increase its efficiency, or a new active system could be replaced with integrated into the existing one. Passive design strategies, such as natural ventilation and solar gain management and high-performance insulation and smart systems are also recommended. [54]

3.4.3.2. Electricity

Rooftop extensions require electrical systems to adapt conditions that would be made necessary regarding upgrading their infrastructure in response to increased demands for electricity. Considering such increased needs that would be imposed by rooftop load addition, there may come a time when the transformers, wiring, or distribution panels would be unable to bear the loads, causing replacement or addition work to be done throughout the whole system. The likelihood of fire hazards and considerations of the revised electrical code have loomed large in the high-rise buildings where measures are in effect for lightning protection and surge management.

Generally, the way suggested is that of redevelopment of the electrical infrastructure to support higher loads and adding forms of renewable energy systems, including possible rooftop photovoltaic panels, to counterbalance the mounting imbalances. Intelligent energy management systems and high-efficiency appliances might yield better energy use, whereas stand-by networks like battery or generator power storage schemes would offer assurance in terms of reliability. All these would not only break the barriers but also allow a new dimension-the green and robust future of rooftop expansions.

3.4.3.3. Sewage water

Adding roofs frequently has a problem regarding the modification of sewage systems because it often intersects with the existing public drain, either poorly associated with the municipal pipeline or cannot be evacuated due to blockage. On the condition of the existing piping systems and their ability to perform with increased wastewater flows, repurposing them will depend. Thus, it usually retains the original pipe for purposes of potential reuse. However, if found in a very bad condition or incapable of serving the new load requirements, the designer has to completely replace the common drainage or provide an alternative system for that extension.

The degree of complication of these changes is determined by the situational pipeline within the building. Up to a point, those that are above cause such a case easy, whereas those that are within or out of reach of environmental aspects complicate the work. In cases where there would not be much future extension possible, project cost and feasibility should be determined early on by the design professionals. Predictive modeling in concert with modern drainage technology will heighten performance and ensure compliance with future increases in demand. These are the guarantees for ensuring that a waste system is functional and adaptable alongside rooftop expansions.[55]

3.4.4. Urban Regulations

There are two ways to determine the allowed maximum height. The first method applies height limits by considering the highest buildings adjacent to the property boundary or the mean height of buildings on the street. This means that no structure can be taller than the other structure immediately adjacent to it or those along the same street. The second method concerns the right to light; thus maximum height should not block the amount of light reaching adjacent buildings. Even when buildings are constructed capable of bearing greater loads, they must be in the city limits.

However, there are also extra restrictions regarding approval by the municipality that tend to protect its architectural heritage. Other relevant factors involve those affecting the environment, social equality, and the fair spreading of densities in neighborhoods. Parameters will ensure a sustainable living environment concerning open spaces, population densities, and adequacy of public transport. [8]

3.5. Construction Principles

3.5.1. Material Selection

There are several criteria that affect the choice of building materials generally. In rooftop extension projects, the choice of lightweight building materials is essential. As a result, the following are some of the few challenges encountered while selecting lightweight construction materials.

In rooftop extension projects, managing surplus weight is ultimately a critical topic to address since total loads include dead, live, wind, and snow loads. The primary area to optimize is dead loads (i.e., these loads are based on the weight of the materials) . Utilizing lightweight materials can lead to a reduction in loads; however, this often results in a compromise of mechanical properties.

The main building materials applied for the works are glulam for the post-and-beam framework and CLT panels for the floors, walls, and roof elements. This combination guarantees the utmost in structural performance, prefabrication possibilities, and environmental equity.

Glulam serves as the structural skeleton given the great strength-to-weight ratio of glulams for long spans without undesirably heavy cross-section. In rooftop extension, this factor can be important since adding heavy loads to the existing structure rightly creates some considerations. Glulam also allows precise working and prefabrication to ensure rapid erection on site, which is quite important within densely developed areas. Then again, timber panels act as stressing and enclosing elements that provide thermal and acoustic insulation along with a high degree of prefabrication. These solid wood panels are engineered with alternate grain direction in two adjacent layers, providing their dimensional stability and resistance to bending or warping.

Together, glulam and CLT create a remarkably compatible system, enabling dry construction, sustainable design aims, and rapid installation with low disruption—all valued qualities in an urban rooftop context. Being renewable and capable of sequestering carbon, glulam and CLT demonstrate small environmental footprints that make them suitable for projects targeting sustainability and urban development objectives. Also, both materials can be easily integrated with modern façade systems, as well as MEP services using reversible connections, which are consistent with strategies for circular construction solutions.

3.5.2. Prefab Construction

Rooftop extensions require construction techniques with efficiency, low weight, and flexibility against existing structures. Among these, prefab and modular construction tops the list by providing many advantages. Therefore, these two seem to be a great choice in the building industry for profitability, sustainability, and flexibility. This method, wherein box-like units or part of the units like walls fabricated off-site are shipped and assembled on an on-site context, is quickly becoming the Paradigm of construction efficiency. Modularity of design usually dictates repeating layouts and site constraints, which, thus, offer justification for the usage of modular construction in the work of hotels, student residences, and social housing.

Speed, indeed, is one of the most unbeatable advantages that this method offers. While one module is being fabricated off-side, on-site preparations are continuing, thus shortening construction schedules immensely. The controlled factory environment is devoid of weather interference; it also allows for a streamlined, industrialized production process that has resulted in increased productivity.[57][58]

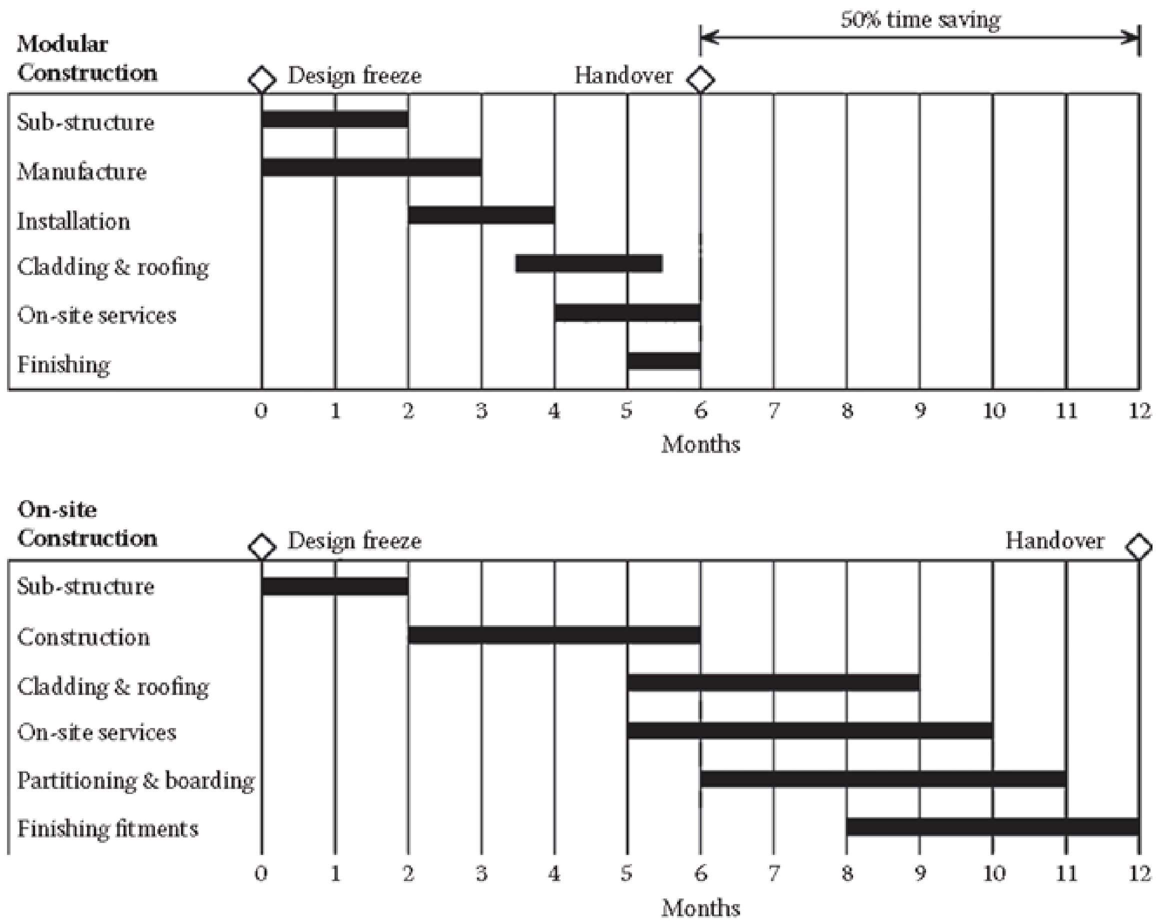


Figure 28 Comparison of construction speed [58]

This method further ensures quality and safety. Indeed, quality control is exacting in the factory setting, allowing in minimizing errors, waste of materials, and damage. In return, workers experience safe working conditions without extremes of temperature or hazardous mine site environments.

Building with these techniques generates the least waste and least impact on the environment. The use of lightweight materials like timber reduces foundation requirements. This reduces noise, dust, and pollution on-site. These are also environmentally friendly, adaptable, reusable, and compatible with current Building Information Modeling (BIM) systems from a sustainability perspective, which gives further credence to their environmental and economic viability.

Modular construction is arguably the perfect remedy for modern building projects from the point of speed, quality, safety, and sustainability: urban environments often these days that have tight schedules and limited space.

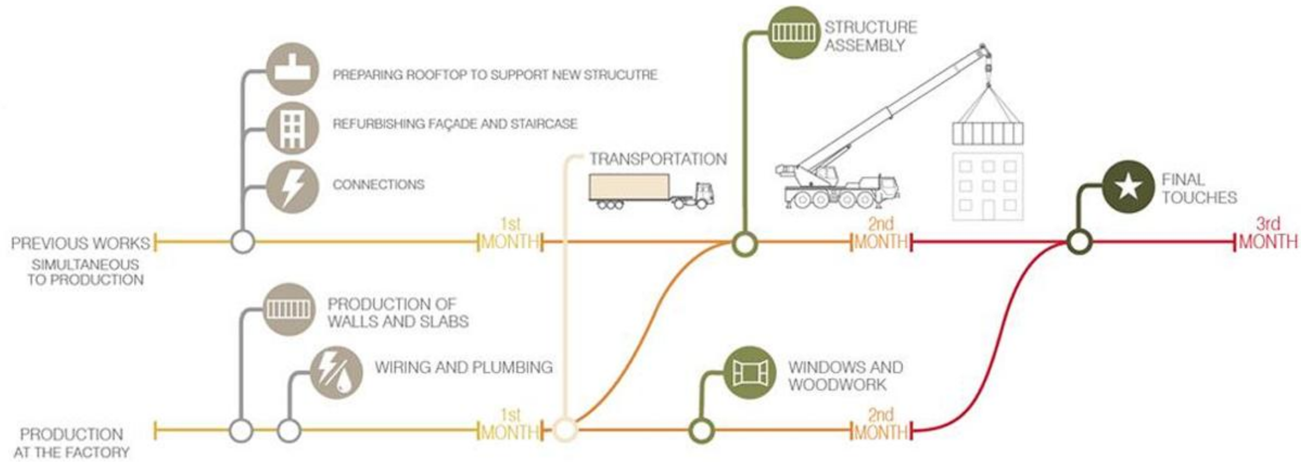


Figure 29 Sequence of building intervention[2]

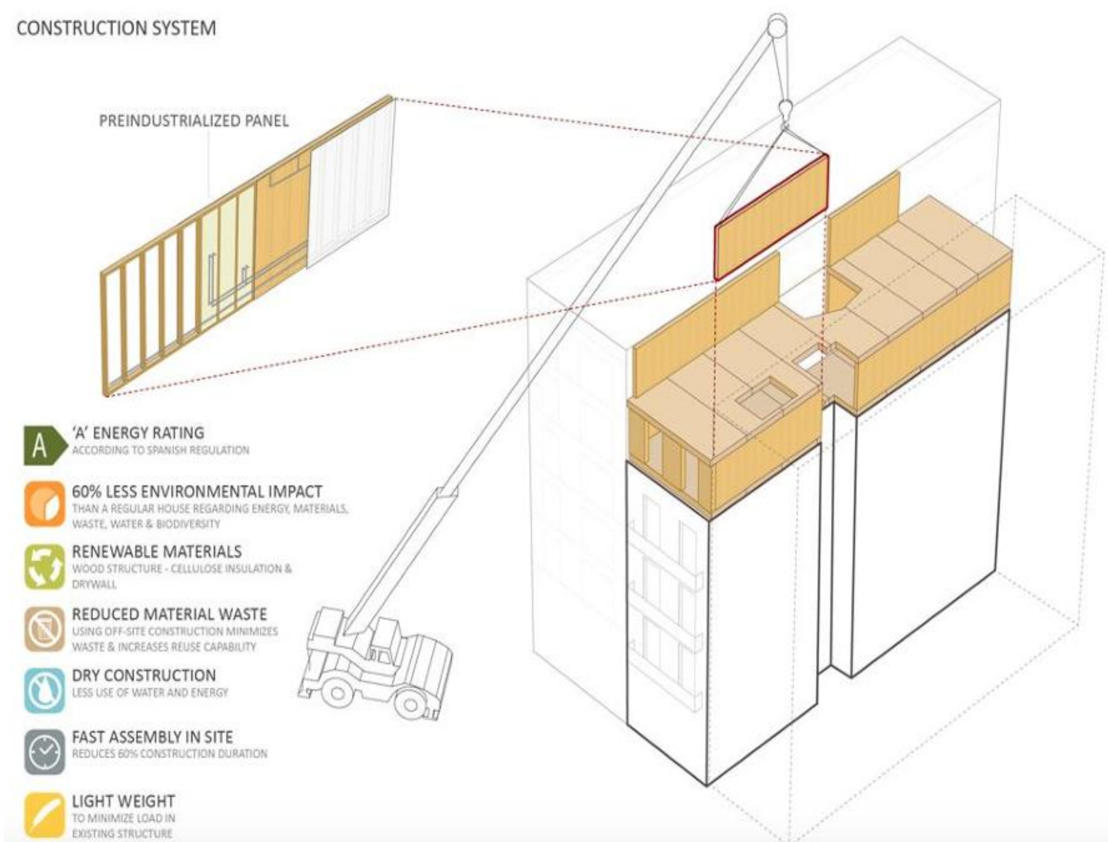


Figure 30 Drawing of industrialized construction operation[2]

3.5.3. Preliminary Preparations

Extensions on rooftops are a very realistic method of urban densification but require thorough preparatory processes to ensure structural integrity and economic feasibility. The first and foremost step is a preliminary assessment of the structure's capability to meet the increased loads. La Casa por el Tejado (LCT) of the architecture known to many as La Ciudad Condal has taken one of the most innovative approaches to adapt solutions to this challenge. Instead, its consideration is for minimizing weight before any retrofit of the structural framework takes place.

This is part of how LCT perceives buildings as "unfinished artifacts" for future densification where neither demolitions nor prohibitively hefty structural reinforcements would apply. The approach of such an institution separates non-essential parts so that there is a reduction in structural load. On this principle, Traditional Catalan roofs, whose character would entail two huge double-bricks slabs holding up ventilated air chambers, are being pulled apart and replaced with very lightweight, insulated modules. Everything else, including trasteros, laundry houses, non-structural non-bearing vaults, and non-load bearing walls, had also been eliminated or will be changed into lighter materials, for example, drywall. This will importantly help in weight reduction to avoid having to place an expensive structural reinforcements requirement. LCT reduces weights of about 1000 kg/m² on average-and adds around another 300 kg/m² with new modules. [59]

Figure 31 Picture of a model representing the Catalan Roof. The top part of this massive structure can be removed by hand to lighten loads of the building given that a new highly-insulated module will cover the building (source: La Casa por el Tejado)

Pre-installation work	Prefabrication work
Rooftop preparation: Utilities expansion, Structure reparations, Stairs expansion, Demolition of any heavy-structures on the roof, Construction of a chained beam and its transversal steel joists, If required, a waterproof layer is applied.	Construction of the main structural frame. Either steel 3D pillars with steel deck or mass timber panels.
Demolition of unnecessary and heavy structures within the apartments below	Installation of enclosures and interior subdivision for the steel structure.
Construction of elevator's pillars, footings, and pit	Installation of fixed furniture including kitchen counters, cooking appliances, lights, windows, and bathroom apparatus
Construction of temporary structure to cover stairs and elevator void	Embedded utilities designed to be attached easily to the building below
Construction of an entrance ramp (preferably connected to the elevator)	
Installation of a new intercom system	
Begin façade restoration	

Table 4 Table of preliminary preparations [8]

For determining the requirements of reinforcements, a thorough analysis of the structures is also important. The few critical interventions are undertaken for structural modifications. The methods adopted include enlargement of brick foundations manually by excavating, closure of discontinuities in columns or beams, and formation of independent structural shells for large-scale projects.[59]

3.5.4. Construction methods

The construction methods for rooftop extensions can be categorized into two distinct sections: [38]

- Load bearing methods
- Installation methods

The methods of load-bearing are intended to demonstrate the mechanisms of load distribution within existing structures. A variety of load-bearing methods were identified in Roof Stacking projects, which will be elaborated upon in detail. The methods of installation pertain to the processes involved in transporting, lifting, and assembling the supplementary floors. Most of Rooftop Extension projects documented in the literature have utilized prefabricated building components, which will be the primary emphasis of our case studies.[60]

3.5.4.1. Load Bearing Methods

Load-bearing methods refer to the different methods that are incorporated to sustain additional loads on existing structures. There were two main ways to load-bearing and they were recognized to be the current structure's inherent strength and the way it is arranged, which extremely effect on the decision. The preliminary way involves directly impacting the on-site framework. The alternative way of tackling this issue is by the incorporation or integration of additional reinforcement is what does it. Within a single project, various methodologies could be used.[61]

Structural support strategies: [38]

To support Vertical Extension, three structural support typologies are identified (**Error! Reference s**

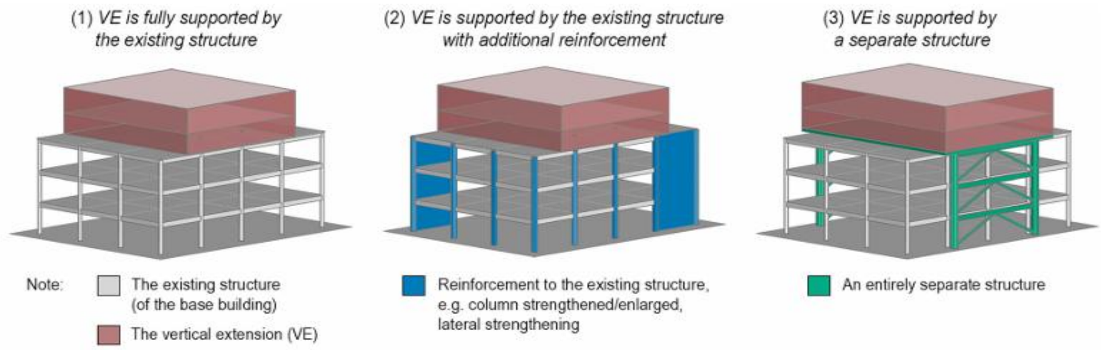


Figure 32 Three structural support strategies for VE [38]

ource not found.):

3.5.4.1.1. Load bearing on existing structure

Most of the projects are comprised of the built structures that have been around since the 19th century. The roof extension projects were made possible by the fact that the buildings already there had structural integrity and could bear the loads of the added extension. This mode of installation highlights the two paths that could be taken when the subject of load bearing is broached. The first method, which is direct alignment, involves the total preservation of the built-in structural elements. Another way to create a load bearing structure is to use an indirect bearing that is provided through load transformation systems and platforms.

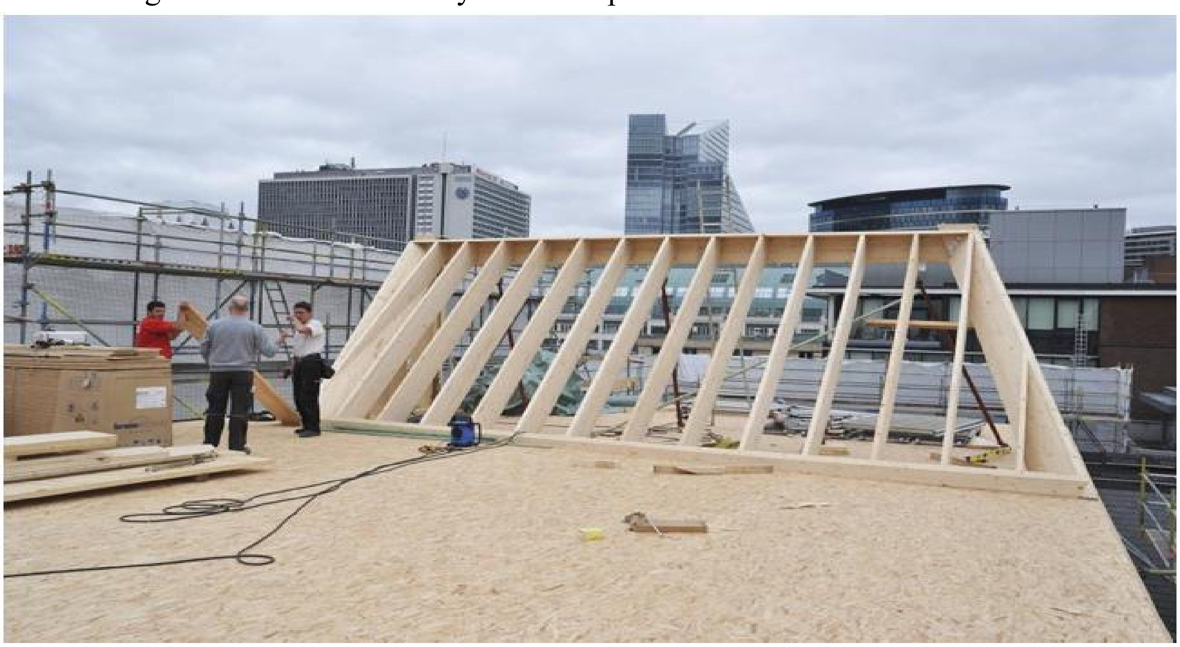


Figure 33 load bearing of roof structure - Atelier d'Architecture Galand (Source: Google.com)

1. Direct load bearing

Direct load bearing acknowledges the integrity of the existing building's structure. The additional structure may be implemented in a manner that is either parallel or perpendicular to the current structure. The structure added perpendicularly is achieved solely through the incorporation of 2D subassembly building components. Wall panels serve as new bearing walls for the support of additional floors. In one project, either approach could be utilized based on the design requirements of the new extension. To apply direct load on the existing structure, it is essential to have a ring beam in place, as illustrated in Figure 35. The ring beam is positioned on the bearing walls of the existing building, serving as a transitional element between the new and old structures. In the case of skeleton or concrete structures, it is possible to apply direct bearing without the need for ring beams.[62]

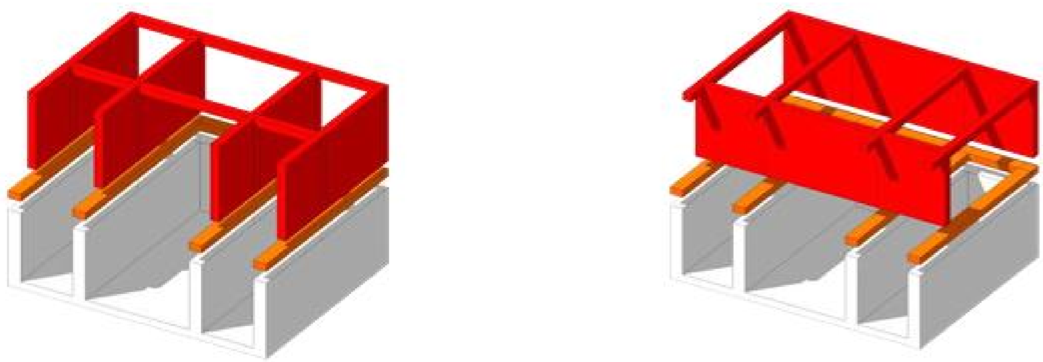


Figure 34 (a) Direct bearing parallel to structure (b) Direct bearing perpendicular to structure[8]

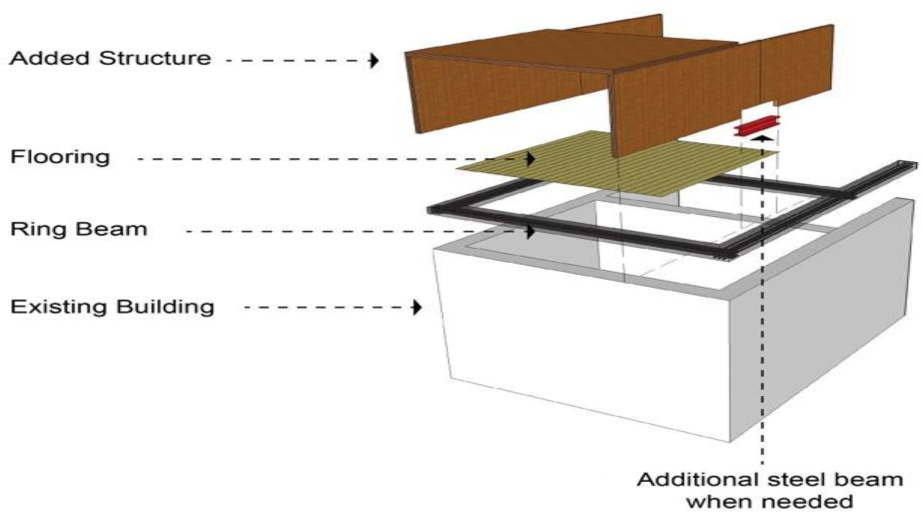


Figure 35 Using 2D subsystem building components as bearing panels. Those panels may rest parallel or perpendicularly on the bearing walls of existing buildings.[8]

2. In-direct load bearing

Most of the rooftop expansion projects have utilized the indirect load-bearing method. This approach demands a load transfer system. This system consists of a reinforced concrete ring beam that integrates the bearing walls and a grid of steel beams, which is engineered to support the loads from the additional extension. A load transforming system can be replaced by a load transforming platform or level. While this platform does increase the load on existing structures, it offers greater design flexibility for the added levels.[62]

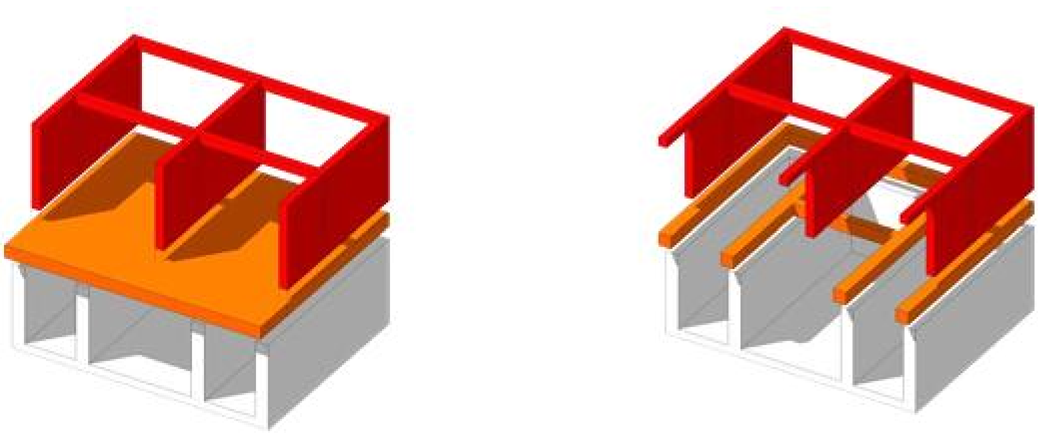


Figure 36 (a) In-direct bearing with a platform (b) In-direct bearing with a system[8]

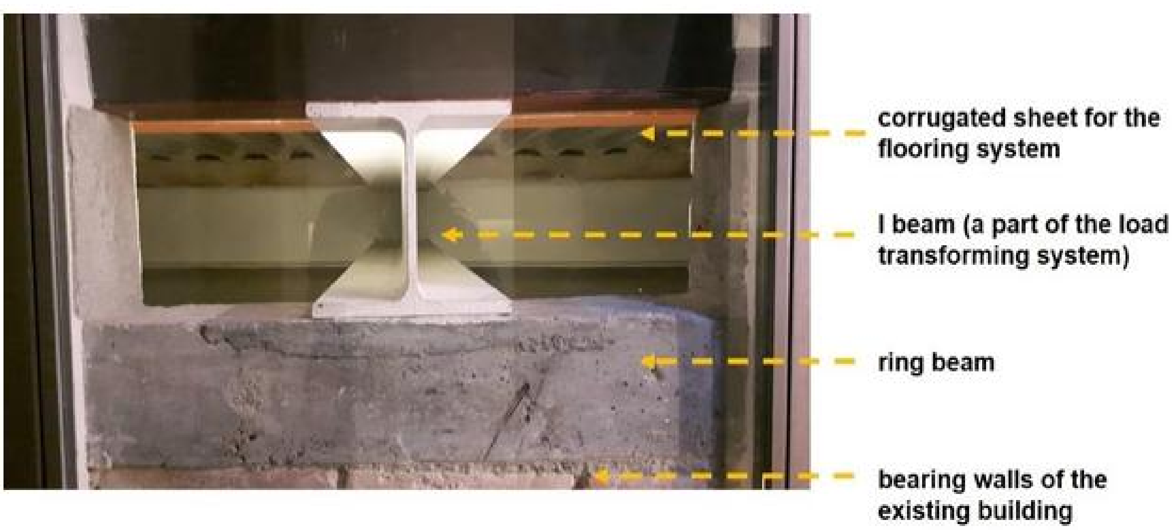


Figure 37 Cross section showing In-direct load bearing[8]

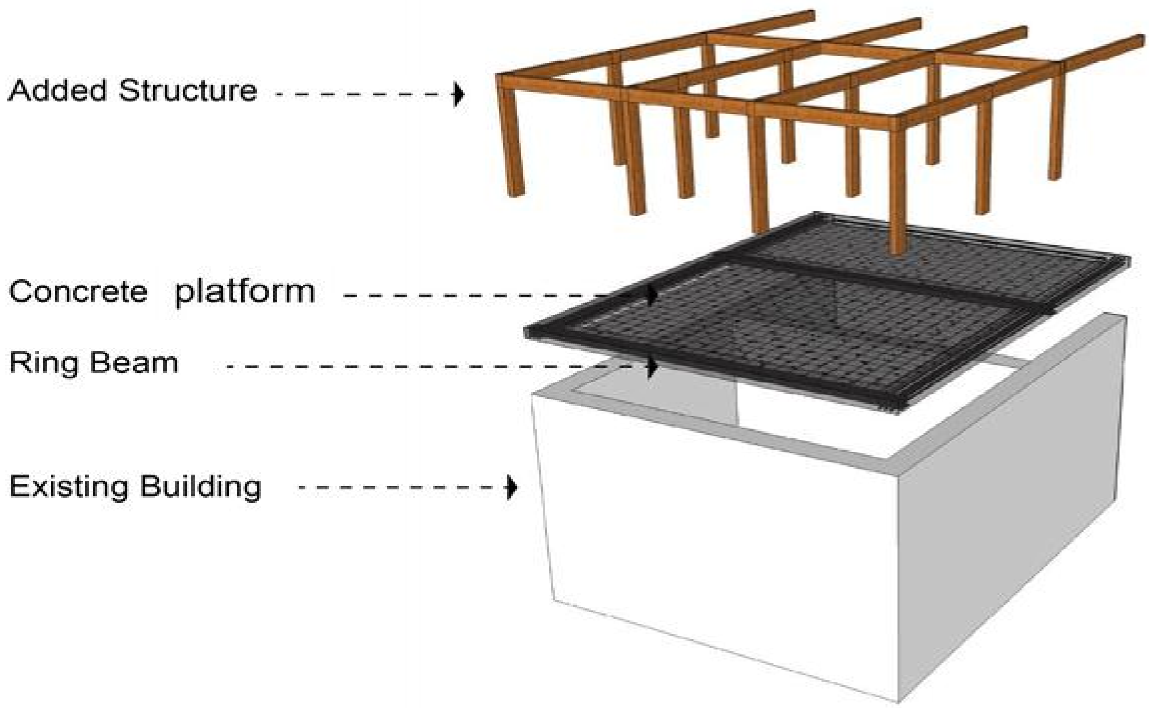


Figure 38 Load distributing through a platform made of reinforced concrete[8]

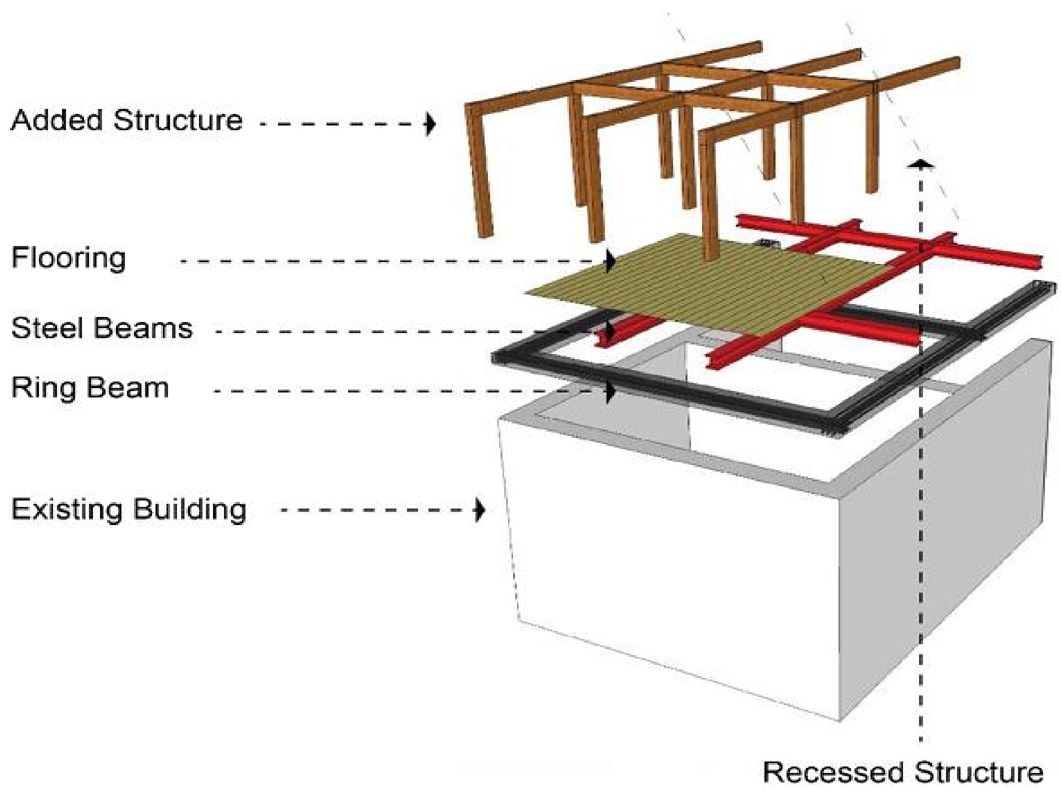


Figure 39 The new extension incorporates main building components that are reflected in the columns and beams. A chance to create a recess from the building's edge for terrace design or to adhere to urban regulations.[8]

3.4.5.1.2. Load bearing with additional Reinforcement

Reinforcement can be implemented at two distinct levels. The initial stage involves implementing minor reinforcements to certain components of the existing structures, particularly those that have experienced deterioration or changes in their structural performance over time. The second level involves significant reinforcement for foundations, soil, or the incorporation of additional columns and beams extending from the ground level to the new extension. The various bearing methods tend to incur significant costs. Nonetheless, they are utilized for structures that possess an irreplaceable location or function.

Categories of supplementary reinforcements:

Various techniques of reinforcement are currently in use. Each technique is employed based on the specific element that needs to be strengthened. [63]

1. Fiber reinforced polymers (FRP) utilized in columns, beams, slabs, and walls
2. Concrete jackets with supplementary reinforcement for columns, beams, and walls
3. Steel jacket technique for reinforcing concrete columns
4. Bonded steel components for slabs
5. Externally bonded steel strips for walls [8]

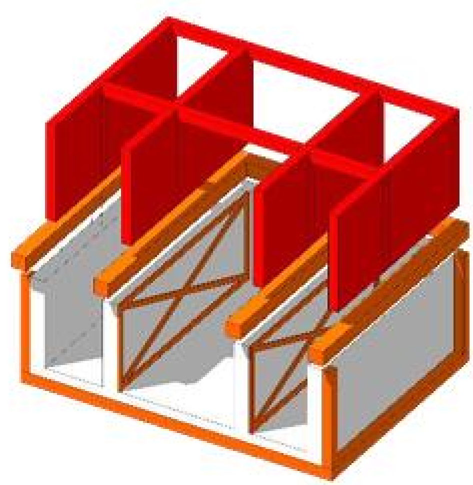


Figure 40 Load bearing with additional reinforcement [8]

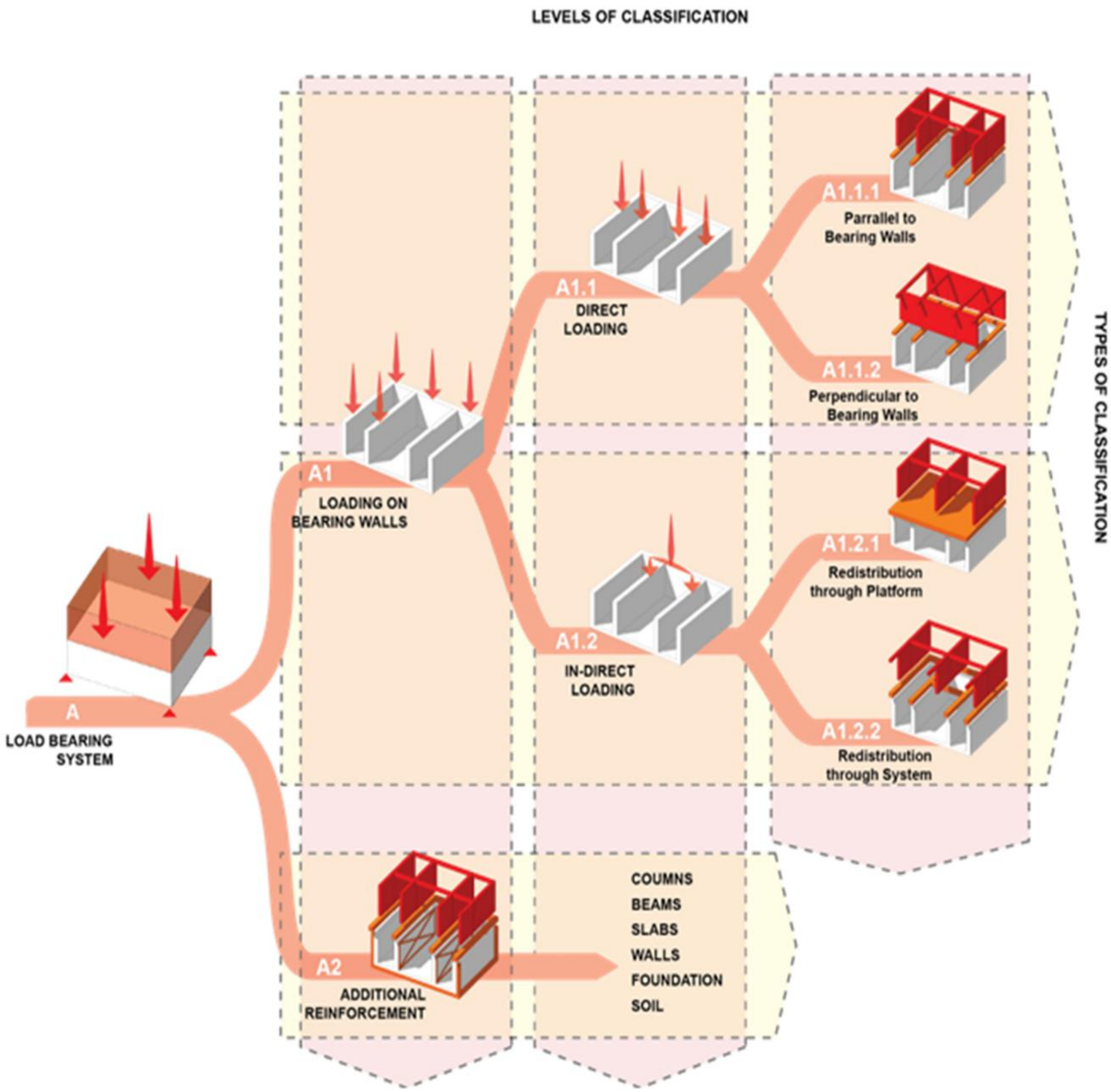


Figure 41 Load bearing methods classification [62]

3.4.5.2.Installation methods

Three main methods of installation were found to be used in Roof Stacking. projects. Installation methods in this report describe the level of prefabricated building component used in Roof Stacking. [64]

1. Assembly of 3D modules

A prefabricated construction system creates modular components that can range from being complete 3D modules to partially finished module components, which get transported to the site, hoisted up, and placed on rooftops of existing buildings. This model demands full cooperation between both designer and manufacturer with the need for a reliable manufacturing firm. Reliable off-site manufacturers will play a role in providing cranes and specialists for the transportation and lifting of modules; this method minimizes the time on-site and is the fastest method among all options. However, it may require specific situations and facilities in a suitable urban context, a reliable manufacturer, and skilled workers. The entire finalizing process usually lasts close to three months, depending on the size of the extra floor.

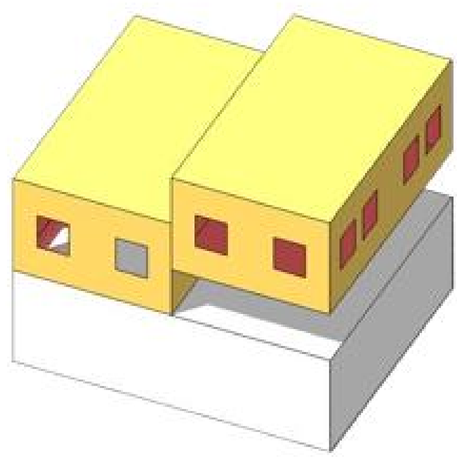


Figure 42 3D modular units[8]

Figure 43 Lifting 3D modules over the rooftop

Figure 44 Offsite 3D modules manufacturing

2. Assembly of 2D subsystem components

The constructional hierarchy is composed of multiple levels of building components, where a subsystem serves as the load-bearing element connecting substructures to the final buildings. In R.S. projects, the components of the 2D subsystem, which include walls, floors, and ceilings, are produced offsite. The components consist of different types of timber and necessitate less crane lifting compared to 3D modules. Nonetheless, the assembly process is time-consuming and demands a high level of precision in both design and fabrication.

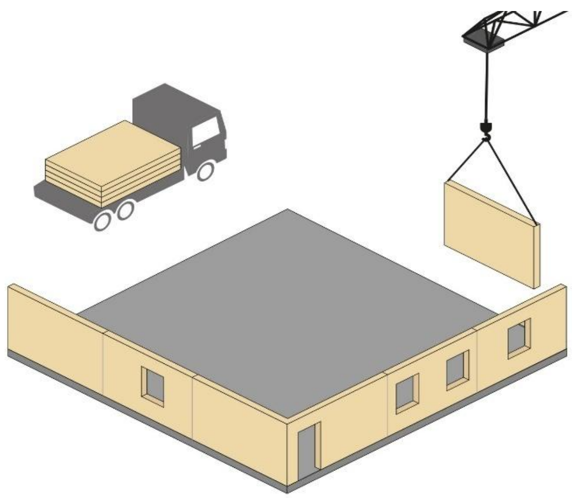


Figure 46 2D modules assembly phase source: rothoblaas.com

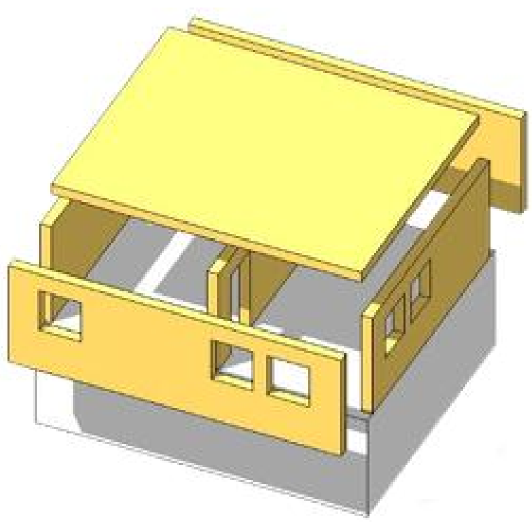


Figure 45 2D subsystem component assembly & installation[8]

3. Assembly of 1D building components

1D building components, including beams, columns, and frame assembly groups, are prefabricated and subsequently delivered for assembly on-site. This approach necessitates more time compared to 3D and 2D assembly, as it involves the acceptance of neighbors, along with considerations of space and duration. Atelier d'Architecture Galand utilized the courtyard for the purposes of loading components, assembling them, and subsequently lifting them to the rooftop, creating a fragmented building envelope. The original roof was utilized during the construction phase prior to transitioning to a new one.

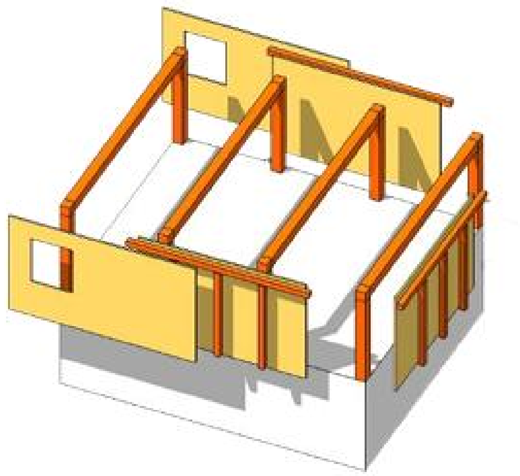


Figure 47 1D building components assembly & install

Figure 48 1D timber elements assembly early phase, Brussels, Belgium[8]

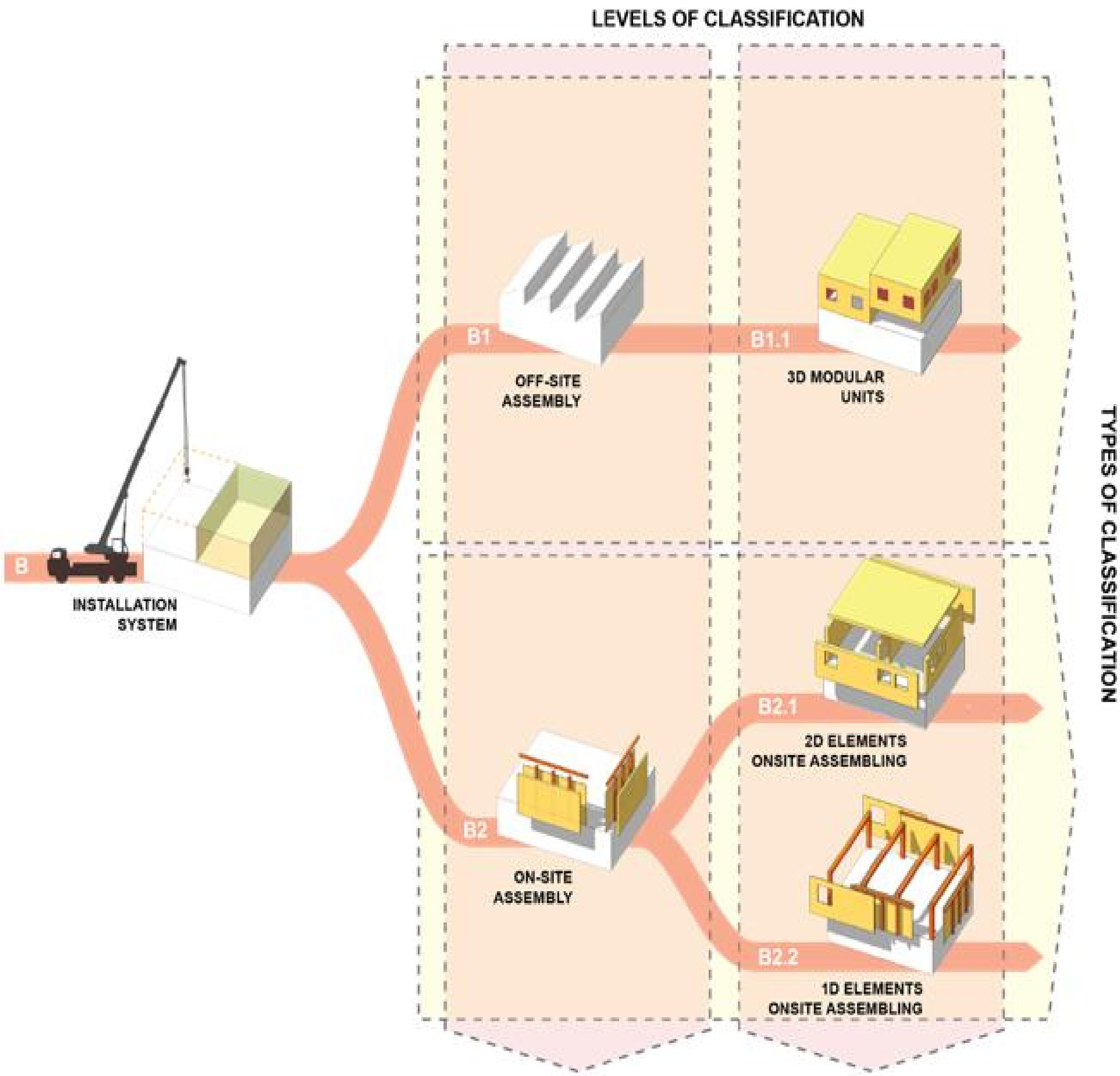


Figure 49 installation methods classification[62]

This flow chart captures the decision-making process for rooftop extensions. The process starts with completing a building assessment to confirm it is structurally sufficient to support the extension, then carries out the analysis and feasibility assessments. If it is feasible, the next step is the selection of the load-bearing method and assembly method, using a multi-criteria analysis of cost, time, safety, logistics etc. to be able to select either a prefabrication method in 1D, 2D or 3D.

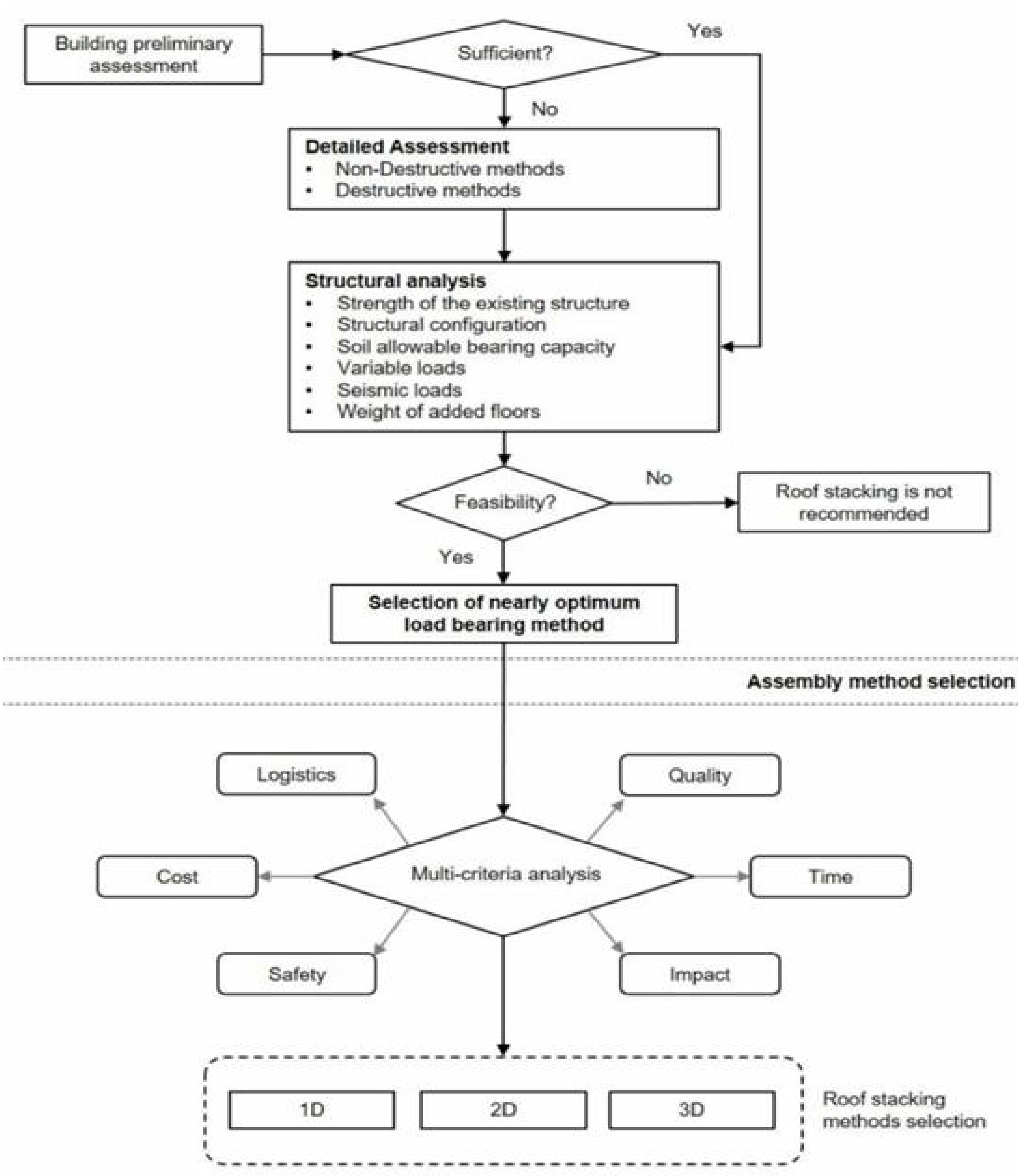


Figure 50 Decision making framework on roof stacking construction technique [65]

	Direct Loading	*In-Direct Loading*
Best Practice	• Old building with strong bearing walls • Narrow spans between bearing walls • Primary design requirements • Less requirement of the number of added floors	• Old building with strong bearing walls • Large spans between bearing walls • Advanced design requirements • Less requirement of the number of added floors • Higher requirements of safety factor
Prerequisites	• Ring beam that bundles bearing walls & ready to receive new loads [12] • Prefabricated frames or 2D elements that cover the span between existing bearing walls • Steel joints in case of perpendicular panels	• Consider the added weight by the new platform • Connect all bearing walls underneath • Define the position of the new loads [47] • Steel beams should comply with fire safety regulations [47] • Integrating the new reinforcements according to the existing structure
Benefits	• Does not require load redistributing system • Reduce costs and usage of materials • Less time is needed for site preparations	• Higher acoustic performance • Flexibility in distributing load (future change of function) • Relatively lightweight distributing system • Cost less money than the platform • Potential structural renovation of the existing building
Drawbacks	• Less flexibility in terms of interior spaces design • Less variety in using building materials and elements (should secure a self-sustained structural stability) • Additional weight is only determined by the actual strength of the existing building	• Additional weight is added without additional space • Requires more time • Additional costs • Less flexibility in distributing loads (no opportunity of changing the design) • Requires additional sound insulation [39] • May contribute in changing the internal or external appearance of the building

Table 5 Comparative analysis of different load bearing methods[65]

4. WORLDWIDE CASE STUDIES

Ther criteria to choose the case studies was tend to include different contrasting projects that achieved different results. Naturally, all the projects are unique because the existent buildings have completely different sizes, architectural layouts, heritage conditions, structural states, and energy consumptions and they all undertake the rooftop expansions through different architectural or construction methods. These analyses aim to evaluate the current state of the rooftop expansions technique, and outline their innovations and problems.

4.1. Case Study 1: The Stealth Building, New York, by WORKac

This residential development, referred to as The Stealth Building, was developed by WORKac architecture office which was originally built in 1884 and then renovated by WORKac in 2011. The building features a comprehensive gut renovation along with new construction situated behind one of New York's most stunning and historic cast-iron facades. A thoughtful approach was necessary for integrating contemporary architecture with the preservation of historic elements. The Landmarks Commission of New York City mandated that any rooftop addition must remain unobtrusive. The building is situated on a prominent corner, directly facing a low, two-story

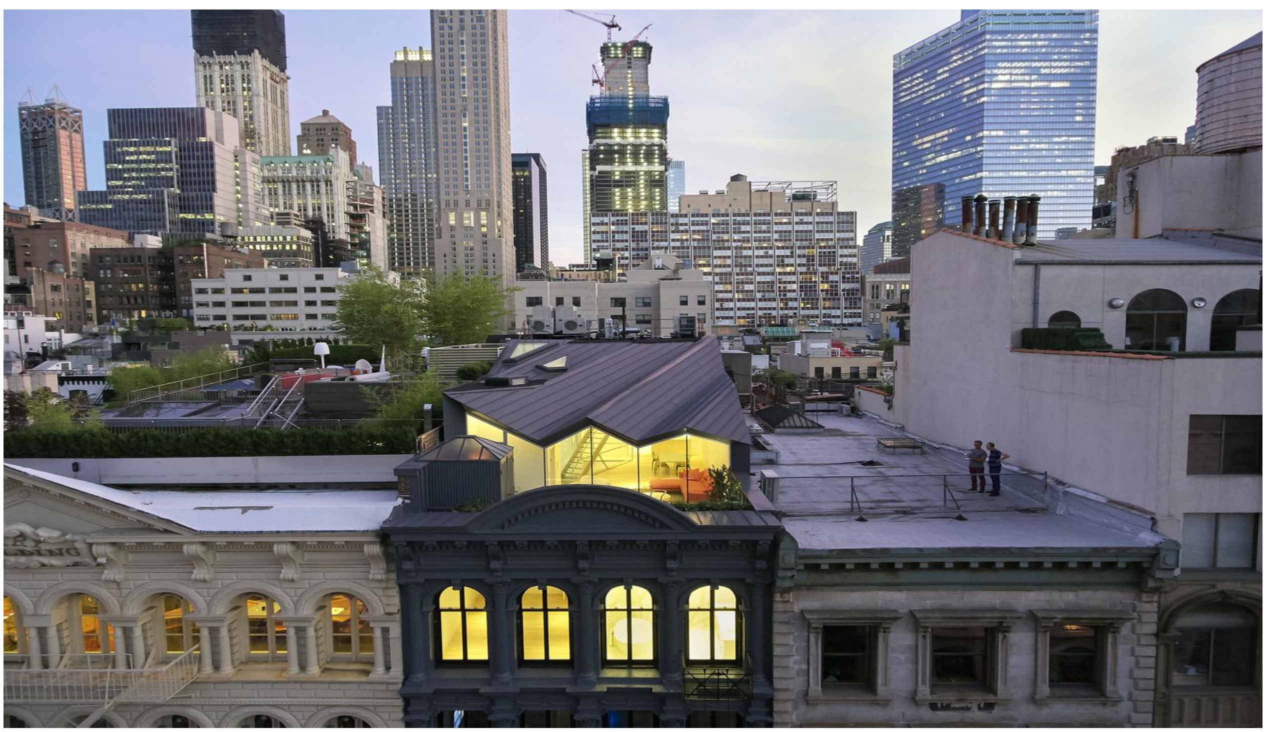


Figure 51 Aerial photo of the stealth building (Source: work.ac/work/stealth-building)

structure on the opposite side of the street. The roof of the building could be seen from nearly three blocks away.

Reconstruction involves an existing structure featuring a two-and-a-half-story penthouse addition. WORKac's Stealth Building has been recognized as a prime example of thoughtful yet boldly modern historic preservation, emphasizing the incorporation of "urban nature"—both actual and envisioned—into architectural design. Four floor-through simplex apartments are arranged around a central kitchen and bathroom core, designed as an insertion featuring a sleeping loft and a mini-greenhouse, which is nourished by steam from the master shower above. Every kitchen features a compact herb garden along with an integrated composting system.

Figure 52 Frontal facade of the stealth building which shows no sight of the extension (Source: work.ac/work/stealth-building)

WORKac traced the cone of vision from the furthest point where the building could be seen, employing three rooftop projections to obscure the mass of an addition. These included the triangular pediment of the historic Carey Building adjacent to it, as well as the circular pediment and an unused elevator bulkhead atop the building itself. The "shadow" produced by these three projections established a significant area for the addition, allowing for a unique angled design for the new roof. The outcome is a sculptural form that remains entirely unseen from the street below.

Figure 53 Aerial photo of the stealth building (Source: work.ac/work/stealth-building)

WORKac designed the apartment interiors and public areas to integrate nature-inspired elements and systems with innovative concepts of urban living. The lobby features a tessellated green wall, while the second, sixth, and seventh floors boast generous planters and balconies, highlighting the importance of outdoor connections. In each apartment, a designated "third space" is established between the bedrooms and living areas, situated at the upper part of the volume, which includes storage and bathroom facilities. This compact "bonsai apartment," standing at less than four feet in height, features a futon, seating areas, and a herb garden situated above the kitchen. The primary characteristic of this space is a fern garden that is linked to the master shower situated below. The steam generated by the shower condenses on the glass walls of the garden, providing moisture for the plants.

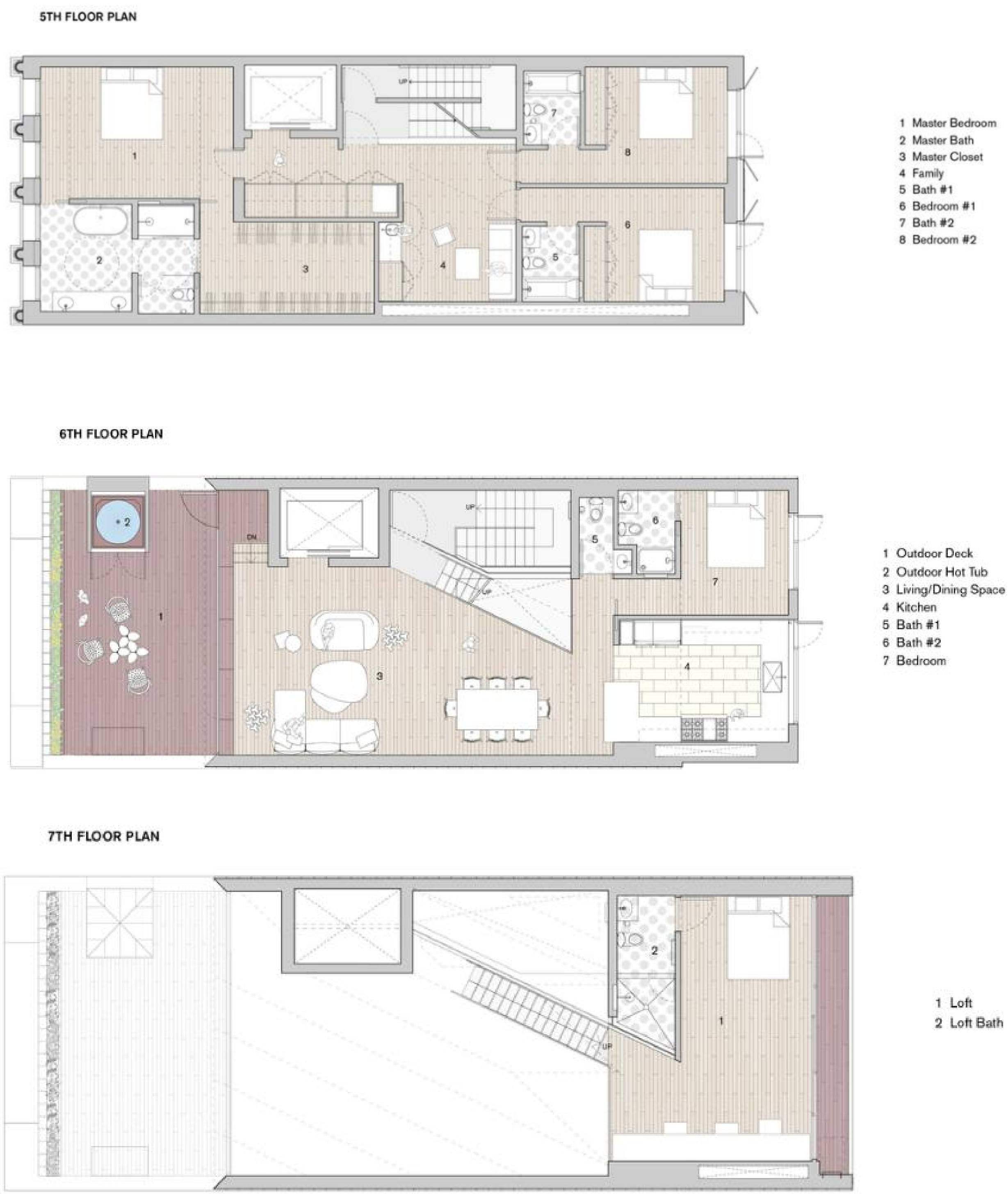


Figure 54 Floor plan of the two and a half floors extension (Source: work.ac/work/stealth-building)

The penthouse integrates sleeping areas and a family room on the original fifth floor of the building with newly designed entertaining and dining spaces beneath the newly constructed roof on the sixth floor. A private terrace is nestled behind the pediment, offering views of the Woolworth Building, while the former elevator bulkhead has been transformed into a hot tub. The elevation provided by the angle created by the cone of vision enables a rear mezzanine that offers views of downtown and the Freedom Tower.

Figure 55 View of the rear mezzanine of the stealth building

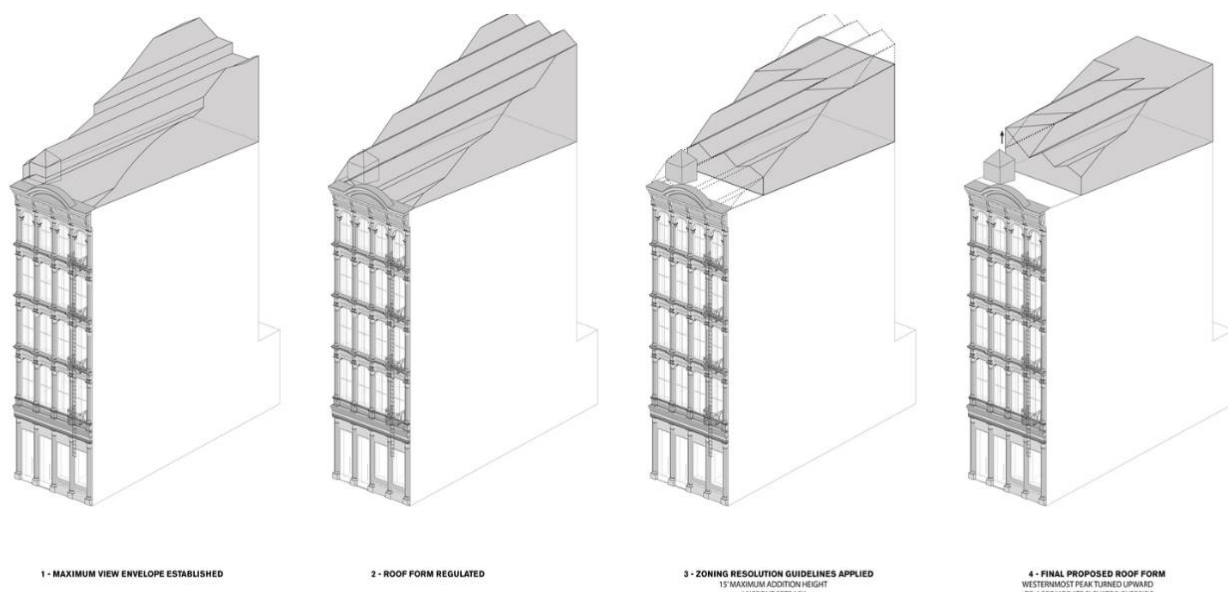


Figure 56 Roof evolution of the stealth building (Source: work.ac/work/stealth-building)

The façade from 1857 has been fully restored. The newly selected charcoal color by WORKac draws inspiration from the building's historical context of being painted in a dark hue, contrasting with its lighter neighboring structures. Figure 67 Since all of the building's Corinthian column capitals had been lost to history, WORKac partnered with the artist Michael Hansmeyer to develop new versions. Hansmeyer developed a computer script that enabled the classical floral elements of the Corinthian order to “grow” in a fractal manner, leading to a novel design that maintains the traditional proportions while incorporating distinctly new forms and characteristics. At first glance, these capitals may seem quite ordinary, much like the rooftop addition; however, a closer inspection reveals the subtle strategy of incorporating contemporary design.

Figure 57 Interior design of the stealth building

Figure 58 Section view of the stealth building (Source: work.ac/work/stealth-building)

This case study presents an operation that emphasizes the significance of the support structure's historical value by concealing the modern rooftop addition. A common perspective among the public regarding urban consolidation in landmark areas is that it helps maintain the city's "Urban Harmony." The two structures must develop a way to coexist simultaneously. It is the responsibility of architects and designers to ensure that both the structural support and the new architecture have their moments of prominence and shine in unison. Melet and Vreedenburgh[7] argue that the public, particularly in Western societies, tends to reject the unusual and prefers to maintain control over it: "We want to conserve the past that we are familiar with." This idealization of the past effectively erases memory and undermines historical development. The continuous replication of an arbitrary segment of time disregards the limitations of history and the linear progression of time. In numerous western cities, there exists a prevailing inclination to halt the passage of time, leading to the perception that the historic centers have reached a state of completion. All potential mutations have been systematically excluded to the greatest extent feasible. Tourists typically do not anticipate encountering change and tension.

4.2. Case Study 2: La Casa por el Tejado, Barcelona, Granados 69

This case study is situated at Enric Granados 69 in Barcelona which was originally built in 1900 and serves as an exemplary project illustrating the effective integration of vertical extensions into existing urban structures, promoting both sustainability and functionality. This project, situated in a central urban area, involves the addition of two new floors to an existing multifamily building, thereby increasing its functionality while maintaining its historical significance. The architectural firm MIBA, in partnership with environmental consultants Societat Orgánica, concentrated on developing a design that prioritizes environmental sustainability. Novadomus habitat produced prefabricated mass timber panels that were utilized for the bearing walls and slabs, which led to a significant reduction in construction time to merely two days. This construction strategy effectively reduced environmental impact through the use of lightweight, modular, and prefabricated materials.

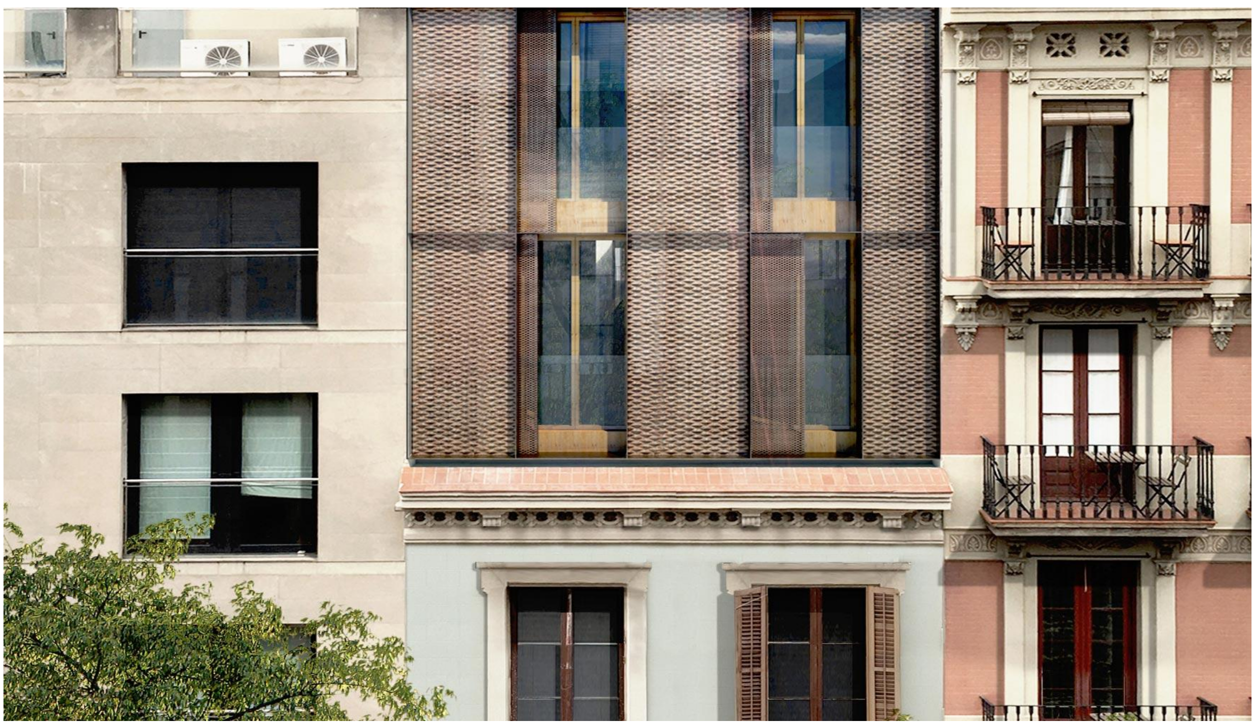


Figure 59 Frontal façade of Enric Granados 69(Source: interempresas.net)

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Figure 60 Lifting the prefab structure(Source: interempresas.net)

The previous multifamily building consisted of four floors, featuring a store on the ground level. Each floor of the existing housing featured a separate dwelling on each level. The two additional floors constructed by LCT comprise two residential units, each with a net area of 161 square meters. The frontal façade of the vertical extensions is in alignment with the planes and utilizes a palette of materials that draws inspiration from the building beneath. This specific detail was implemented to enhance the historic façade of the building that faces Eric Granados, thereby improving the urban landscape of the area. The rear façade of the extension is aligned with the fourth floor; however, the penthouse façade has been set back by 1.7 meters to establish an open terrace that provides a view of the inner courtyard of the block.

Additionally, the prefabricated units feature an expanded interior courtyard that facilitates natural cross-ventilation and allows for ample natural light. This plan ultimately provided a private outdoor space for the owners.

Figure 61 Front view of the extension during the construction

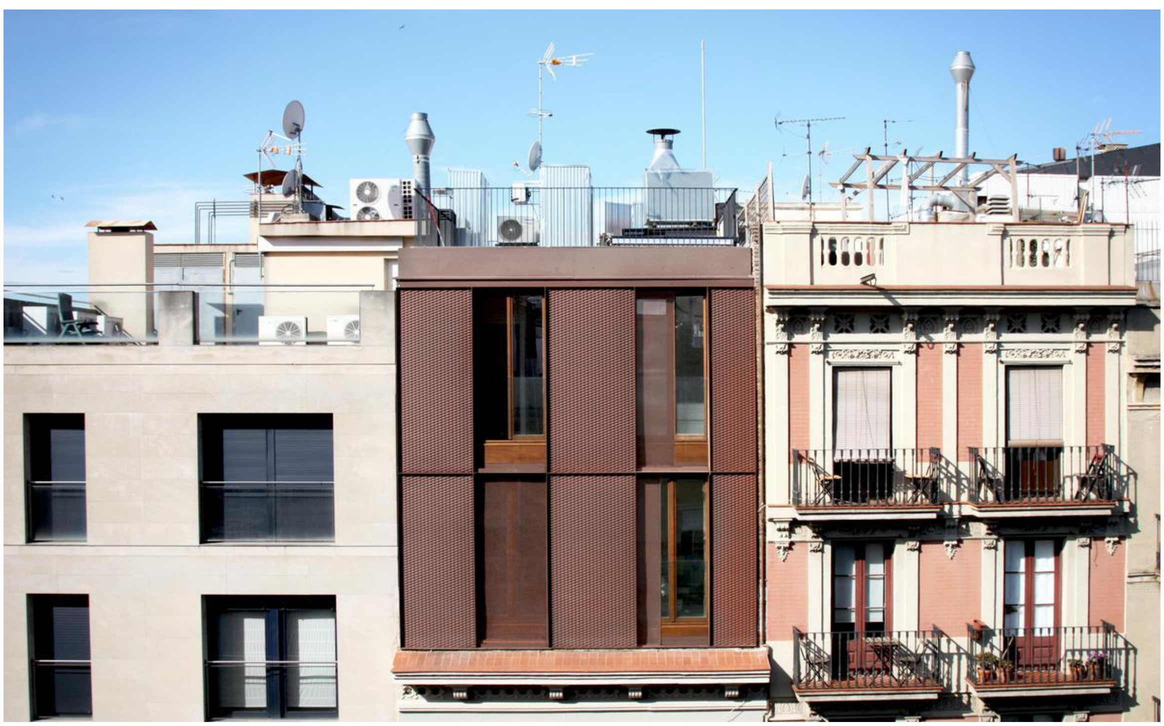


Figure 62 Front view of the extension after the construction

Figure 63 Left: Render of front façade. Right: Render of rear façade (Source: interempresas.net)

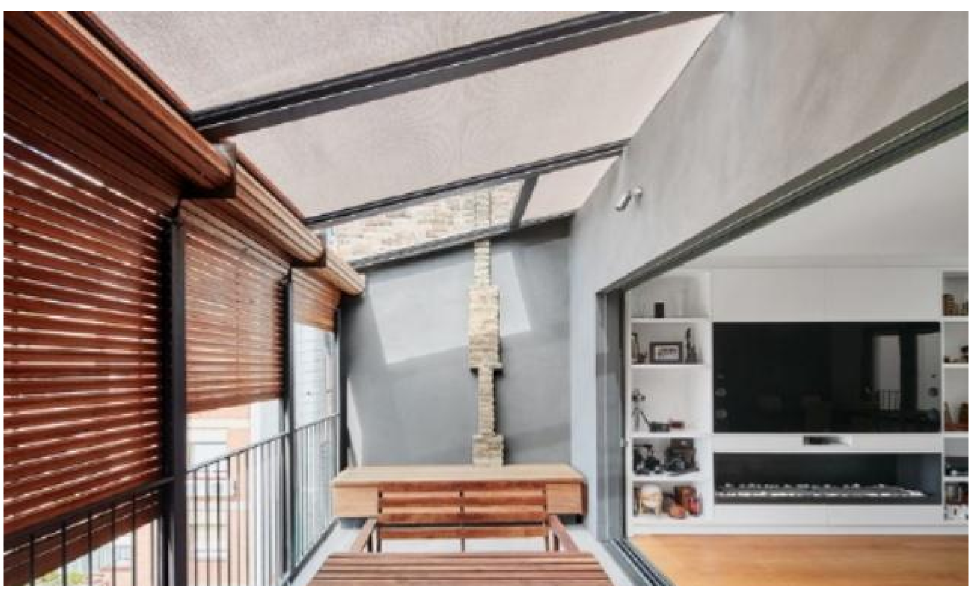


Figure 64 Interior Design (Source: www.houzz.es)

Figure 65 Left: Front façade. Right: Rear façade[66]

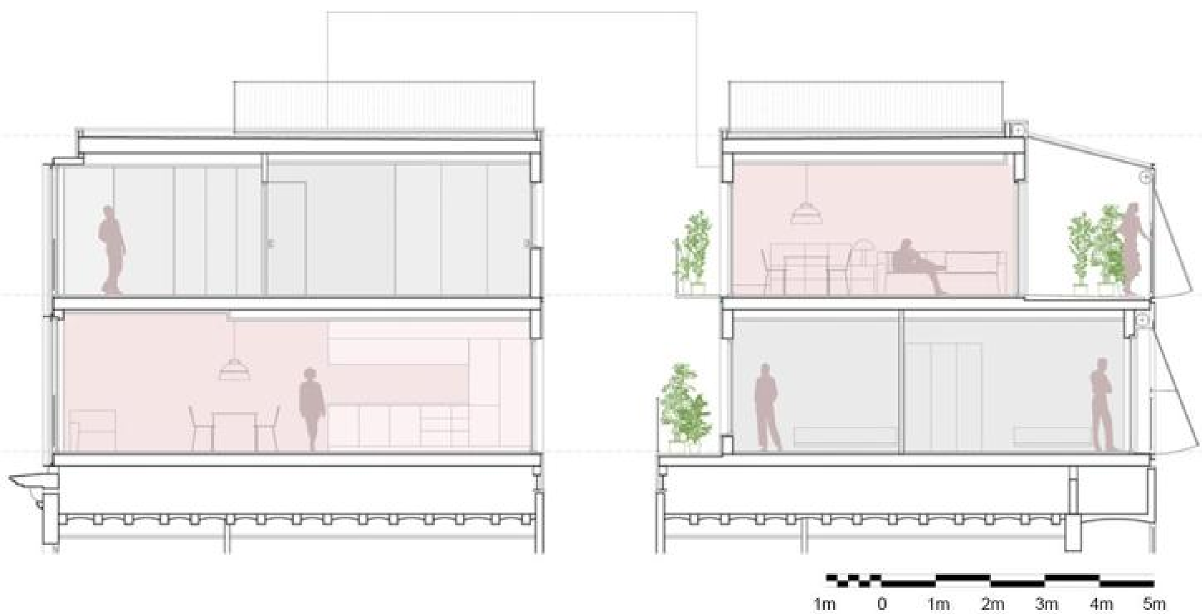


Figure 66 Cross section of the project. Grey color represents private areas and red areas represents social areas[66]

Figure 67 Floor plan of the two-level expansion[66]

This project, developed by LCT, utilizes a 2D assembly light laminated wood frame system along with semi-passive house insulation, resulting in an A level in energy efficiency ratings. The bearing walls and slabs were constructed from prefabricated wood panels, which were installed in just two days with the assistance of a crane system. Therefore, the development of the expansion is characterized by a high level of industrialization while also prioritizing environmental sustainability.

The construction process on-site occurs in distinct phases. Initially, industrialized wooden panels are utilized to construct the slabs and walls. The remaining components, including windows, façades, and finishes, are delivered prefabricated and are hoisted into place by a crane in complete sets and they were installed in their respective locations.

The envelope of this project is constructed with prefabricated wooden panels. Nevertheless, the frontal façade consists of a ventilated façade featuring expanded metal panels in a transparent red color. This system enabled the project to blend effortlessly into the street's palette while maintaining a modern aesthetic. The interior façade features a more traditional design, incorporating cedar wood louvres and retractable enclosures.

LCT implemented a load reorganization system in which they substituted the heavier objects on the top slab with lighter finishes and incorporated a new prefabricated unit. In this instance, the modules were not composed of 3D steel prisms; rather, they consisted of 2D mass wooden panels. The panels consist of three distinct layers of hardwood sheets, each varying in structural composition and density levels. Their dimensions range from 2.42 to 2.95 meters in width and from 3 to 8 meters in length. With a weight of 506.83 Kg/m2, these panels present a lighter alternative when compared to conventional concrete and steel constructions, which typically range from 2,000 to 15,000 Kg/m2.

In addition to the mass wood panels, this project also incorporated two other materials. Initially, composite beams made of steel and wood, reinforced with epoxy resins (Figure 68), were employed to shield the steel from fire exposure and to enhance the flexural strength of the mass timber panels. Additionally, a layer of Fermacell Aestuve (Figure 69) was incorporated as a fire insulator and interior finish, offering a dry solution with the required thickness.

Figure 68 Steel and wood structural beams (Source: minivi.uadla.com)

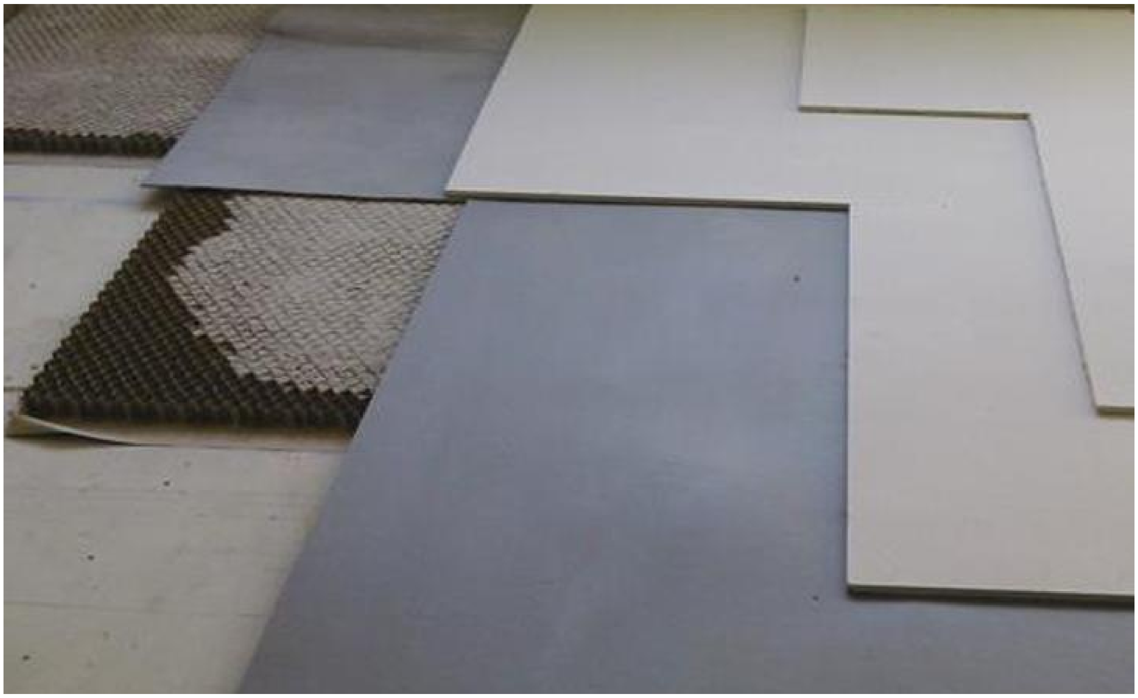


Figure 69 Complementary acoustic and fire insulation Fermacell Aestuve: Gravel board and plasterboard. (Source: minivi.uadla.com)

This project excels in environmental sustainability, distinguished by its materials, construction, and design, which integrate passive strategies to create a highly sustainable and lightweight development. The roof of the new penthouse is equipped solely with the necessary telecommunications facilities, air extractors, and a solar-powered water heater. The remaining area is filled with crushed pine to mitigate the heat island effect.

Assessing the environmental impact of these projects presents unique challenges, as it differs considerably from conventional projects. Consequently, Societá Organica created a tool named SENDA, which is utilized by LCT in various projects across Barcelona, Madrid, Pamplona, and Bilbao. This tool was created to assess a particular kind of construction, specifically new rooftop expansions, and it meets the standards set by the environmental certification (Certificación Energética de Edifícios) from the Ministry of Industry and Tourism in Spain. The tool guarantees that all of its components adhere to environmentally sustainable construction standards. For instance, the tool examines the effects on “biodiversity, consumption of non-renewable energy, deterioration of drinking water, impacts caused by materials, and generation of pollutants” (Delgad). According to the report by Delgado, SENDA has demonstrated notable differences when compared to traditional housing construction methods.

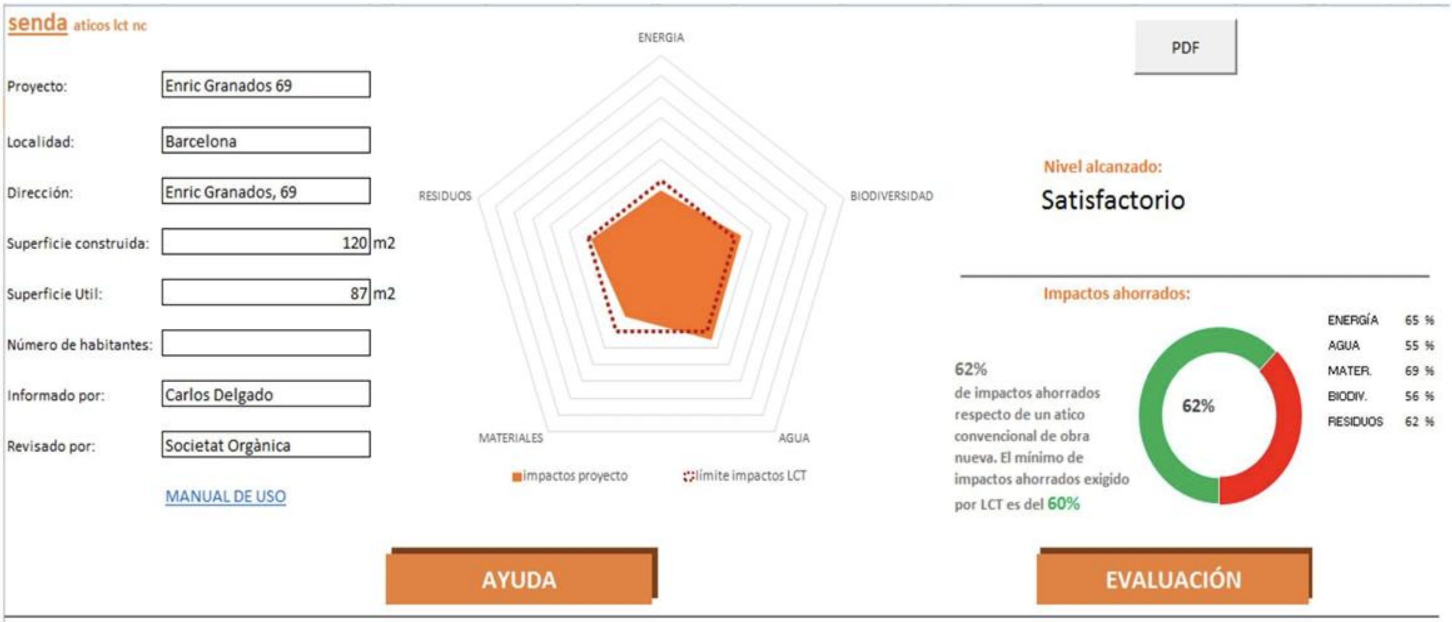
The environmental outcomes of the Enric Granados 69 intervention are presented in the table below:

Parameter	*Reference building*	*Project building*	*Improvement*
Heating demand (CTE HE1)	24,81 kWh/m2 yearly	10,93kWh/m2 yearly	56%
Cooling demand (CTE HE1)	15,00 kWh/m2 yearly	2,33 kWh/m2 yearly	85%
Non-renewable primary energy (CTE HE0)	57,22 kWh/m2 yearly	25,30 kWh/m2 yearly	56%
Total CO2 emissions (Energy Certification)	19,30 kgCO2/m2 yearly	4,10 kgCO2/m2 yearly	79%
Category (Energy Certification)	D	A	79%
Global savings of impacts (Senda tool)	0%	62%	62%

Table 6 Summary of environmental strategies at Enric Granados 69 [2]

In conclusion, this project serves as a significant illustration of sustainable vertical expansion, enhancing an existing building while maintaining its historical importance. The project features significant insulation that minimizes energy loss, especially through the roof, thereby improving energy efficiency for the apartments situated beneath. LCT's implementation of a tailored environmental analysis tool reflects its dedication to sustainability; however, it is advisable to seek further validation from independent entities. The incorporation of mass plywood panels and steel-wood beams highlights innovative, lightweight, and environmentally sustainable construction techniques that may set a precedent for future vertical developments.

Senda environmental assessment and support tool



Energy certification

	Clase	kWh/m²	kWh/año	Clase	kWh/m²	kWh/año
Demanda calefacción	B	6,5	1258,5	D	26,1	5021,8
Demanda refrigeración	B	3,0	585,4	G	19,7	3798,0
	Clase	kgCO2/m²	kgCO2/año	Clase	kgCO2/m²	kgCO2/año
Emisiones CO2 calefacción	A	2,0	384,6	D	8,4	1615,4
Emisiones CO2 refrigeración	B	1,0	192,3	G	7,5	1442,4
Emisiones CO2 ACS	A	1,1	211,5	D	3,4	662,1
Emisiones CO2 totales	A	4,1	788,5	D	19,3	3719,9
	Clase	kWh/m²	kWh/año	Clase	kWh/m²	kWh/año
Consumo energía primaria calefacción	A	7,9	1522,5	D	37,9	7281,6
Consumo energía primaria refrigeración	B	4,0	770,8	G	30,8	5924,9
Consumo energía primaria ACS	A	4,3	830,0	D	14,2	2735,5
Consumo energía primaria totales	A	16,2	3123,3	D	82,9	15942,0

4.3. Case Study 3: La Casa por el Tejado, Barcelona, Aragó 359

In 2014, La Casa por el Tejado (LCT) undertook the development of the project, with design contributions from Tesgat Architects. The total area measures 551.79 m², which includes 449.04 m² designated as private space and 102.75 m² allocated for balconies and terraces. The extension is located in a centric area of Barcelona, positioned above a neoclassical building in Carrer d'Aragó 359. The aim of the architectural project was to create a cohesive solution that connects the existing four-story building with the planned addition of two new levels.

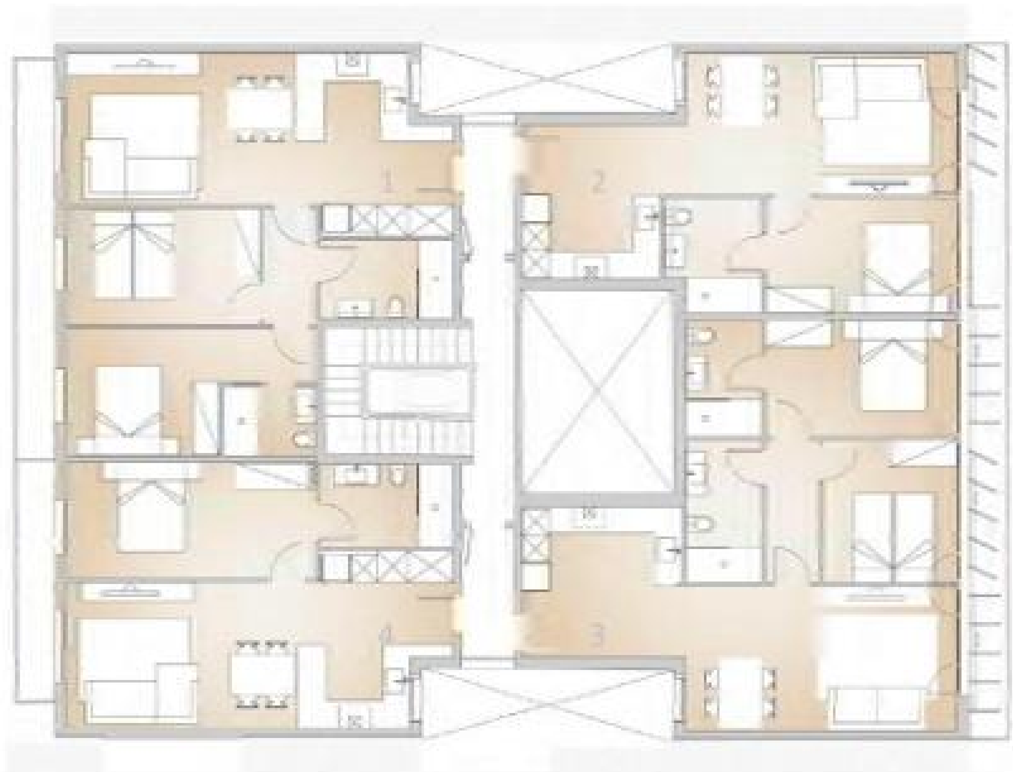
Figure 71 Project before the intervention

Figure 70 Project after the intervention

The newly constructed fifth floor comprises four apartments, each featuring an average area of 60 square meters, a single bedroom, and one bathroom. The sixth floor consists of two newly constructed units, each with an average area of 100 square meters. One of the apartments features two bedrooms, while the other includes three bedrooms.

Figure 72 Left: Frontal façade. Right: Rear façade (Source: www.houzz.es)

Figure 73 Above: Floor plan of the fifth-floor extension Right: Floor plan of the sixth-floor extension (Source: www.houzz.es)



This project was constructed utilizing off-site, prefabricated methods. This approach is crucial for the project's success as it reduces the overall construction time, thereby minimizing any disruption to the daily activities of nearby residents. The modules can feature floor and top covers constructed from a steel deck system with poured concrete, or alternatively, utilize structural wood beams, offering a lighter and more environmentally friendly option. The decision is influenced by the budget constraints and the specific structural requirements of each project. A main three-dimensional steel framework, along with insulated walls in a sandwich structure that encases the building while maintaining a lightweight design has been implemented.

From a structural perspective, LCT seeks to achieve a balance between the weight that is removed and the weight that is added. Typically, the loads that are removed are greater than the loads that are added, taking into account the weight of the expansion. However, in some instances, the loads that are removed are less than the new additions, which necessitates structural tests and reinforcements to ensure the safety of the construction.

Figure 74 Pictures of the process of transportation and installation (Source: arquitecturayempresa.es)

This project presents a unique case study, as the completion of the project resulted in an increase in the overall weight of the building. Nonetheless, the structural tests demonstrated that, despite a minor increase in the foundations of the party wall and the stress experienced in the most critical areas of the bearing walls, the results remained within acceptable limits after applying the safety coefficient. This indicates that the building can support the loads without requiring significant structural reinforcement.

This table provides a summary of the structural strategies employed by LCT for the project.

Name	*Description*	*Observations*	*Test*	*Function*	*Reinforcement*
Floor	Fill of 0,9m thickness over hard clay and silt	Breaking load with a safety factor 3, of 3,8 kg/cm3	Geotechnical probes, determine real tension below foundation	Supports the load of the building and the vertical extension of two floors	Not necessary
Foundations	0,6 m wide and 1,25 m high footings set in clay and silt	No significant deficiencies	Visual inspection for digging, test real tension below foundation	Supports the load of the building and the vertical extension of two floors	Not necessary
Load-bearing walls	0,3 m wide solid ceramic brick	No significant deficiencies	Test for limits, response not inferior to the effect of own weight, overloads, etc.	Supports the load of the building and the vertical extension of two floors	Not necessary
Upper slab	Slabs of ceramic bricks on steel joists	No significant deficiencies	Test for limits, response not inferior to the effect of own weight, overloads, etc.	A structure which distributes the load of the vertical extension and resists horizontal forces must be incorporated	Make a chained beam of the support walls with forged cement
Vertical Extension	3-dimensional steel frame, welded	Folded steel slab with concrete layer	Design which complies with moder regulations	Supports standard use, transport and lifting	Not necessary

Table 7 Summary of structural strategies at Aragó 359 [2]

Figure 75 Images of the finished units at Aragó 359 (Source: www.tigat88.com)

This project illustrates a scenario in which the total load of the building was elevated following the expansion of the rooftop. In contrast to the assumptions held by architects, the project remained viable due to the relative simplicity of the required repairs. It is indeed noteworthy that Aragó 359's new overall weight exceeds its former weight while still being capable of supporting over 500 mt2 of additional expansion, as demonstrated by a structural safety test. In addition to the chained forged beam implemented in the upper slab (Figure 76), the tests indicated that no additional reinforcement was required.[2]

Figure 76 Picture of the central structural intervention on Aragó 359: the chained forged beam is seen at the bottom of the picture

Identifying the necessary load that can be extracted is crucial to this approach, ensuring that the costs associated with reinforcement do not render the project unfeasible over time. It is essential to recognize that not all structures require or are capable of accommodating additional loads. At times, buildings reach their maximum structural capacity, prompting architects to work alongside civil engineers to assess the costs and benefits associated with project development.

4.4. Case Study 4: The AF Skyroom, London, David Kohn

The AF Skyroom in London is a creatively conceived rooftop venue crafted by David Kohn Architects, who received the UK Young Architect of the Year Award in 2009, with structural engineering provided by Form Structural Design. The venue commenced operations in September 2010, aligning its opening with the London Design Festival, and has since hosted a variety of events as part of the AF's public program.

The Skyroom offers a blend of covered and open areas, thoughtfully designed to serve as an unconventional outdoor events venue for The Architecture Foundation. It also functions as a communal space for the building's tenants to come together, while providing a fresh destination for visitors to explore in London. The central courtyard, exposed to the sky, provides a backdrop for the ascending structure of The Shard, the newest feature in London's skyline. A balcony that extends over Tooley Street provides stunning views across the More London development, showcasing the Thames and the Tower of London in the distance.

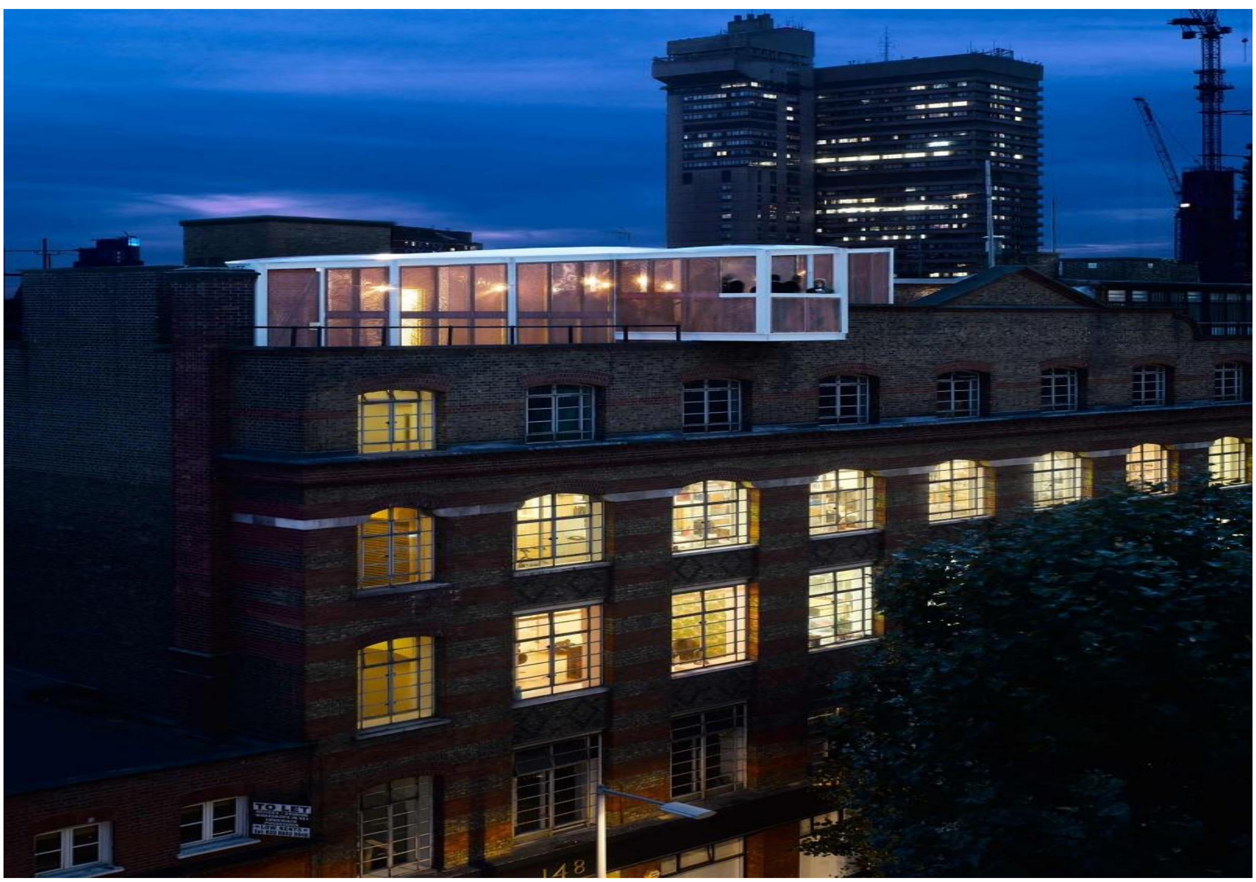


Figure 77 Frontal facade of the AF skyroom (Source: davidkohn.co.uk)

The project involves a Rooftop Pavilion situated atop the "Lake Estates for the Architecture Foundation" Building. This project aims to showcase the importance of granting access to London's rooftops while also celebrating the remarkable views the city has to offer. The structure in question is a warehouse dating back to the 19th century. In response to challenges associated with accommodating the new structural loads, a new steel deck was developed, and the updated pavilion structure was integrated with the existing steel columns of the original building. The recent addition includes an open courtyard that beautifully integrates the sky with the iconic skyline of London. The courtyard features a range of diverse arrangements, along with four smaller, intimate spaces designed for meetings and relaxation, which serve as an extension of the main courtyard.

Figure 78 Aerial photo of AF skyroom (Source: davidkohn.co.uk)

The Skyroom is a custom-built structure made from steel and covered with copper mesh facades, featuring larch wood flooring and built-in furniture. The roof is clad in transparent ETFE pillows, giving it a soft, cloud-like look. The walls featured layers of copper and stainless-steel mesh, which produced striking moiré patterns as individuals navigated the area, resulting in an impression of lightness and transparency.

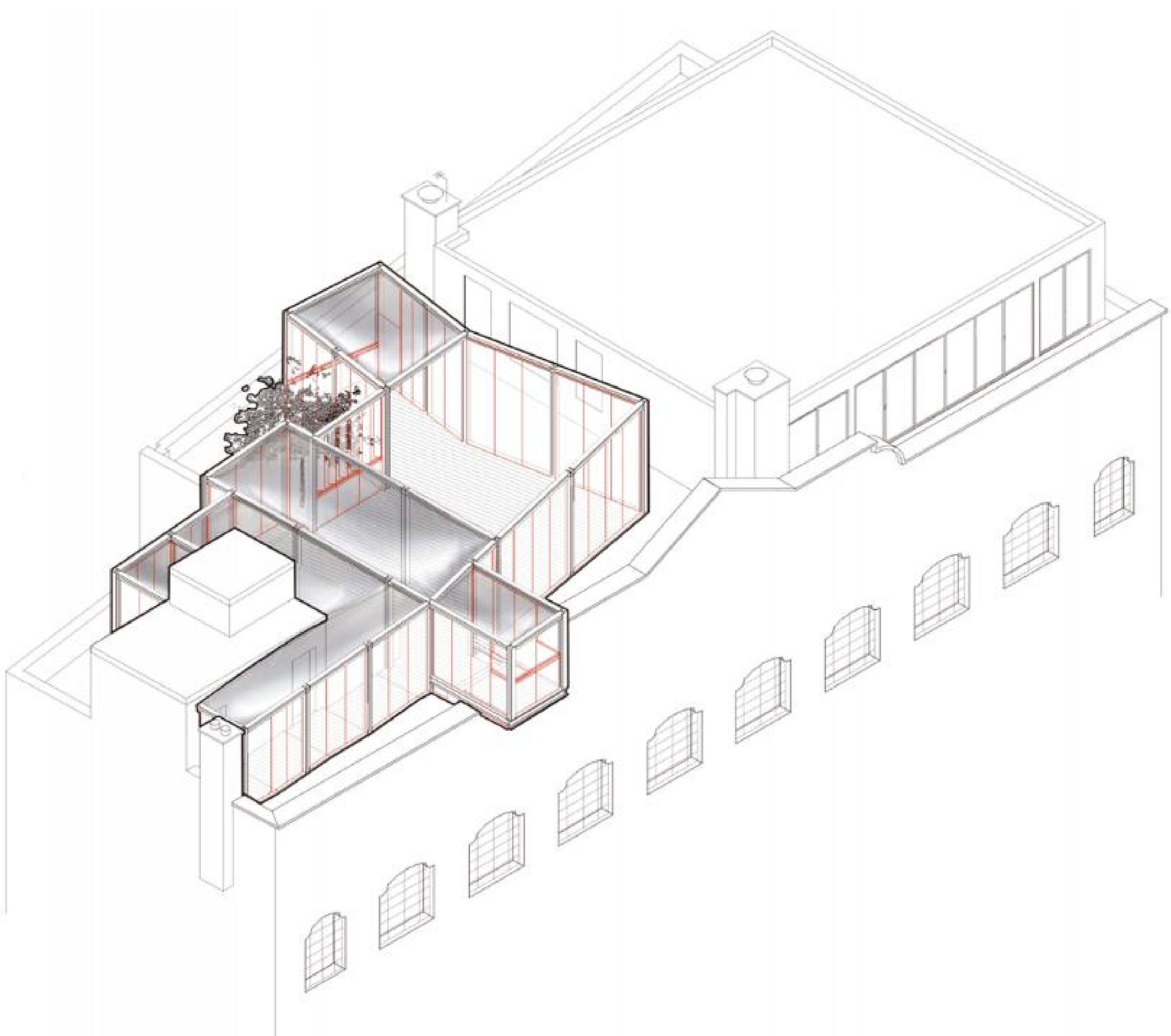


Figure 79 Axonometric drawing of AF skyroom (Source: davidkohn.co.uk)

The Skyroom offers an alternative space, imaginatively and opportunistically re-using of one of London's neglected roofscapes, to demonstrate the possibilities of adapting the capital's skyline and increasing capacity, even when faced with the planning control and pressures of a conservation area such as London Borough of Southwark.

Figure 80 Copper and stainless steel mesh creates strong moiré patterns (Source: architecturefoundation.org.uk)

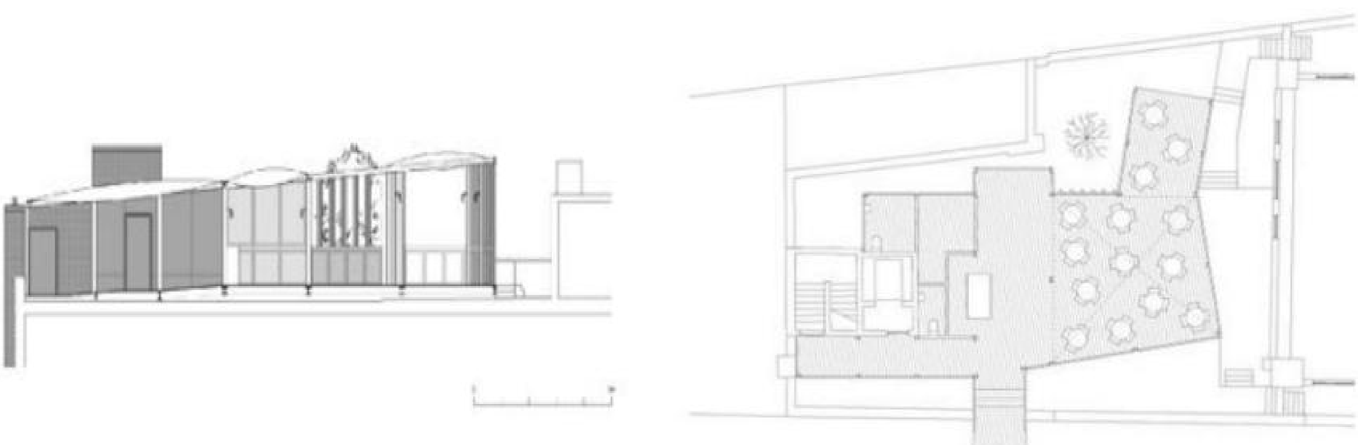


Figure 81 Left: Section view Right Floor plan (Source: architecturefoundation.org.uk)

The project has effectively made its presence known on the roof of the 19th Century warehouse building through a small, cantilevered balcony. This architectural gesture is intriguing as it allows both structures, through the subtle act of suggestion, to express themselves and engage with the surrounding environment. We hold that this design approach honors both structures, effectively conveying the project's architectural message of celebrating London's roofs to pedestrians.

Figure 82 Balcony cantilevered over the street

4.5. Final Remarks

The case studies in this chapter provide insight into the various roof extension techniques and how they contribute to creating adaptable, sustainable cities. Each project embodies different architectural concepts, structural remedies, and material innovations meant for a given urban context. Barcelona's lightweight modular timber and hybrid structures and New York's maintenance of historical integrity and London’s recreational place present case studies that underscore the necessity to balance new interventions with the existing urban fabric.

It is not hard to tell that the four case studies share vastly different goals and building techniques. One aim was not just to develop the available area but also to work with the technology for upgrading existing buildings to modern requirements. The second goal was to create ecologically sustainable houses by working towards units surpassing the present environmental regulations rather than solely depending on the existing structure's intrinsic energy. Using prefabricated methods and very light materials for the units would assist in developing a safe path for structural viability.

A key realization set forth is the need for structural flexibility. Thus, while The Stealth Building provides an account wherein new additions can remain aesthetically discreet but contribute towards maintaining the historical character of the city, La Casa por el Tejado underlines the essentiality of minimizing extra loads with the help of lightweight, prefabricated materials. In a similar vein, AF Skyroom within London explores the potential of neglected rooftop space as areas for social gathering, showing that vertical extensions can go beyond residential use and thus participate in urban placemaking.

Besides, these strategies emphasize sustainability. In turn, this implies that the energy efficiency of new rooftop additions can be greatly enhanced when environmentally friendly timber and other prefabricated materials are used, as was the case with 69 Enric Granados. That fits into a broader trend in contemporary architecture that prioritizes modularity, circular building, and resource efficiency.

These case studies showcase that rooftop extensions can enhance urban landscapes without compromising structural integrity, historic value, or environmental responsibility; thus, they serve to prove the feasibility of urban densification.

4.1. Italian Case Studies:

- Vertical extension & energetic retrofit of 1950s apartment buildings, Bolzano, Italy.

Figure 84 The original building before renovation

Figure 83 After renovation and vertical extension

In 2019, a collection of 1950s apartment blocks in Bolzano, Italy, received an extensive energy-efficient renovation from Area Architetti Associati. The intervention enhanced the buildings by upgrading them from CasaClima certification class G to class A. It also added 14 new units via a vertical extension that replaced the initial pitched roofs and introduced a sculptural facade that integrates new lift shafts and loggias. This conversion added to the functionality and aesthetics of the buildings as well as to the character of the area. This project is included in the larger Project SINFONIA, which will implement a 40-60% reduction of energy consumption in Bolzano's mid-20th-century residential districts. (Source: www.sto.com)

- House on House extension, Raimondo Guidacci, Turin

Figure 85 Picture of the extension (Source: www.theplan.it)

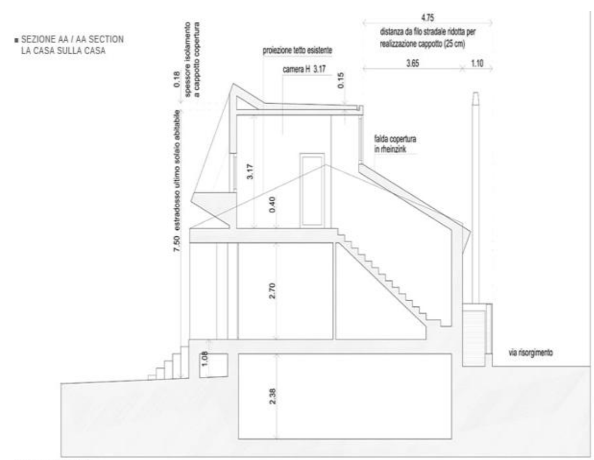


Figure 86 Section view of the building (Source: www.theplan.it)

In the Turin suburb of Trofarello, architect Raimondo Guidacci designed an extension on the roof of a standard low-density dwelling house. The extension features a bedroom with an ensuite bathroom, made of a frame composed of fir pillars and beams. The extension encroaches on part of the existing roof and is marked at each side by two lateral terraces, covered with transparent metal railings. The cladding is characteristic of Rheinzink panels displaying vertical and at angles ribs, contributing to the modern appearance, contrasting with that of the initial structure. Design was significantly determined by the area zoning regulations, which provided conditions of road width and surrounding building separation, determining in turn the volume of extension. The building design consists of a parallel-pied body attached to a flat roof that, together, accommodates a prism that repeats the original sloping eaves. The design shows a combination of traditional design and modernity in an improvement of practicality and beauty.

(Source: www.theplan.it)

- Pilot project in Florence, Italy

Figure 88 Building before renovation [67]

Figure 87 The SuRE-FIT solution [67]

SuRE-FIT (Sustainable Roof Extension Retrofit for High-Rise Social Housing in Europe) implemented between 2006 and 2008 tested new ways of rooftop extension for enhancing energy efficiency, expanding residential opportunities, and urban regeneration. In this work, retrofitting of existing domestic buildings with the help of prefabricated, energy-efficient roof extensions was taken into special consideration in the case of high-rise social housing.

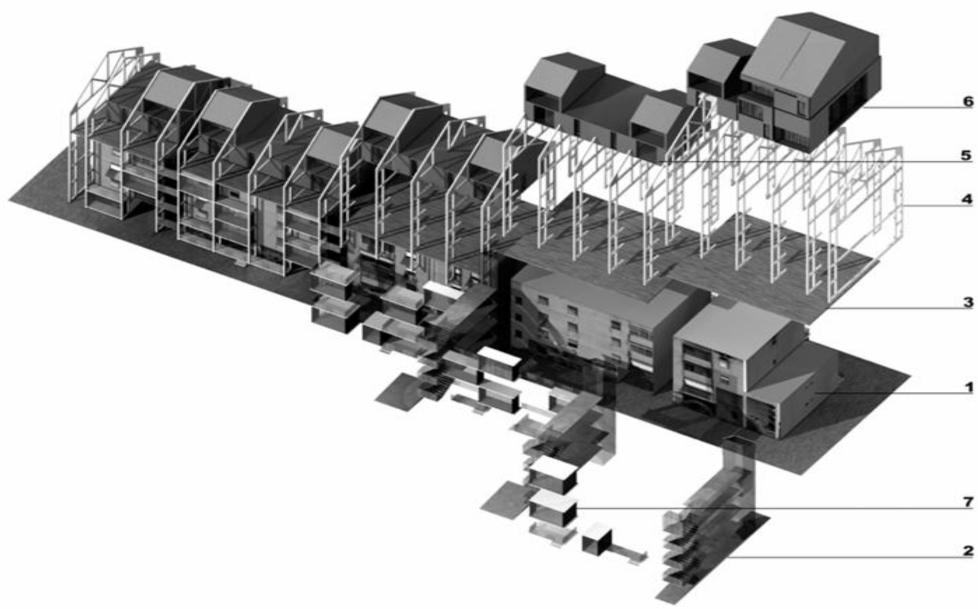


Figure 89 The Pilot Project concept:[67]

1) Existing building 2) New staircase 3) Platform on top 4) Structural steel bridges

5) New dwellings on top 6) Public spaces and facilities 7)" Small boxes" on facade

The pilot project for Florence, Italy, was used as a case study, highlighting the possibility of using modular timber and lightweight steel structures for roof extensions without causing existing foundations to become overloaded. The SuRE-FIT process is focused on energy neutrality, with new roof homes designed to run entirely on renewable energy. It aims to decrease total energy consumption in existing buildings by as much as 50%. Benefits also include increased insulation, increased accessibility by way of better stairways and lifts, and the establishment of social and public facilities.

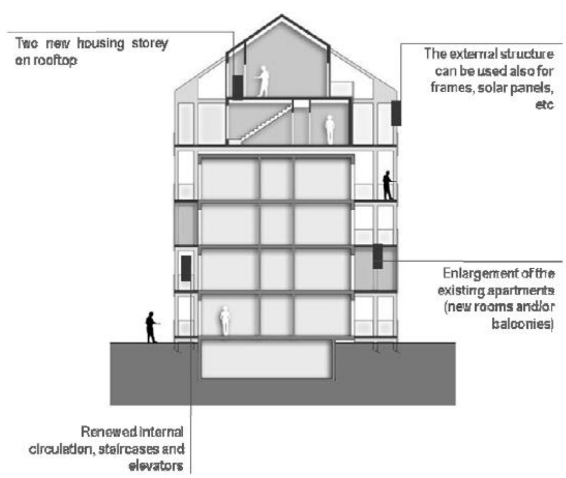


Figure 90 The structural system[67]

While there are promising benefits, there are also severe challenges, such as regulatory hurdles, seismic restraints, and the added complexity of obtaining approval from current residents, especially in social housing environments. The research indicates that effective implementation demands precise structural analysis, complete stakeholder involvement, and responsive prefabrication strategies. The SuRE-FIT model enables scalability, material efficiency, and cost reduction in urban densification plans through industrialized construction techniques.

This study refers to rooftop extensions as the sustainable model of urban growth, showing that underutilized rooftops may be redeveloped into useful, efficient living areas without adding to carbon footprint and enhancing the existing housing infrastructure.

5. The Potential of Rooftops in Turin

5.1. Context

Turin contains great potential for rooftop development, yet it is significantly underutilized, With its rich architectural heritage and high concentration of flat roofs and underutilized rooftops, Turin holds excellent chances of tackling urban challenges while maintaining its historical context.

Roofs can be activated to respond to urban challenges like housing demands, energy use, and climate resilience while still respecting built heritage. They also can be active sites for housing, green infrastructure, and renewable energy, establishing more energy-efficient and adjustable cities for the future.

Figure 91 Aerial photo of Vanchiglietta neighborhood in Turin

5.2. Case Study: From Urban Scale to Building Scale

This chapter investigates the potential for rooftop extensions in Turin by moving from a broader urban analysis to a detailed building-specific study. First, through an area-based roof survey, buildings with flat roofs were located in two neighbourhoods serving as a foundation for understanding large scale applicability. Afterwards, the focus narrows to a detailed assessment of a specific target building, where architectural, structural, and contextual factors were examined to assess its feasibility for a vertical extension using a prefabricated hybrid mass timber system.

5.3. Area-Based Survey:

For the sake of this study two areas in Turin were selected for more in-depth study. Which is the Centro and Vanchiglietta areas.

Figure 92 Aerial footage of Centro

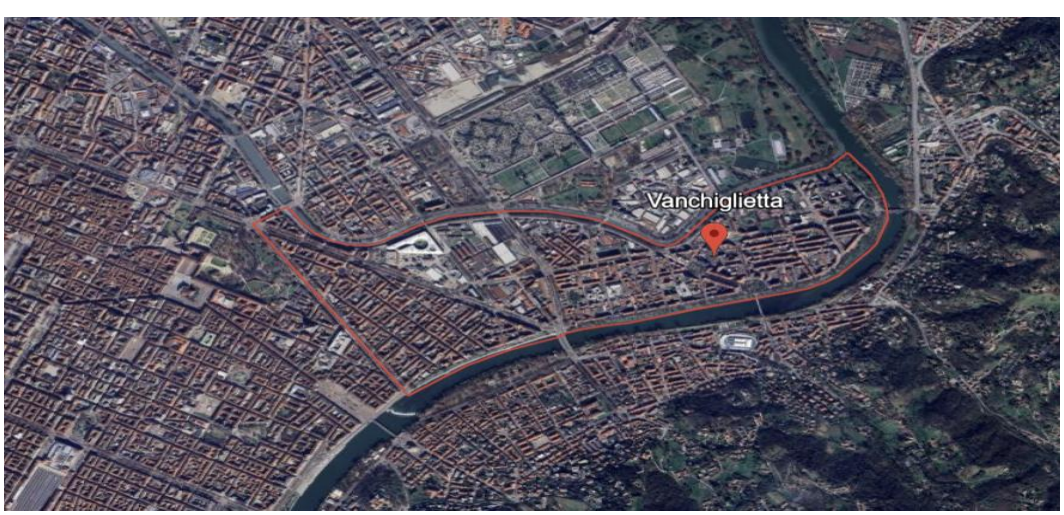


Figure 93 Areal footage of Vanchiglietta

The zoning of such areas for the assessment of the possibility of rooftop extensions was based on their urban characteristics, with historical growth, architectural styles, and types. These different districts portray multiple facets of the built form of the city and, therefore, provide different accounts of the impact and the feasibility of such expansions in the urban context. Centro is the historical and administrative heart of Turin. It contains a dense urban fabric made of heritage buildings for which land value is high. The area has many multi-story residential and mixed-use flat roof buildings that are good candidates for building on top. Since outward expansion in the city of Turin is severely limited, the increase in rooftop spaces over the buildings in Centro would assist in creating housing space, keeping with the established architectural form. Even more, the region's well-known complex zoning and heritage control offer unique potential for lightweight construction that is reversible and non-intrusive to the existing structures when addressing the urban overcrowding issue.

Vanchiglietta, on the other hand, is northeast of the Centro area just along the banks of the Po River. This area provides an alternative place for rooftop extension. Vanchiglietta has traditionally been an industrial and working-class area, but after urban regeneration, nowadays the area is characterized by mid-century apartment buildings. This very territory has lower population density than Centro and a greater demand for housing in the new metropolitan area. In addition, since these properties are much more modern and mostly built after the Second World War, the flat roofs of these buildings allow more possibilities for new modular rooftop additions. Also, in this case, urban renewal possibilities and closeness to green nature provide a good environment for sustainable rooftop additions with green roof systems and energy-saving technologies.

In-depth consideration of these areas will offer various architectural, regulatory, and socio-economic aspects that would impact rooftop additions in Turin. These contexts include Centro, very highly exposed to heritage concerns, often with very high density, where rooftops are worked out with a very fine balance between preservation and new life. Vanchiglietta, on the other hand, supplies a more flexible area within which the modernist concept of vertical expansion can be pursued with fewer constraints. This comparative study enables an extensive appreciation of the concerns and opportunities associated with rooftop extensions in Turin, thus forming a basis from which to evolve contextually based design strategies for future larger-scale interventions.

5.3.1. Climate and Environmental Assessment

Turin has a humid subtropical climate, featuring cold, damp winters (average lows around 0 °C, with frequent fog and occasional snow) and hot, humid summers (average highs in the mid 20s °C, often exceeding 30 °C). Rainfall is well distributed (~900–950 mm per year), peaking in spring and late summer due to thunderstorms.

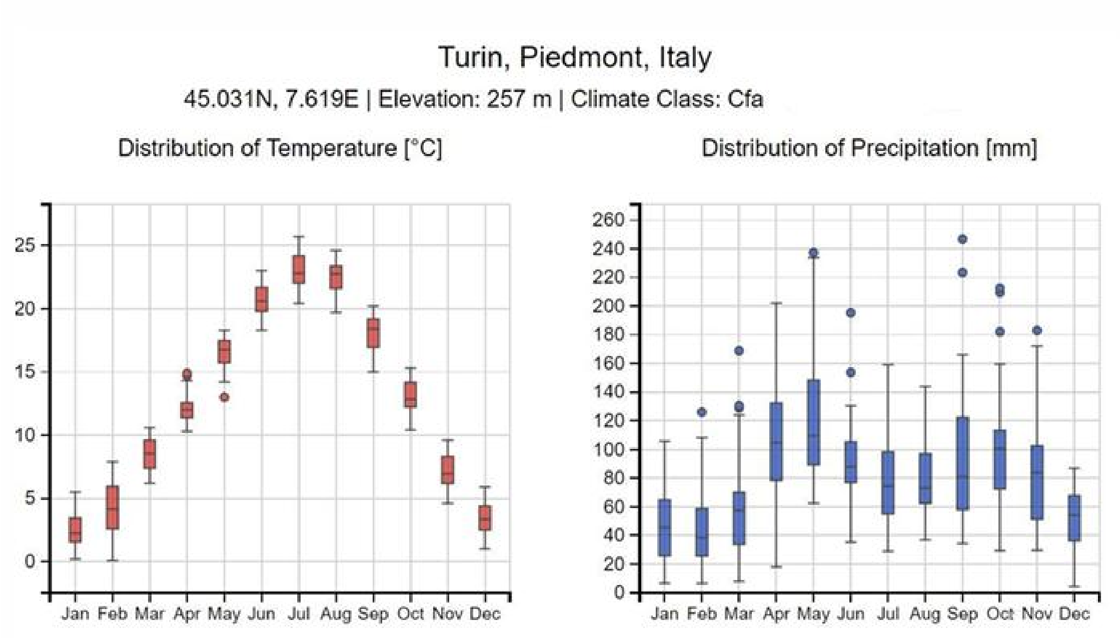


Figure 95 Distribution of Temperature and Precipitation in Turin

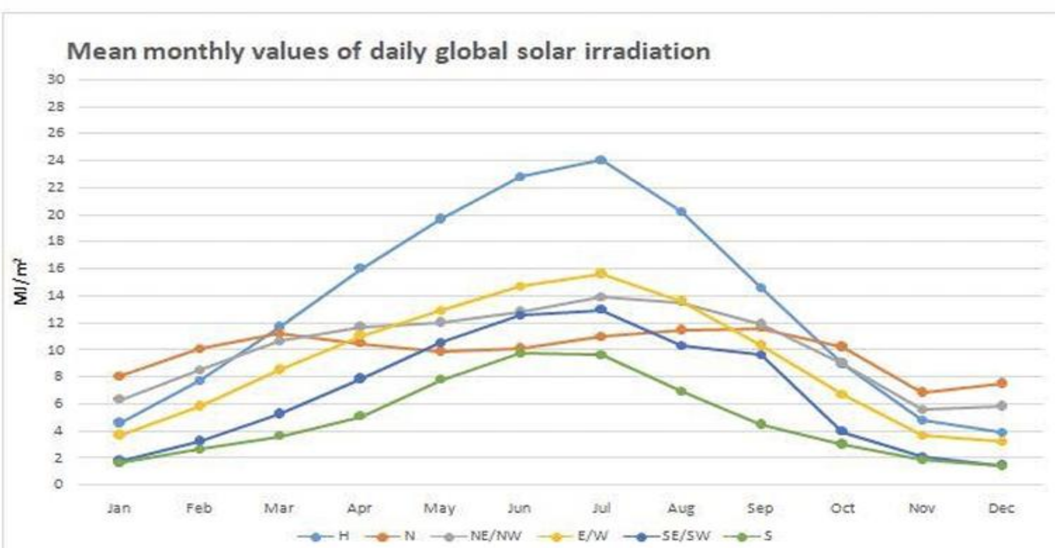


Figure 94 Monthly values of solar irradiation

The city faces a pronounced Urban Heat Island (UHI) effect, with temperature differences between urban and rural areas ranging from 3–5 °C at night, especially during heatwaves. Contributing factors include high building density, low vegetation cover, and limited airflow due to surrounding mountains. As a result, incorporating green roofs, ventilated façades, and high-albedo surfaces into rooftop extensions can meaningfully reduce ambient temperatures, improve thermal comfort, and enhance urban air quality.

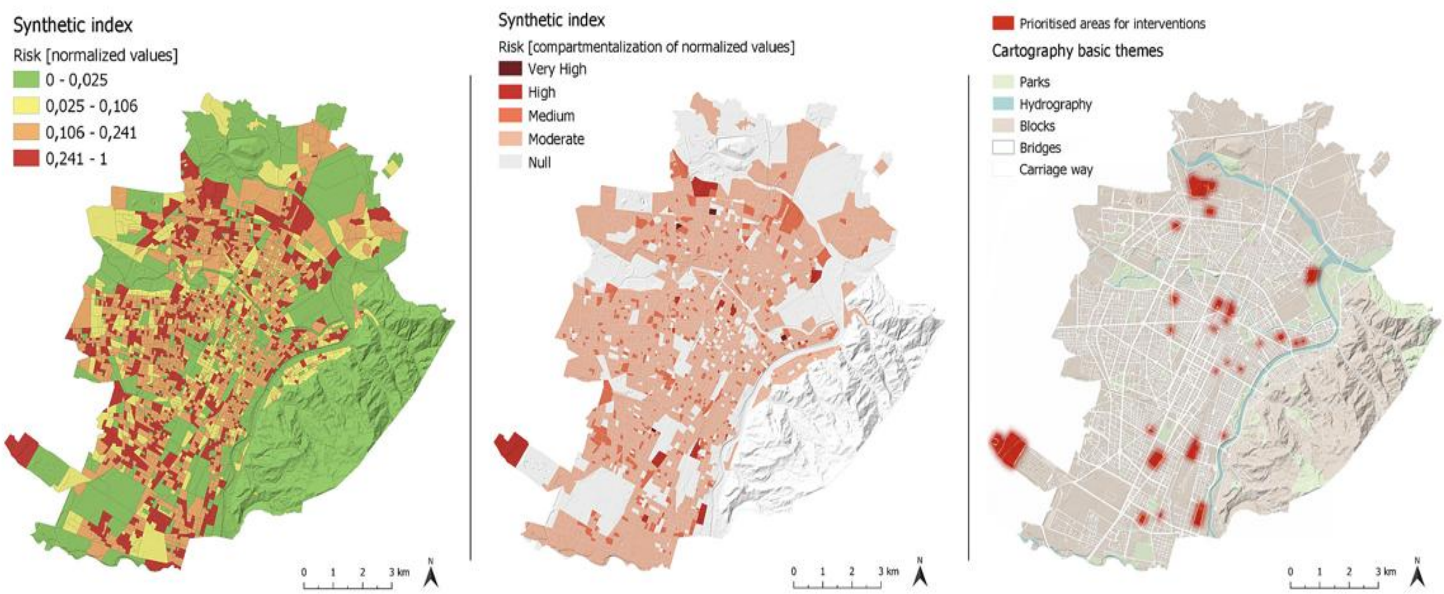


Figure 96 Mapping the UHI risks (left and middle) and the prioritized areas for intervention (right) [70]

5.3.2. Methodology

In order to explore the benefits of rooftop development for Turin, a study was undertaken to determine the available flat roof space within the city. Pitched and other styles of roofs were omitted for this study; however, it is recognized that with a more detailed analysis and evaluation some of these roofs might be able to be adapted and modified for specific rooftop developments which respond to the different roof forms.

The following study was carried out with the use of Google Maps and Google Earth to analyze the location and typology of the buildings and QGIS software to map the buildings with potential for rooftop development.

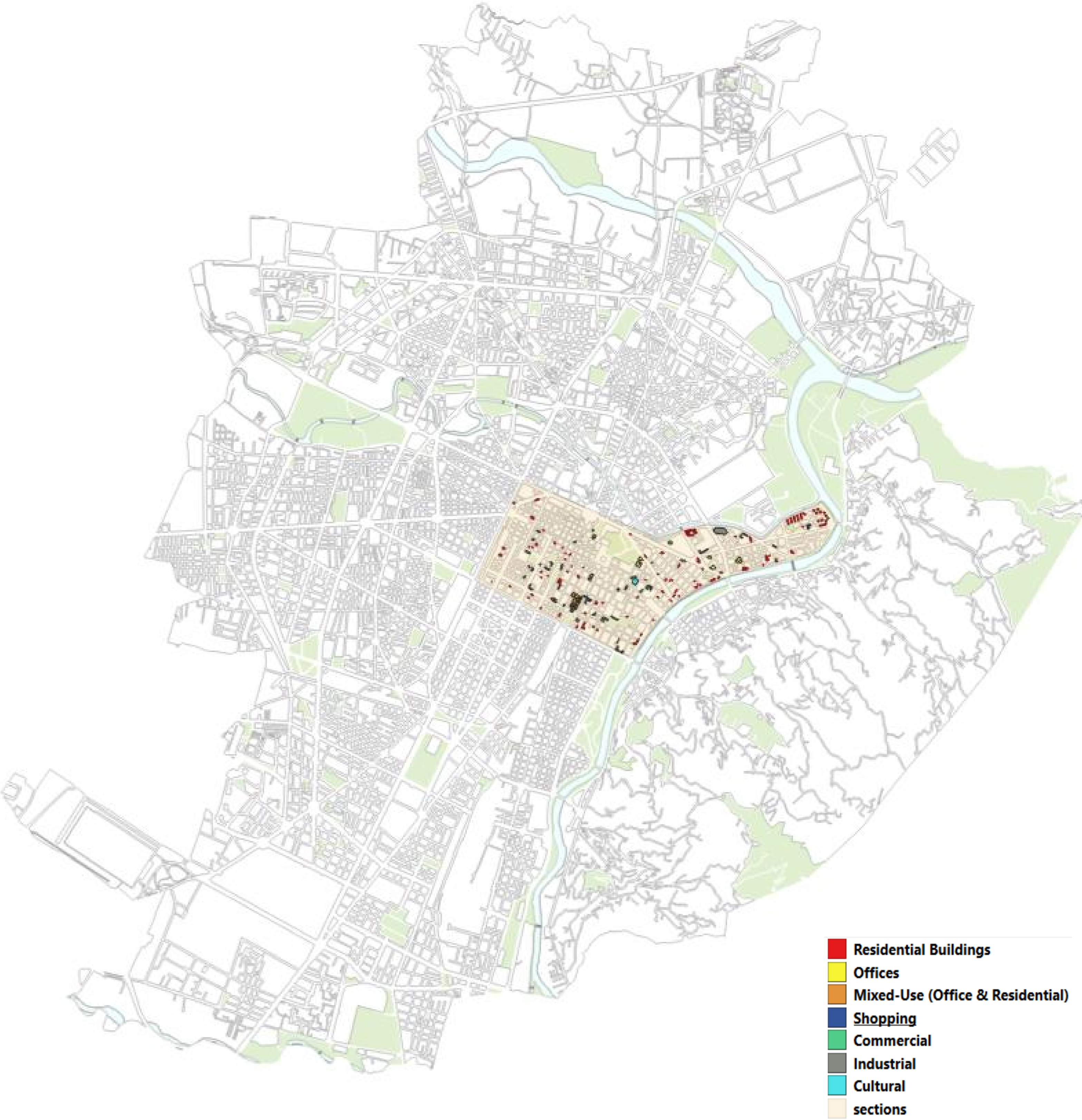


Figure 97 Map of flat roofs in Centro and Vanchiglietta areas in Turin (Source: Author)

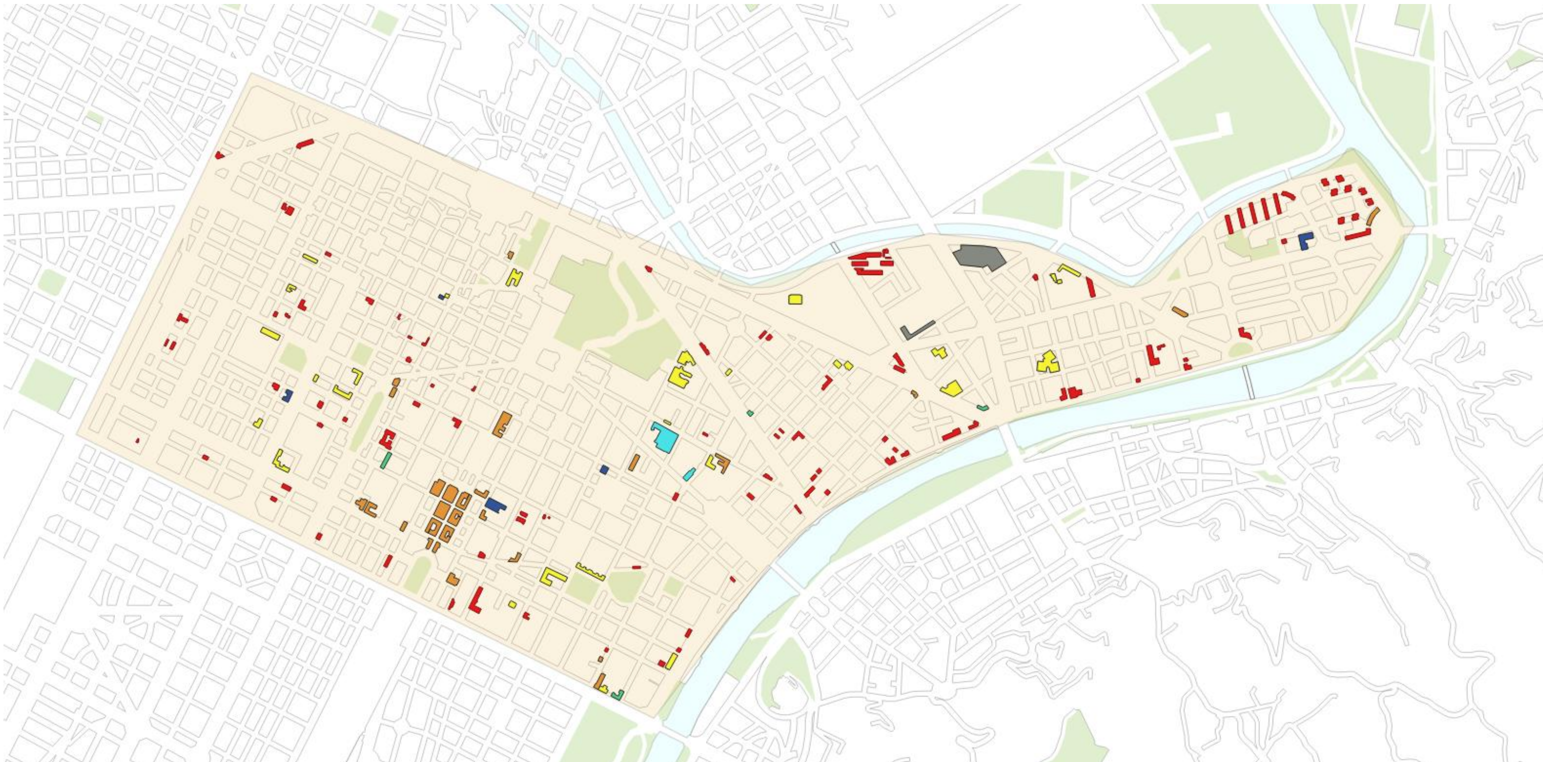


Figure 98 Close view of the map of flat roofs in Centro and Vanchiglietta areas in Turin (Source: Author)

5.3.3. Results

Use	*Size (m^2)*	*Percentage*
Residential	59.341	35.8 %
Offices	38.731	23.3%
Mixed Use	35.612	21.4%
Shopping	6.344	3.8%
Commercial	2.732	1.6%
Industrial	15.651	9.4%
Cultural	7.326	4.4%
TOTAL	165.737	100%

Table 8 Available spaces by functionality of the potential flat roofs in Turin (Source: Author)

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Extracting solely the buildings in which residential use has been established, the flat roof space equates to 59.341m^2. In 2016 HTA architectural company in London did similar research and they considered Melet and Vreedenburgh's topping up approach [7] which allows for the vertical expansion. They calculated the potential number of additional housing units by taking an average of 60m^2 per home, which utilizes 75% of the total available roof.

By applying the same formula in Turin it would appear that there is a potential for near 1000 new homes in Centro and Vanchiglietta areas only by addition of one story to residential houses and of course more units could be created through more than one story being added.

As discussed before, the use of the rooftop isn't limited to one function or culture. Social rooftops have potential to breathe new life into dense areas of the city through the provision of new activities and space. Schools, hospitals and other public buildings have the potential to support such vertical additions, either providing additional space for the existing building or opening up to the public.

Schools, hospitals, leisure facilities and other public buildings commonly have large expanses of flat roofs, Rooftop playgrounds and sports pitches can provide much needed activity spaces to schools and nurseries within Turin, allowing expansion without additional land consumption. More than 30,000m^2 of flat roof space sits above these spaces, typically supporting services, unlocking this potential would allow for the creation of new recreational spaces. With the development of new technologies, the need for rooftop services is diminishing and through consideration, the rooftops could begin to become inhabited.

5.4. Detailed Assessment of a Target Building for Vertical Extension:

The proposed case study located at Lungo Po Niccolò Machiavelli 25, 27, 10124 Torino, it consists of two typic buildings that are strongly tied to the Vanchiglietta neighborhood which is an area of diverse transitional urban forms between historical centers and peripheral growth. The neighborhood is located to the northeast of Turin's central metro area and is characterized by post war urbanization patterns, including: linear street grids, moderate building height, and a predominance of residential land uses.

Figure 99 Selected Building for intervention

The buildings are situated on a defined urban block and are exposed to both vehicular and pedestrian circulation. The position offers possibilities for vertical densification that would not alter the historicity of the place; and the building located there could utilize existing capacity without overwhelming planned infrastructure. The intended site location also is well served by public transport routes and is located near the Po River which contributes to the livability of the building and the building's relationship to the larger urban network.

Figure 100 Selected Building front view

Figure 101 Location of the selected Building

The buildings rise to six stories and exhibit a flat roof with minimal impediments, a great situation in dense infill neighbourhoods like Vanchiglietta. Based on architectural plans, photos and known regional typology, the building utilizes a reinforced concrete frame with infill masonry walls; a structural system used throughout Italian mid-20th century stock of housing. This configuration allows for vertical extensions, principally in line with lightweight materials to limit the additional loading imposed. The roof is not being used for any purpose, therefore it appears to have considerable area for the building of more residential apartments oriented around a lightweight Glulam mass timber framework and cross-laminated timber (CLT) panels for walls, roof and floors.

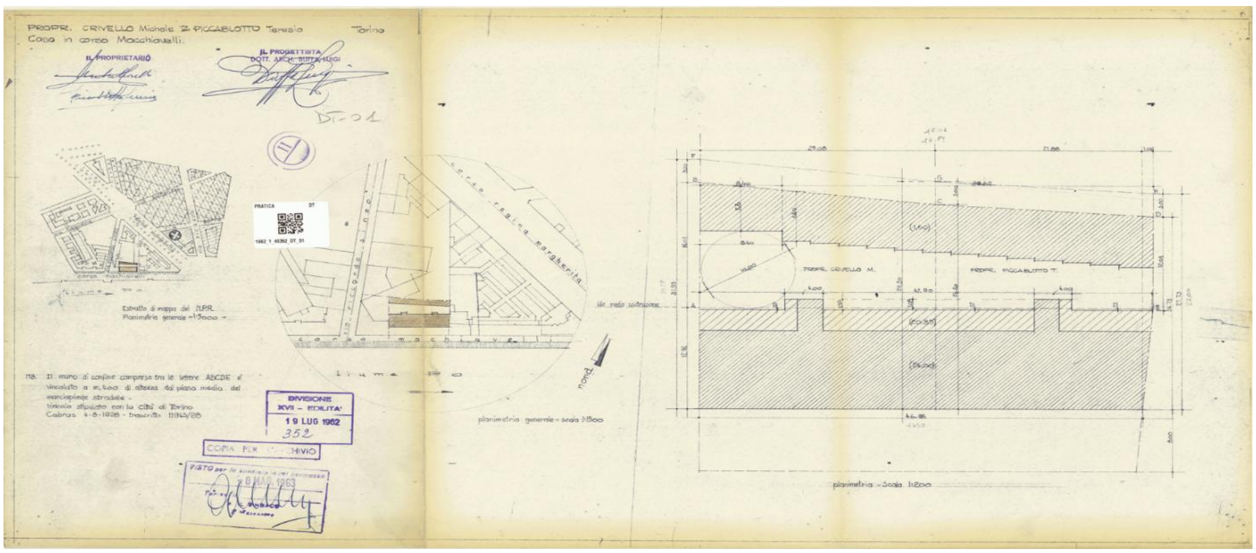

Figure 102 Original plan of the existing building in 1963

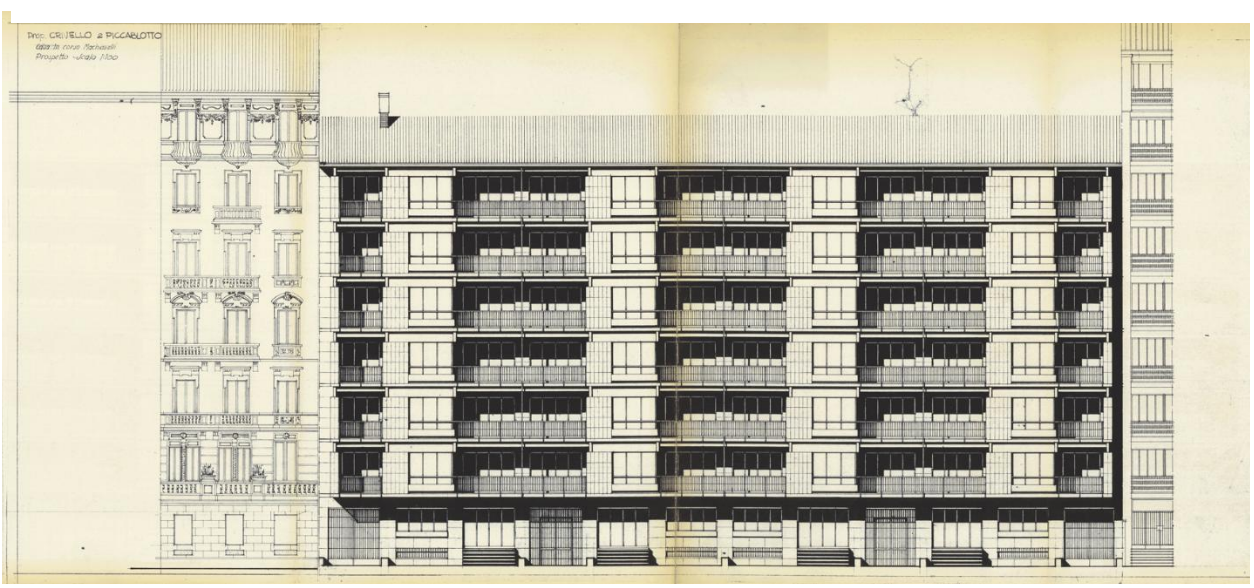

Figure 103 Original elevation view of the existing building in 1963

5.4.1. Design Process

This approach to the rooftop extension includes a mixed design with a traditional post and beam system and a modern Cross-Laminated Timber (CLT) panel system. This hybrid typology achieves the best overall result in terms of structural efficiency, construction flexibility, sustainability, and response to the context, particularly with respect to vertical extensions to buildings in cities with densely layered historic precedent, such as Turin.

Post and beam, as a construction methodology, is an established construction practice that uses a unique and simple process of assembling vertically and horizontally simple and robust visual and structural elements (posts and beams). In this case, glulam (glue-laminated timber) columns and beams will be proposed for resiliency and to maximize/simplify as long a span as possible without mid-span support to minimize weight transferred down to the existing building structure. The glulam columns and beams will be the main structural assembly with the prefabricated CLT panels as a secondary layer added to the structure.

CLT panels will be specified for the floor slabs, wall panels, and roof panels. CLT panels have excellent load performance characteristics, dimensional stability, and fire resistance, all while being lightweight compared to traditional concrete or masonry options, a significant benefit for rooftop construction. Because CLT panels can be prefabricated off-site, they can reduce on-site construction time, and the associated impacts on the occupied spaces below, and they offer a higher precision and development of the finish.

The core elements of the extension, including the elevator shaft and stairway, will be constructed using reinforced concrete (RC). This decision is made based on the need for increased lateral stiffness, durability, and fire resistance for these important vertical circulation and service elements. The RC core acts as a rigid and strong spine for the timber extension. The RC core can efficiently resist lateral loads from wind and seismic loads, which is an important consideration in the design of the safety and structural efficiency of the whole building. An RC core also allows for effective load transfer down to the existing structure and provides a fire protected enclosure creating a safe condition for occupants. The connection between the RC core and the timber structure is designed to account for differential movements and to enhance the constructability of the building.

In terms of sustainability, this system is highly sustainable. CLT and glulam are made from sustainably managed stands of timber (a renewable resource, that sequesters carbon over its lifetime), with the panels manufactured from low-emissions adhesives, and the dry construction system uses less water and generates waste on site. CLT also has many thermal and acoustic insulation properties making it a great contributor to energy performance while providing a better sense of comfort for occupants.

This hybrid amount of material is in line with circular construction as it supports the principles of reversibility and adaptability; the post and beam system can be assembled using mechanical connections providing the ability to take apart or renovate the structure while leaving the major framework intact. The CLT panels can also be detached, switched out, or reconfigured to help increase the capacity for adaptability in the event the future use dictates it.

The system also allows for a flexible design as it accommodates a variety of façade treatments, shading systems, and green technologies (e.g. ventilated cladding; modular façade cassettes; integrated photovoltaics).

In summary, the choice of a conventional post-and-beam framing together with CLT panels and a reinforced concrete core represents a technically sound, sustainable, and sensible project that is cohesive; it uses the strengths of traditional and modern building types and responds to environmental, logistical, and structural aspects of rooftop development in historic urban environments.

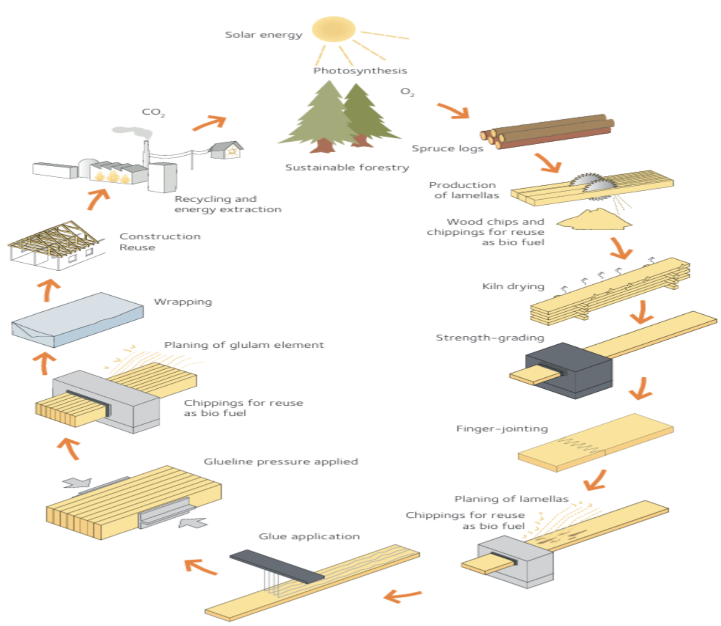

Figure 104 Life cycle of glulam

Architectural Plans:

The architectural plans were designed thoughtfully with respect to quality residential development. The proposal would provide two luxury apartments of approximately 120 square meters which would include two large private outdoor yards of 21 sqm and 47 sqm respectively for each apartment. While this arrangement could facilitate a high standard of spatial organization, it also presents a model of indoor-outdoor living that is vital to the rooftop element of urban living.

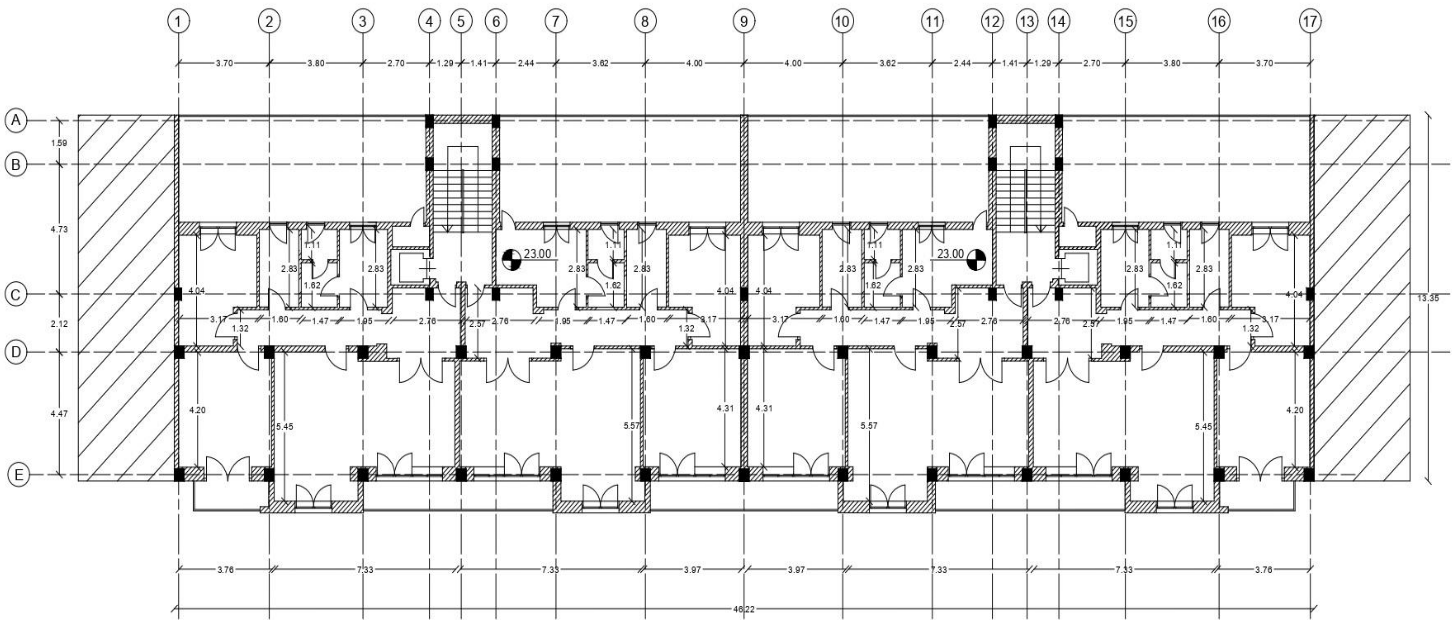

Figure 105 Architectural plan of the last story of the existing building

The layout of each apartment has been designed as highly functional: there is a large living room integrated with the open kitchen, master bedroom and independent bathroom. Circulation is well organized with a clear boundary between public activity and private bedrooms. The measurements imply a good level of comfort and functionality. The use of CLT for walls and floors, combined with the open post-and-beam system, allows for generous openings and adaptable interior planning. The clear advantages to having larger openings within the walls and flexibility for interior planning will be accommodated. The outside yards allow private areas to be filled with light, ventilation and plant matter, adding to quality of life, while improving environmental performance and the well-being of users.

In summary, the proposed rooftop addition is well-considered, structurally logical, and visually consistent, ensuring the site is optimally utilized while also respecting the building below. It demonstrates how rooftop architecture can provide modern, sustainable, and desirable housing in a dense urban area like Turin.

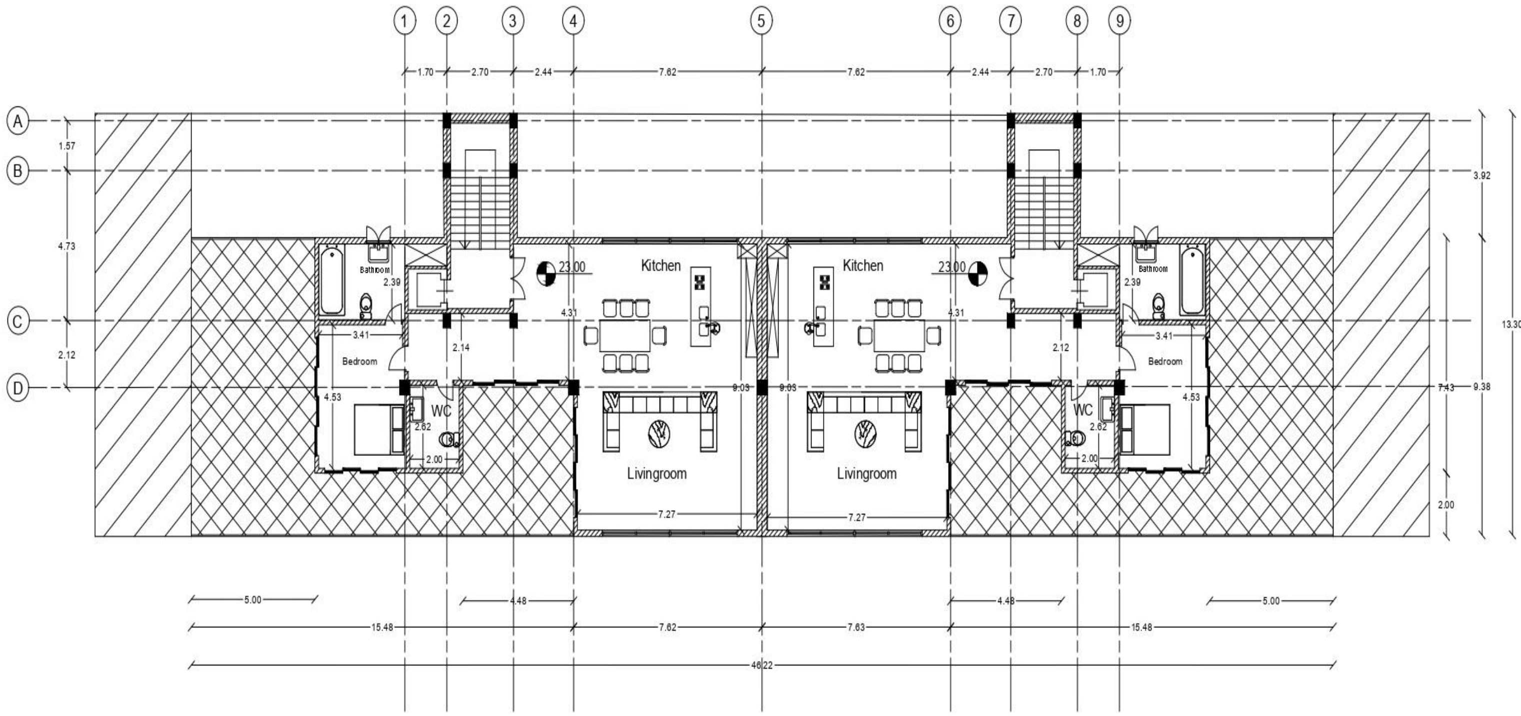

Figure 106 Proposed architectural plan of the new extension

Energetic Assessment

Achieving excellent energy performance is fundamental to making rooftop extensions in contemporary buildings, and especially for dense urban locations such as Turin. This project proposes to combine passive and active methods of reducing energy demand and enhancing comfort, while achieving sustainability goals through a material, construction system, and building envelope that is carefully designed.

The energy assessment investigates how well the new rooftop extension limits thermal dispersal, supplies renewable energy and reduces operational consumption. For rooftop extensions, important considerations include weight, thermal bridging, continuity with existing structures. Given the level of exposure for rooftop structures, insulation and solar protection are also particularly of importance.

CLT panels were already considered for high thermal performance and also natural ventilation, solar control with shading, and maximization of daylight were taken to be integral to the intended design. Safety from fire and airtightness were managed alongside thermal performance with use of insulated / sealed jointing and prefabricated details.

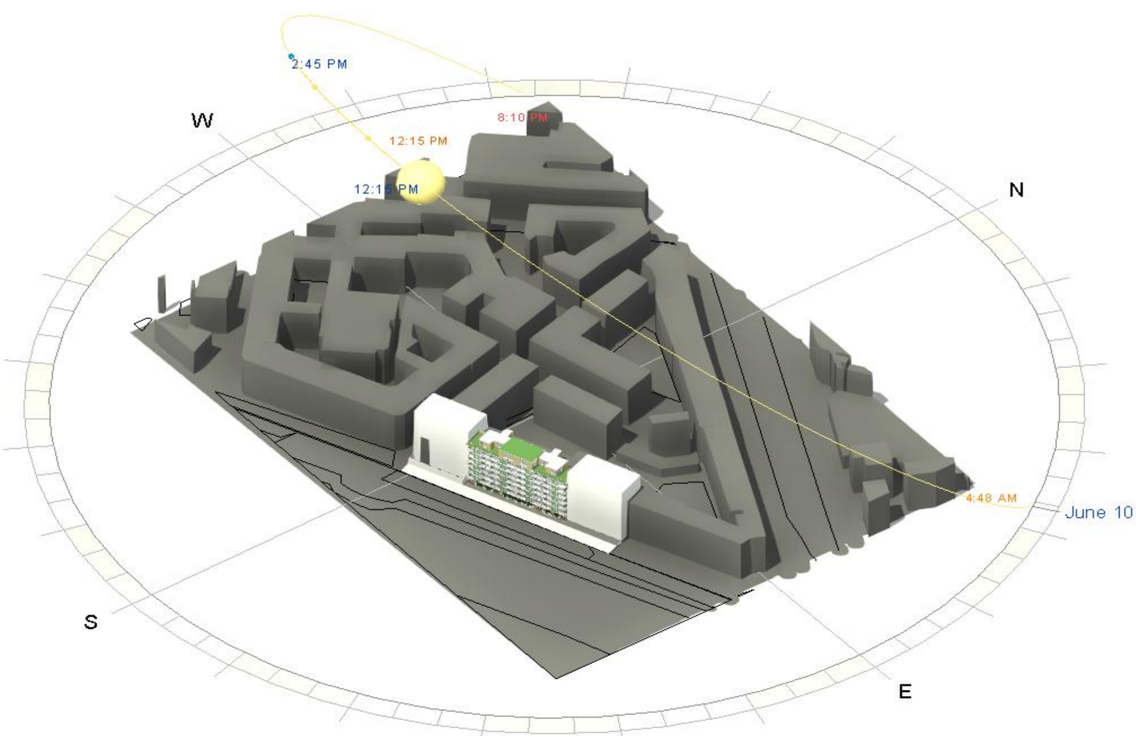

Figure 107 Sun path for the 10th of June

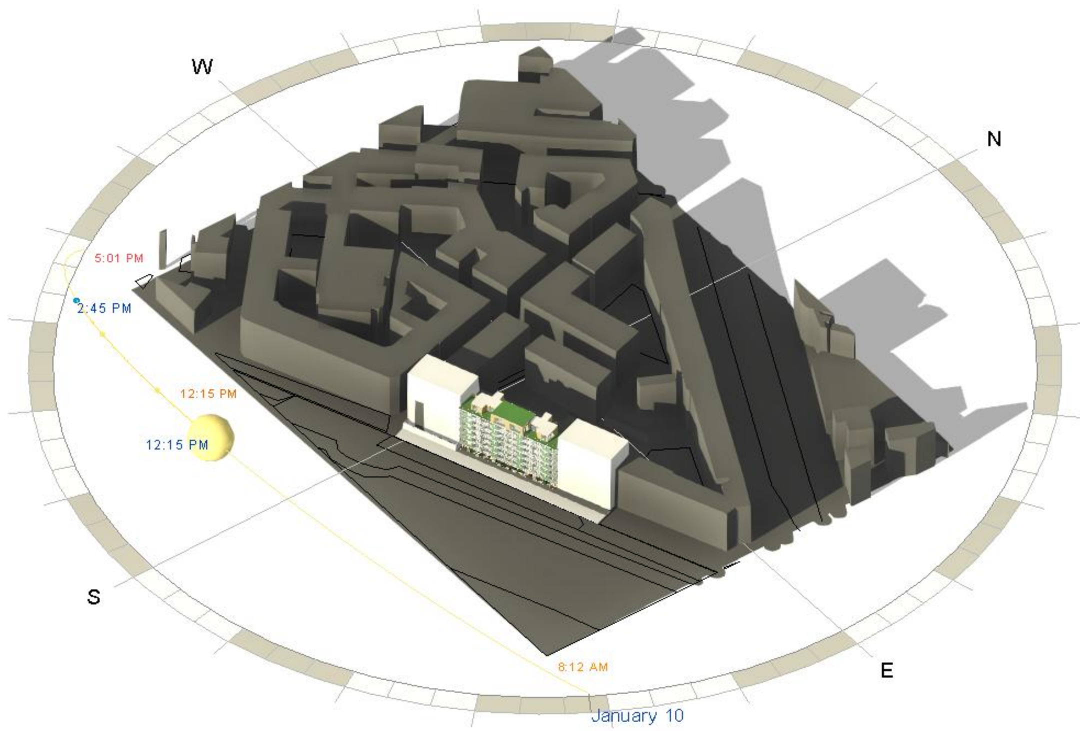

Figure 108 Sun path for the 10th of January

The project integrated various strategies for long term sustainably and improving energy efficiency:

• Green Roof System: A vegetated roof with layers gives thermal mass and mitigates the heat island effect, promotes rainwater retention, and serves partly as thermal and acoustic insulation.

• Prefabricated Timber Panels: These high-performance prefabricated CLT and glulam components help with thermal bridging minimization and precision fitting for enhanced airtightness and thermal continuity.

• Ventilated Façade: This project proposes a ventilated façade system with a CLT panel, an external insulation layer, an air cavity, and opaque cladding. The ventilated air gap allows for thermal performance improvement through enhanced reduction of heat transfer between warm and cold exterior walls and improved management of moisture. The ventilation system results in lower energy consumption and improved energy efficiency, and it also facilitates the integration of BIPV elements without compromising the aesthetics and longevity of an end-use building user.

• Building Integrated Photovoltaic (BIPV) windows: these semi-transparent windows reduce comparative solar gain while also generating power, and they help the building meet its renewable energy component while maintaining daylighting and visibility.

Figure 109 Building Integrated Photovoltaic (BIPV) window

Element	U-Value (W/m²K)
External Wall	0.16
Internal Partition Wall	0.22
Roof (Green Roof System)	0.15
Window (BIPV Glazing)	1.10
Floor (over existing slab)	0.27
RC Core Wall (internal)	0.30

Table 9 Physical characteristics of components

Note: Maximum U-values in Italian Climate Zone E are typically:

- Walls: 0.28 W/m²K

- Roof: 0.20 W/m²K

- Floor: 0.26 W/m²K

- Windows: 1.40 W/m²K

Regulations: Extensions cannot be seen as specific interventions in a property (except in particular cases) but as an intervention that modifies the overall behavior of the property. This is clearly reported in the NTC2018.

8.3. VALUTAZIONE DELLA SICUREZZA

La valutazione della sicurezza deve effettuarsi quando ricorra anche una sola delle seguenti situazioni:

- riduzione evidente della capacità resistente e/o deformativa della struttura o di alcune sue parti dovuta a: significativo degrado e decadimento delle caratteristiche meccaniche dei materiali, deformazioni significative conseguenti anche a problemi in fondazione; danneggiamenti prodotti da azioni ambientali (sisma, vento, neve e temperatura), da azioni eccezionali (urti, incendi, esplosioni) o da situazioni di funzionamento ed uso anomali;
- provati gravi errori di progetto o di costruzione;
- cambio della destinazione d'uso della costruzione o di parti di essa, con variazione significativa dei carichi variabili e/o passaggio ad una classe d'uso superiore;
- esecuzione di interventi non dichiaratamente strutturali, qualora essi interagiscano, anche solo in parte, con elementi aventi funzione strutturale e, in modo consistente, ne riducano la capacità e/o ne modifichino la rigidezza;
- ogni qualvolta si eseguano gli interventi strutturali di cui al § 8.4 ;
- opere realizzate in assenza o difformità dal titolo abitativo, ove necessario al momento della costruzione, o in difformità alle norme tecniche per le costruzioni vigenti al momento della costruzione.

8.4. CLASSIFICAZIONE DEGLI INTERVENTI

Si individuano le seguenti categorie di intervento:

- ***interventi di riparazione o locali:*** interventi che interessino singoli elementi strutturali e che, comunque, non riducano le condizioni di sicurezza preesistenti;
- ***interventi di miglioramento:*** interventi atti ad aumentare la sicurezza strutturale preesistente, senza necessariamente raggiungere i livelli di sicurezza fissati al § 8.4.3;
- ***interventi di adeguamento:*** interventi atti ad aumentare la sicurezza strutturale preesistente, conseguendo i livelli di sicurezza fissati al § 8.4.3.

Solo gli interventi di miglioramento ed adeguamento sono sottoposti a collaudo statico.

Per gli interventi di miglioramento e di adeguamento l'esclusione di provvedimenti in fondazione dovrà essere in tutti i casi motivata esplicitamente dal progettista, attraverso una verifica di idoneità del sistema di fondazione in base ai criteri indicati nel §8.3.

Qualora l'intervento preveda l'inserimento di nuovi elementi che richiedano apposite fondazioni, queste ultime dovranno essere verificate con i criteri generali di cui ai precedenti Capitoli 6 e 7, così come richiesto per le nuove costruzioni.

Per i beni di interesse culturale ricadenti in zone dichiarate a rischio sismico, ai sensi del comma 4 dell'art. 29 del DLgs 22 gennaio 2004, n. 42 "Codice dei beni culturali e del paesaggio", è in ogni caso possibile limitarsi ad interventi di miglioramento effettuando la relativa valutazione della sicurezza.

8.4.3. INTERVENTO DI ADEGUAMENTO

L'intervento di adeguamento della costruzione è obbligatorio quando si intenda:

a) sopraelevare la costruzione;

b) ampliare la costruzione mediante opere ad essa strutturalmente connesse e tali da alterarne significativamente la risposta;

c) apportare variazioni di destinazione d'uso che comportino incrementi dei carichi globali verticali in fondazione superiori al 10%, valutati secondo la combinazione caratteristica di cui alla equazione 2.5.2 del § 2.5.3, includendo i soli carichi gravitazionali. Resta comunque fermo l'obbligo di procedere alla verifica locale delle singole parti e/o elementi della struttura, anche se interessano porzioni limitate della costruzione;

d) effettuare interventi strutturali volti a trasformare la costruzione mediante un insieme sistematico di opere che portino ad un sistema strutturale diverso dal precedente; nel caso degli edifici, effettuare interventi strutturali che trasformano il sistema strutturale mediante l'impiego di nuovi elementi verticali portanti su cui grava almeno il 50% dei carichi gravitazionali complessivi riferiti ai singoli piani.

e) apportare modifiche di classe d'uso che conducano a costruzioni di classe III ad uso scolastico o di classe IV.

In ogni caso, il progetto dovrà essere riferito all'intera costruzione e dovrà riportare le verifiche dell'intera struttura post-intervento, secondo le indicazioni del presente capitolo.

Nei casi a), b) e d), per la verifica della struttura, si deve avere $\zeta_E \geq 1,0$. Nei casi c) ed e) si può assumere $\zeta_E \geq 0,80$.

Resta comunque fermo l'obbligo di procedere alla verifica locale delle singole parti e/o elementi della struttura, anche se interessano porzioni limitate della costruzione.

Una variazione dell'altezza dell'edificio dovuta alla realizzazione di cordoli sommitali o a variazioni della copertura che non comportino incrementi di superficie abitabile, non è considerato ampliamento, ai sensi della condizione *a)*. In tal caso non è necessario procedere all'adeguamento, salvo che non ricorrano una o più delle condizioni di cui agli altri precedenti punti.

Figure 110 NTC 2018

Capacity of the Existing Building: A review of original design drawings and documents confirms reserve capacity in the existing columns and foundations. The lightweight nature of mass timber (approximately 50 kg/m² for floors) ensures negligible additional dead load. In the case of lightweight rooftop extensions, using prefabricated timber systems results in significantly lower dead loads compared to traditional masonry or concrete walls and floors. Structural assessments of mid-20th-century buildings often show that they can support lightweight additions in timber, thanks to conservative original design safety factors.

Stairs and Elevator: The shafts for the elevators and stairways can be easily extended above into the existing concrete by extending the reinforced concrete core. Using reinforced concrete to extend the vertical circulation components provides structural integrity as well as the necessary fire resistance, which provides the best safety for occupants and the buildings stability. When extending the reinforced concrete core, the shaft provides a continuous enclosure that will not only replace the existing elevator and stair shaft but will also act as a load transfer and provide lateral stability for the building. Extending the existing reinforced core and extending the elevator and stair shafts in the hybrid rooftop extension will make the construction process very simple. Constructing the core can be achieved with standard formwork and placing methods while providing a strong frame and enclosure that supports the timber extension surrounding it.

Crane Position: The mobile crane will be placed in front of the building to lift the prefabricated CLT panels and glulam columns. The street in front of the site is just under 12 meters; there is plenty of room for the crane to efficiently lift the panels and columns to the roof, while still maintaining controlled access for vehicles and pedestrians. With typical mobile crane dimensions and safety standards, a street width of approximately 10–12 meters are considered appropriate for safe outrigger deployment, lifting radius, and access clearance for materials. Temporary site fencing and traffic management will be put in place to maintain safe operations during lifting periods. The street condition in combination with lightweight, prefabricated timber elements supports a low impact and efficient installation method in an urban environment and does not require deeper construction staging or long-term road closure.

Fire Protection and Safety: Fire protection is a key consideration in the design of vertical extensions. One of the main focuses is to ensure that the level of occupant health and safety protection is provided. To achieve this, the design utilizes passive fire protection, active fire detection and suppression techniques, as well as measures to protect the building during construction.

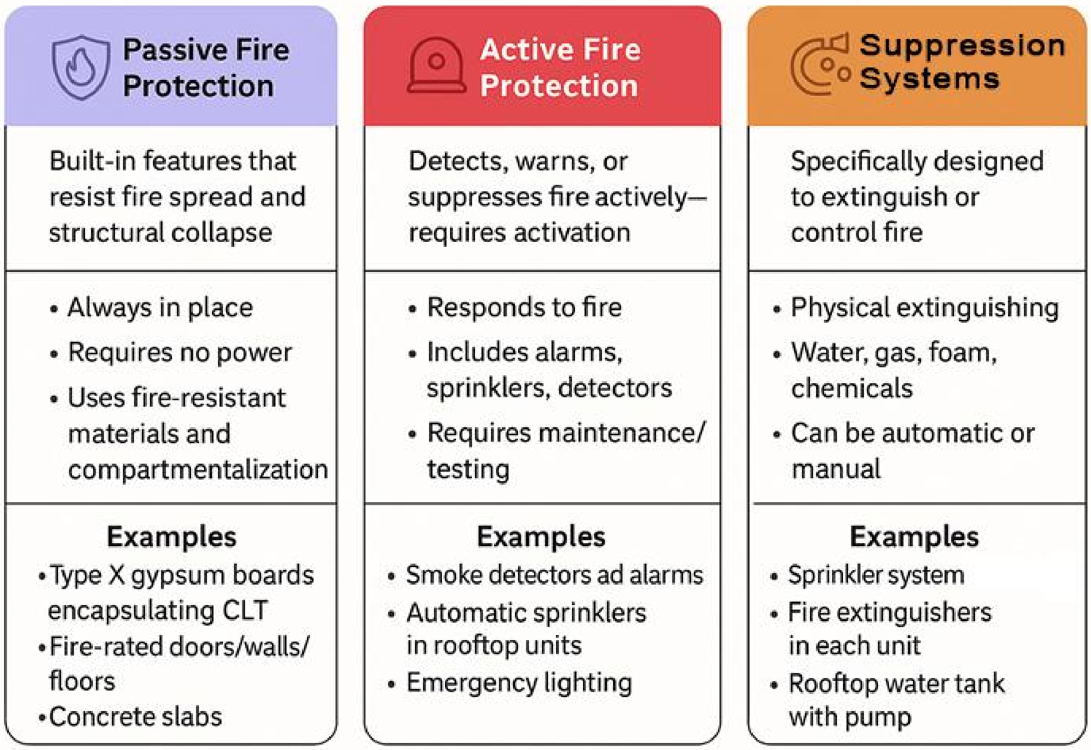

Figure 111 Fire Protection Strategies (Source: Author)

Operational Guideline:

The first phase includes the casting of the reinforced concrete core extension, including elevator shafts and stairways. During this phase, steel plates and anchors are placed in the concrete walls and slab to facilitate bolted connections to the timber structure. After the concrete cures and sets to a suitable strength, holes are drilled in the slab where bolts will be installed to secure the column base connections.

The next phase is the installation of the steel hollow structural sections (HSS). The smaller HSS pieces are fixed to the bottom of the glulam columns using epoxy-set threaded rods, connecting to the larger HSS stubs that are embedded in the concrete slab. These are bolted together to form a true load path, allowing vertical loading transfer from the column system into the existing structure.

Next, the prefabricated CLT panels for the floor, wall, and roof are installed. Connection systems include bolted wood connections for the elements that connect to the glulam columns. Steel base plates are installed on the first floor. the wall-to-wall and wall-to-beam connections used prefabricated interlocking male and female connectors. All elements interlocked, sliding or stacking into place without the need for onsite anchors, saving time, and providing with accuracy and repeatability.

The interface with the reinforced concrete core consists of CLT floor and wall panels resting on steel ledger angles welded to embedded plates cast into the core walls. The ledger connections transfer the vertical load and horizontal shear forces, providing a well supported and rigid connection at this junction. Steel drag straps are connected at the tops of the CLT panels and anchored to the tabs welded to the RC core, to provide a mechanism to resist lateral loads. The number and spacing of drag straps is dependent on the required lateral resistance at different levels of structure.

The RC core extension forms a strong and fire-resistant alternative structural spine for the addition, while also housing the elevator and stairs and providing critical lateral stability. The first step is to build this durable concrete core. Next, the prefabricated timber can be placed quickly into the core and assembled, creating limited disruption to building occupants below while minimizing waste and allowing for precise assembly in just days.

Finally, once everything was in place, the final review and inspection confirm that all bolted and interlocking connections are fully engaged, lined up, and safely and securely fastened. This step keeps this rooftop addition structural, sound, safe, and meets current standards for adaptability, durability, and modular.

Structural Connections:

Because of the hybrid form of this extension, there are three potentially different connection types, firstly between the mass timber structure and the concrete core, secondly within the mass timber structure, and thirdly between the mass timber structure and the roof. Considerations for the connections will include: Effective transfer of vertical (gravity) loads and the panel shear loads; Function of the floor panels as diaphragms and transfer of lateral loads to the cores; Minimizing the transmission of vibrations throughout the building; Settlement and shrinkage of the wood elements due to moisture content and loading; and Constructability of the assemblies, and ease and speed of installation.

Column To Concrete Slab:

The connection of the column to column/CLT panel consists of round steel hollow structural sections (HSS) attached to steel plates connected at the bottom of each column with threaded rods which have been epoxied into the column. The smaller HSS at the bottom of the column is intended to fit into the larger HSS at the top of the slab below. The HSS stub will be set in the RC slab either with chemical anchors or bolts. The CLT panels are bolted to the steel plates with four threaded rods. The connection only transfers vertical load from the CLT panels to the columns.

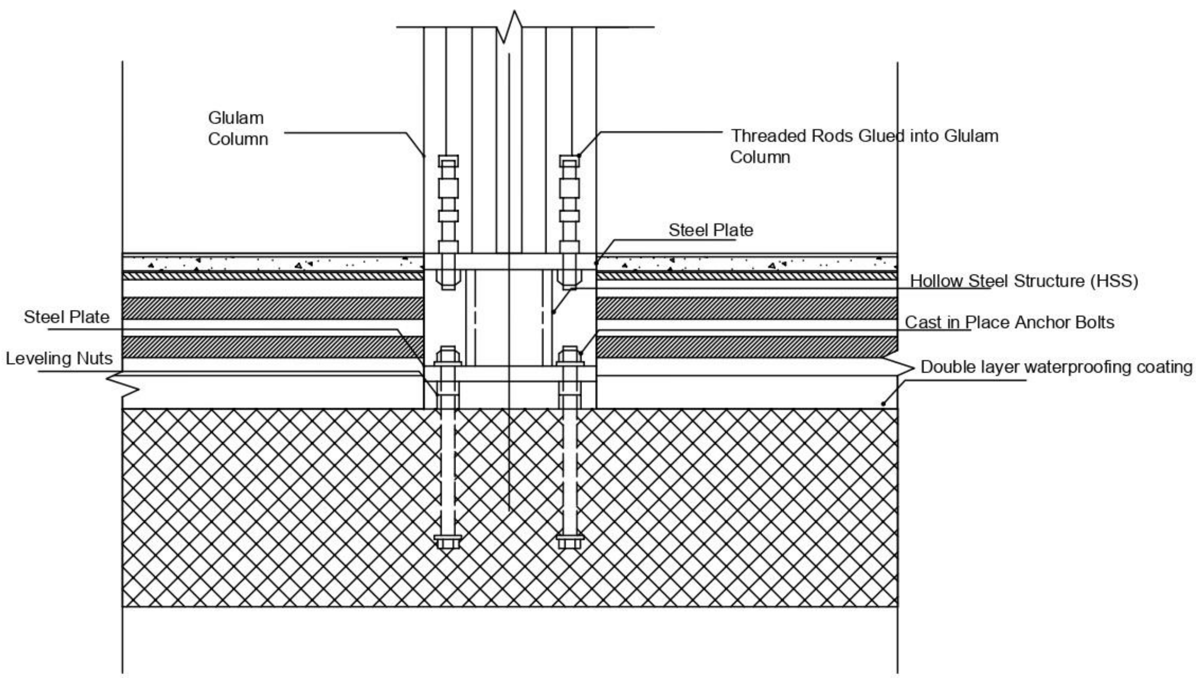

Figure 112 Column to Concrete Slab Connection (Source: Author)

Core To Slab Connection:

Drag Straps: The drag straps are of steel plates (100 mm wide) the screws were torqued into the tops of CLT panels and bolted to the steel tabs which are welded to embed plates on the cores. The drag straps transfer lateral loading from the floors to the core. Strap length, thickness and spacing vary depending on the position in the structure as different loading conditions are considered, with larger and closer spacing on the upper levels.

Figure 113 Drag Straps

steel ledgers: CLT is supported at the concrete core by a steel ledger angle that is welded to an embedded plate which was cast into the core walls. the connection will transfer both vertical and horizontal shear at the connection point.

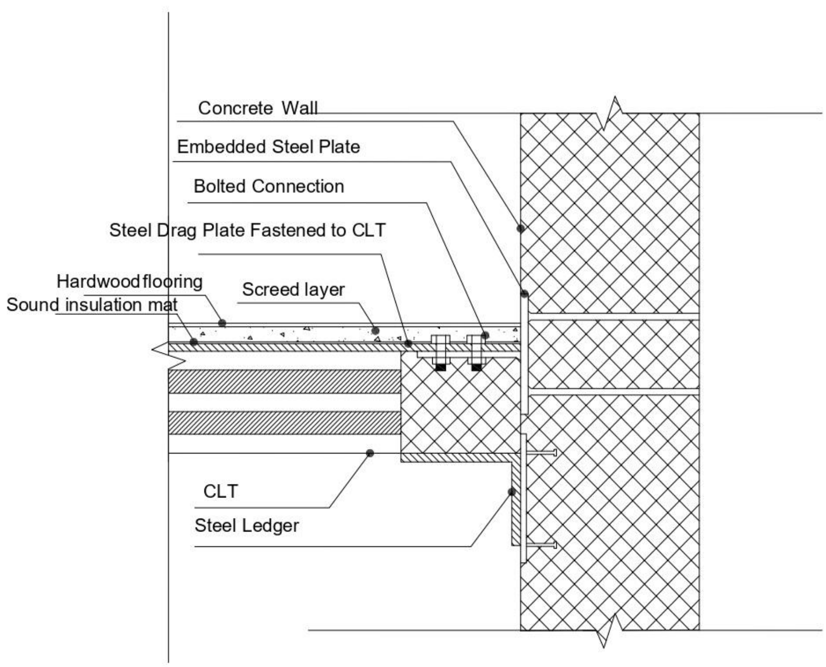

Figure 114 Core to Slab Connection (Source: Author)

Interlocking Connection System:

In conventional CLT construction, metal fasteners, angle brackets and dowels are frequently used to make connections. While these systems provide flexibility and strength, typically the installation and disassembly of these connections leads to permanent damage to the timber due to the damaging effects of crushing timber around the fasteners, as well as reduced stiffness, residual deformation, and reduction in seismic performance, particularly due to pinching effects and brittle modes of failure. This means that these connection systems are usually non-repairable and difficult to reuse.[71]

To overcome these limitations, a prefabricated interlocking connection system is proposed. This system utilizes mechanical engagement between male and female steel connectors to connect

(a) (b)

Figure 115 continuous connectors attached on the CLT panels using fasteners: (a) shear connectors, (b) tensile connectors [71]

various structural elements without adhesives or mechanical connection methods. The connection is engaged through assembly, via stacking (for shear resistance), and sliding (for tensile resistance), substantially reducing on-site assembly time or labor because they do not have to be manually aligned or fastened. Once in place, the connections are entirely encapsulated within the structure and protected from exposure to the environment.

The system consists of thin-walled steel components that are intended to yield under load, focusing on deformation in ductile metal members and leaving the timber and female connectors intact. This damage control strategy promotes ductility, allows controlled displacement, and allows large diameter screws to be used-in contrast with traditional systems where mechanical screws are small fasteners to promote ductility.

In panelize CLT assemblies, panels are assembled layers: floor panels are assembled first, followed by vertical wall panels, and lastly roof elements. The interlocking connections are located on module edges in a continuous strip-like system. Improving force transfer to panels creates better distributed loads, reduced stress concentrations, and more consistent in-plane resistance. In-plane resistance is critical in CLT systems, which are very stiff in-plane but normally less stiff in bending.[72]

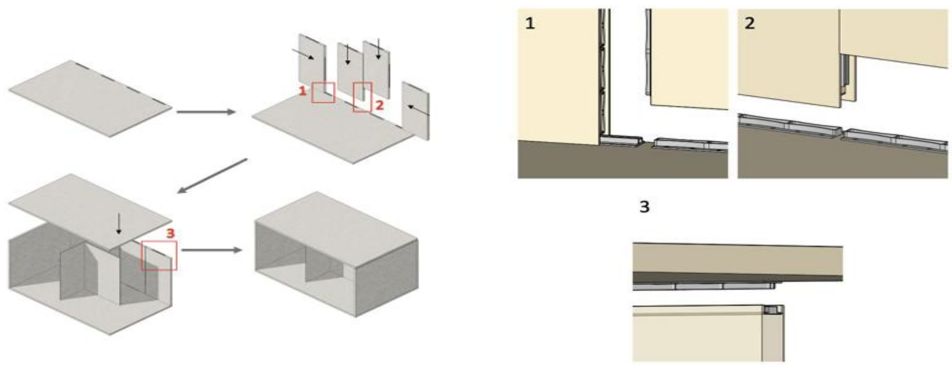

Figure 116 Application overview of the interlocking connection system for CLT panelized structures [72]

Once modules are positioned, end-locking plates allow to secure the connection and ensure that the modules will not move after assembly. A careful placement of shear and tensile connectors ensures that the structure is reinforced in the total arrangement: edge panels are locked to move up and down by sliding connections, and the middle panels are locked for lateral movement by using stacking connections. [71]

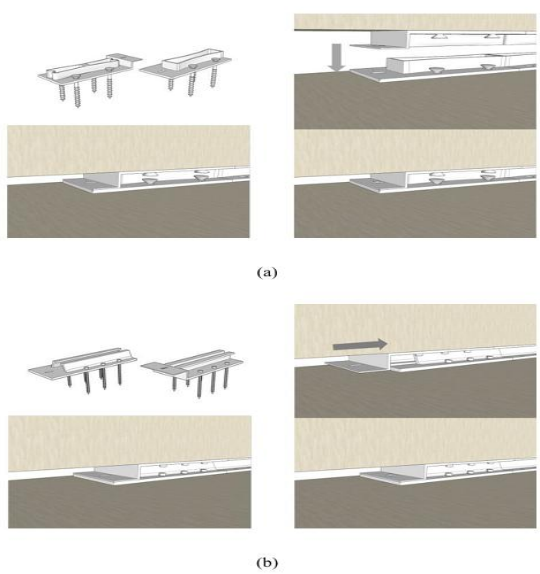

Figure 117 End-locking devices for (a) shear connection and (b) tensile connection [71]

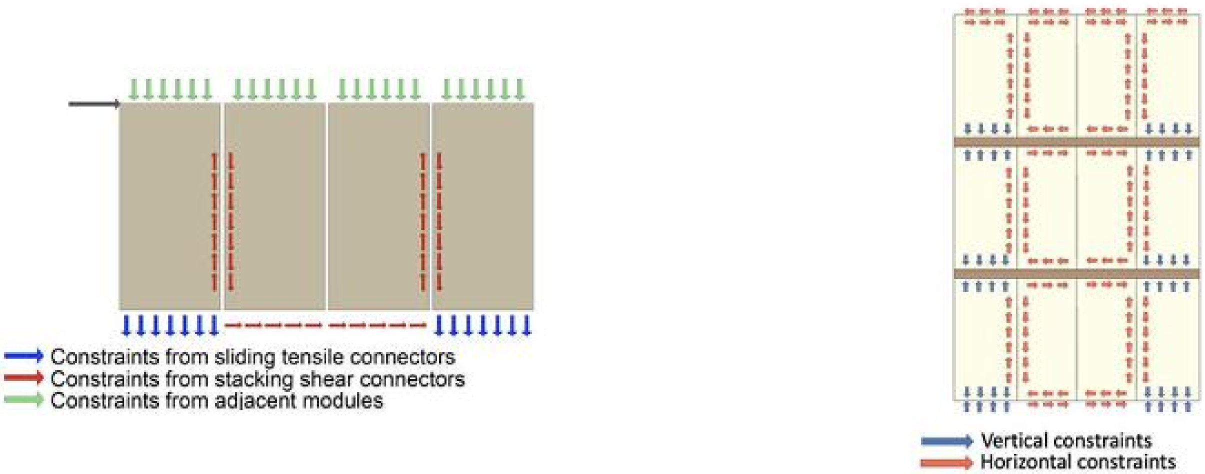

Figure 118 The illustrations of the interlocking connection working mechanism showing the overall constraints [72]

An essential aspect of this system is its alignment with circular construction principles. Whereas most connections create waste by damaging building materials during deconstruction, with interlocking joints the connection can be deconstructed, allowing the connectors and timber panels to be reused. This reduces waste, limits the demand for new raw materials, and supports a more sustainable building methodology.

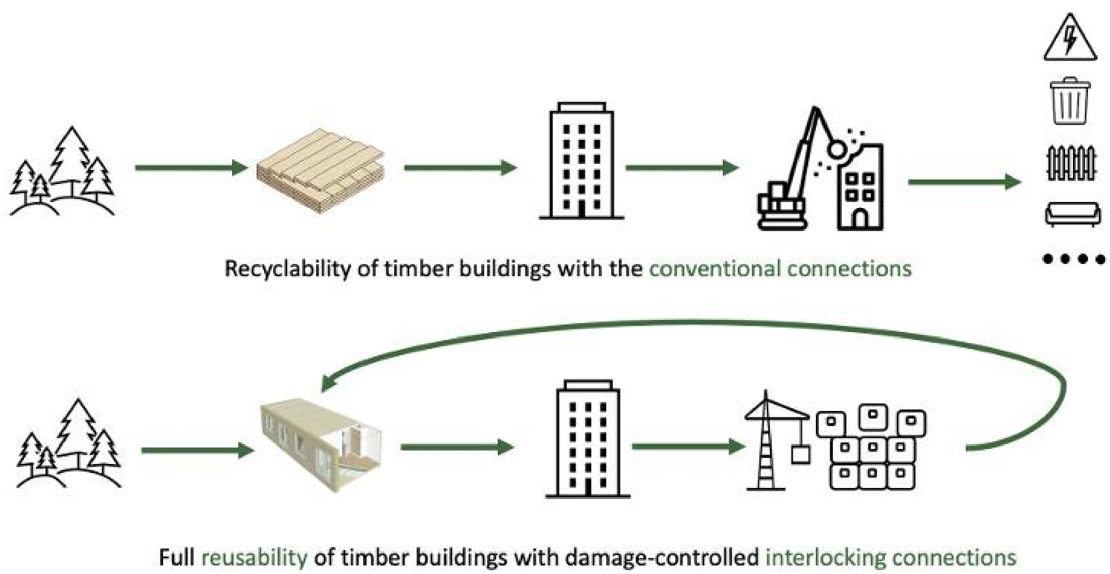

Figure 119 Comparison in potential building life cycles between CLT buildings using conventional connections (top) [72]

Preliminary investigations also indicate that the interlocking connection system may also provide better flame resistance. It needs further testing but timber will char and create a protective barrier when exposed to fire that may insulate and protect the steel components embedded in it. This characteristic is advantageous for improving the safety performance of the system.

In conclusion, the proposed interlocking system provides a quick, flexible, and sustainable option to conventional CLT connections. It is a prefabricated system which is structurally efficient and can be reused and thus is well suited to modular timber construction and timber construction that occur in rooftop spaces.[71][72]

Enhancing Moisture, Fire, and Acoustic Detailing

At the interface between the new and old structures, detailing is critical:

- Bituminous membranes or flashing can be added to prevent water ingress.
- Acoustic strips and vibration isolators may be installed to separate sound and structural transmission.
- Firestopping is included between new timber and existing concrete or masonry structures.

Enhancing Load Distribution and Structural Reinforcement:

Before connection, the existing building's load-bearing capacity is analyzed:

- If adequate reserve load-bearing capacity is insufficient, reinforcement is done by:
    - Adding steel plates or carbon-fiber reinforcement to existing beams
    - Inserting supporting steel posts through existing floors
    - Spreading loads across multiple connection points

Sometimes, a secondary steel frame or foundation shell is added outside the main footprint to carry the new vertical load.

Reversibility and Lightness: In many urban European contexts, the goal is to keep the intervention reversible:

- Avoid cutting into the existing structure whenever possible
- Use mechanical (not chemical) fixings

Rainwater Management System: An internal drainage system will be built into the reinforced concrete core, manages rainwater. The site has a slightly sloped flat roof that sends water towards internal drains leading to vertical down pipes. This system eliminates the need for exposed down pipes or roof drainage features to maintain the visual appeal of the façades and to perform their role of protecting the building components from weathering. There are also metal or membrane flashing elements at all exposed joints including the junctions between CLT, glulam, and concrete, to protect all timber components from moisture so that this hybrid structure can survive and perform historically.

Seismic Considerations:

The proposed rooftop extension employs a combination of light timber and reinforced concrete (RC) structural components to introduce a level of seismic resilience. The RC core is the main lateral force-resisting element, providing overall lateral stiffness and stability to the rooftop extension. Using prefabricated CLT panels and glulam columns reduces the seismic mass, and subsequently inertial forces when the building experiences earthquake loading.

A key design element embedded in this structural system was the interlocking steel material connectors, which were purposefully designed for deformation control. The steel connectors can yield in steel while still preserving the timber integrity, both of which encourage energy dissipation through hysteretic, and allow for easy repair of the building after seismic events. This design also provided large diameter screws into timber to improve load distribution patterns and reliability of connection.

When designing the rooftop extension, importantly, all introduced seismic forces will be collected by both CLT floor diaphragms and transferred to the RC core (using the drag straps made of steel anchored to plates embedded in the RC core). The RC core and interlocking panel-to-panel connections help maintain diaphragm continuity, produce an effective force transfer and mitigate inter-panel slippage. Collectivity, all of the designed means create a convenient, efficient and reliable load path for resistance to seismic loads, all the while improving the ductility and recoverability or post-earthquake behaviors of the configuration.

Challenges and Opportunities: Although the proposed expansion to the rooftop offers great architectural opportunities and benefits to the environment, there are a number of identified limitations in its practicality. One of the key limitations is the impracticality of an external stair for independent access. Given the layout of the building and its adjacency on either side, and particularly at the rear, there is no possible location to accommodate an external stair, and again there are no other access points that can connect the rooftop independent of existing private units. This makes shared internal circulation the only feasible option, requiring coordination with the existing owners and compliance with fire safety and accessibility codes

A different challenge also pertains to logistics during construction with constraints such as limited amount of site space and an operational crane from the street with minimal neighbors and traffic disruption.

Despite all the restrictions, the project offers important opportunities. The flat roof shape and prefabricated timber system lend themselves well to lightweight prefabricated construction. Increasing the building value with two spacious and high-standard apartments with private outdoor space also demonstrates how urban densification can be achieved without compromising design and livable space. Finally, the project provides a repeatable model for eco-friendly rooftop.

Strategy	*Description*	*Function*	*Notes*
Reinforced Concrete Core Extension	Cast-in-place concrete for elevator and stair cores	Main lateral and vertical load-bearing elements	Provides fire safety and seismic stability.
Glulam Beam and Column Frame	Glued laminated timber used for beams and columns	Light-weight primary structural frame	Light weight prevents substantial load on existing structure and allows for larger open spans
Prefabricated CLT Panels	CLT used for floor, walls, and roof	Diaphragm action and enclosure system	Faster build time and greater accuracy with prefabrication
Hollow Structural Steel Column to Concrete	Hollow steel sections are within the slab with threaded rods to transfer vertical load to the concrete Ensure secure base connection of the glulam columns	Ensures secure base connection for glulam columns	Epoxied and bolted for stability
Interlocking Steel Connectors	Novel damage-controlled connections are designed for panel connections	Provides ductility and dissipates seismic energy	Increases ability to recycle and enable controlled yielding
Steel Ledger Angle Support	Bolted to embedded plates in concrete core	Transfer horizontal and vertical shear connect floor slabs to core	Connection of floor slabs to core
Drag Strap System	Anchored steel straps located between the CLT and concrete core	Transfer lateral loads to Marcel RC core	Optimized to allow a height-dependent strap spacing
Light-weight Construction	Utilizes timber in entirety	Lower seismic mass and allows for prefabrication	Allows for urban rooftop retrofitting

Table 10 Summary of Structural Strategies

5.5. Future Possibilities

Rooftop extensions can serve as a functional and transformational answer to the issue of continual asset management and underutilization of old buildings. Incrementally, cities can create policies that both enable air rights and provide renovation or redevelopment incentives, creating economic value of vertically enhancing the building. Policies that facilitate rooftop extensions, revitalization with minimal environmental impacts, result in housing stock and considerable improvement to the resilience and sustainability of the urban ecosystem, which will present massive benefits in response to future environmental uncertainty.

Future rooftop extensions can include environmental performance that includes renewable energy technologies such as solar facades and green roofs. When financial and social benefits for rooftop extensions are measured against environmental benefits that promote sustainability, rooftop extensions can become a critical, and replicable, model for regenerative urban growth that preserves architectural artifacts whilst minimizing land consumption. Existing local government incentives will become important, because rooftop extensions, through policies already mentioned, can promote conventional vertical densification that ultimately can benefit urban retrofitting on a much broader scale, and that Kofler precedent demonstrates support for long-term urban sustainability.

6. CONCLUSION

All over the world, most of the urban centers are growing at incredible levels, and the cities are in dire need of innovative solutions for further housing these populations without denying more precious land resources. One such way is to utilize the underused rooftop spaces effectively and convert them into usable areas for urban densification as well as re-sustainability.

There has been the existence of a practice of constructing buildings on top of already existing structures for centuries. However, modern-day rooftop extensions can be excellent additions if carefully evaluated. Important considerations are ensuring the structural stability of the existing building in addition to abiding by zoning codes, using lightweight, prefabricated materials for ease of construction, and catheterizing typical areas nearby. The case studies show that rooftop development can successfully be blended with pre-existing architecture without loss of neighborhood character and added accommodation and recreational spaces if appropriately executed.

Rooftops serve more than just creating spaces; they also generate spaces such as green roofs, which offer many environmental benefits, including improving air quality, conserving energy, and even mitigating urban heat island effects. Incorporating vegetation features into rooftop designs can also open cities to improved biodiversity, stormwater management, and pleasant microclimates for residents. Most importantly, green open spaces can be multipurpose and serve as communal areas for social contact among the populace while generally improving life in the city.

Rooftop extensions are not free from difficulties, though. Capitalizing rooftops that are resource-worthy would need an exploration of structural capacities, possible legal hindrances, and costs involved. The relationship between the new constructions and the existing structures should also be considered by the designer, in terms of social within the two contexts. Cities can produce homes, better land use, and richer urban environments by metamorphosing and repurpose such spaces.

Rooftops converted into extra functions will help create new spaces, especially for modern cities, where building extensions are a response to the growing population while conserving open space. Such an approach not only supports the need for housing but also improves the longevity and energy efficiency of existing structures. Rooftop extensions, when designed carefully, contribute to resilient cities, smart land use, and ecological urbanism.

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BIBLIOGRAPHY

[1] Bhatta, B. (2010). *Analysis of urban growth and sprawl from remote sensing data*. Springer Science & Business Media.

[2] Artés Pérez, J., Wadel Raina, G., & Martí Audí, N. (2016). Vertical extension and improving of existing buildings. *The Open Construction and Building Technology Journal, 2017, 11,(Suppl-1, M4)*.

[3] Trancik, R. (1991). *Finding lost space: theories of urban design*. John Wiley & Sons.

[4] Saporito, E. (2017). OrtiAlti as urban regeneration devices: An action-research study on rooftop farming in Turin. *Future of Food: Journal on Food, Agriculture and Society*, *5*(1), 59-69.

[5] Pomeroy, J. (2012). Room at the top—the roof as an alternative habitable/social space in the Singapore context. *Journal of Urban Design*, *17*(3), 413-424.

[6] Bellini, O., & Mocchi, M. (2019). Rooftop architecture and urban roofscape: designing the new vertical city. *TECHNE-Journal of Technology for Architecture and Environment*, 264-277.

[7] Melet, E., & Vreedenburgh, E. (2005). Rooftop architecture: building on an elevated surface. *NAi Publishers.*

[8] Amer, M., & Attia, S. (2017). Roof stacking: Learned lessons from architects.

[9] MVRDV, "Rooftop Catalogue," (2021). *Rotterdamse Dakendagen.*

Website: https://mvrdv.com/publications/4081/rooftop-catalogue

[10] Yang, J. (2024). Construction of urban livability evaluation index system by principal component analysis combined with entropy value method. *Applied Mathematics and Nonlinear Sciences*, *9*(1).

[11] Eisenschmidt, A. (2012), *City catalyst: Designing architecture for the global metropolis*.

[12] Eken, C., & Alpar Atun, R. (2019). The self-organizing city and the architecture of metabolism: an architectural critique on urban growth and reorganization. *Sustainability*, *11*(19), 5326.

[13] Martin, L. (1972). The grid as generator, Leslie, M and March, L.(Eds), Urban Space and Structures. *Cambridge university press.*

[14] Kaal, H. (2011). A conceptual history of livability: Dutch scientists, politicians, policy makers and citizens and the quest for a livable city. *City*, *15*(5), 532-547.

[15] Marique, A. F., & Reiter, S. (2014). Retrofitting the suburbs: Insulation, density, urban form and location. *Environmental Management and Sustainable Development*, *3*(2).

[16] Abdrabo, K. I., Hamed, H., Fouad, K. A., Shehata, M., Kantoush, S. A., Sumi, T., ... & Osman, T. (2021). A methodological approach towards sustainable urban densification for urban sprawl control at the microscale: Case study of Tanta, Egypt. *Sustainability*, *13*(10), 5360.

[17] Conticelli, E., Salvo, C., Tondelli, S., & Francini, M. (2024). A Multi-Scale Method to Drive Sustainable Urban Densification Processes: A Case Study in Italy. In *2024 IEEE International Workshop on Metrology for Living Environment (MetroLivEnv)* (pp. 213-217). IEEE.

[18] Tam, V. W., & Hao, J. J. (2019). Adaptive reuse in sustainable development. *International Journal of Construction Management*, *19*(6), 509-521.

[19] Vardopoulos, I. (2023). Adaptive reuse for sustainable development and land use: A multivariate linear regression analysis estimating key determinants of public perceptions. *Heritage*, *6*(2), 809-828.

[20] Attia, S. (2015). Overview and recommendation on urban densification potential in Liège, Belgium. In *International conference on high-quality retrofit and redensification with timber construction systems*.

[21] Moudon, A. V. (1991). Finding Buildings to Fit Main Street [Housing on Toronto's Main Streets]. *Places*, *7*(2).

[22] Khalid, N. S., Hilal, S., & Marzukhi, M. A. (2018). Lost space in urban core areas of Kuala Lumpur in relations to physical urban environment. *Planning Malaysia*, *16*.

[23] Akkuzu, Í. (2019). Revitalizing lost space in kadikoy, istanbul. *Urbanizm: Journal of Urban Planning & Sustainable Development*, (24).

[24] Eldek, M. H. A., Khedr, A. M. S., & Abdelaziz, D. M. A. (2022). Rehabilitation of the Lost Urban Spaces below the Elevated Movement Axes within the City.

[25] Ford, L. (2000). *The spaces between buildings*. JHU Press.

[26] Pelczynski, J., & Tomkowicz, B. (2019). Densification of cities as a method of sustainable development. In *IOP Conference Series: Earth and Environmental Science* (Vol. 362, No. 1, p. 012106). IOP Publishing.

[27] R. Ooshuizen, N. Palit, C. Dove, R. Bergin, D. Mason, and V. Bagnall. (2016). *London's Rooftops: Potential to Deliver Housing for Apex Airspace Development*.

Website: www.hta.co.uk

[28] Aravena, A. (2010). Elemental-Interview. *Perspecta*, *42*, 85-89.

[29] Salat, S. (2017). A systemic approach of urban resilience: power laws and urban growth patterns. *International Journal of Urban Sustainable Development*, *9*(2), 107-135.

[30] Boyko, C. T., Cooper, R., & Dunn, N. (Eds.). (2020). *Designing future cities for wellbeing*. Routledge.

[31] Anderson, C. (2006). *The Long Tail: Why the Future of Business Is Selling Less of More*.

[32] Habraken, N. J. (2021). *Supports: an alternative to mass housing*. Routledge.

[33] Johnson, P., & Wigley, M. (1988). Deconstructivist architecture. New York: The Museum of Modern Art.

[34] Karacalı, A. O., & Polat, T. E. (2022). Considering sidewalls as an architectural ground: Parasitic architecture approaches in design studio. *Journal of Design Studio*, *4*(1), 81-92.

[35] Zamperini, E., & Lucenti, S. (2014). Symbiotic architecture: rooftop additions on existing buildings. In *REHAB 2014. Proceedings of the International Conference on Preservation, Maintenance and Rehabilitation of Historical Buildings and Structures* (Vol. 2, pp. 1203-1212). Green Lines Institute for Sustainable Development.

[36] Robson, S. (2014). *Rooftop Pavilion for Aldwych House*,

Website: https://www.archdaily.com/565371/sheppard-robson-designs-rooftop-pavilion-for-aldwych-house

[37] Lin, Q. (2024). Ecological benefits of roof gardens and the difference of roof gardens in different regions. *Applied and Computational Engineering*, *85*, 24-32.

[38] Julistiono, E. K., Oldfield, P., & Cardellicchio, L. (2024). Up on the roof: a review of design, construction, and technology trends in vertical extensions. *Architectural Science Review*, *67*(1), 63-77.

[39] Tomajian, H., Ojo, D., Gyergyák, J., Borsos, Á., & Medvegy, G. (2024). Achieving adaptability through various urban housing typologies. *Pollack Periodica*.

[40] Ballarini, I., Corrado, V., Madonna, F., Paduos, S., & Ravasio, F. (2017). Energy refurbishment of the Italian residential building stock: energy and cost analysis through the application of the building typology. *Energy Policy*, *105*, 148-160.

[41] Corrado, V., Ballarini, I., & Corgnati, S. P. (2012). National scientific report on the TABULA activities in Italy. *Dipartimento di Energetica, Gruppo di Ricerca TEBE, Politecnico di Torino, Torino, Italy*.

[42] Vitomir, J., & Nastić, V. (2024). Modular structures: Sustainable ecological structures made of recycled aluminium. *Zbornik radova sa Nacionalne konferencije sa međunarodnim učešćem–Zelena Gradnja 2024*, (Green building), 163-168.

[43] Iuorio, O., Napolano, L., Fiorino, L., & Landolfo, R. (2018, November). Sustainability of modular lightweight steel building from design to deconstruction. In *International Specialty Conference on Cold-Formed Steel Structures* (pp. 515-528). Missouri University of Science and Technology.

[44] Tenório, M., Ferreira, R., Belafonte, V., Sousa, F., Meireis, C., Fontes, M., ... & Branco, J. M. (2024). Contemporary strategies for the structural design of multi-story modular timber buildings: A comprehensive review. *Applied Sciences*, *14*(8), 3194.

[45] Wong, L. (2024). *Adaptive reuse: extending the lives of buildings*. Birkhäuser.

[46] Atef, A., Zayed, T., Hawari, A., Khader, M., & Moselhi, O. (2016). Multi-tier method using infrared photography and GPR to detect and locate water leaks. *Automation in Construction*, *61*, 162-170.

[47] Saarenketo, T., Matintupa, A., & Varin, P. (2012, August). The use of ground penetrating radar, thermal camera and laser scanner technology in asphalt crack detection and diagnostics. In *7th RILEM International Conference on Cracking in Pavements: Mechanisms, Modeling, Testing, Detection and Prevention Case Histories* (pp. 137-145). Dordrecht: Springer Netherlands.

[48] Todinov, M. (2024). Lightweight Designs and Improving the Load-Bearing Capacity of Structures by the Method of Aggregation. *Mathematics*, *12*(10), 1522.

[49] Cheng, M. L., Guo, S. H., & Huo, Z. P. (2024). Numerical simulation study on mechanical bearing behavior of arch steel–concrete composite sandwich roof. *Buildings*, *14*(1), 218.

[50] Clark, J. I. (1998). The settlement and bearing capacity of very large foundations on strong soils: 1996 RM Hardy keynote address. *Canadian Geotechnical Journal*, *35*(1), 131-145.

[51] Guadagnuolo, M., & Faella, G. (2020). Simplified design of masonry ring-beams reinforced by flax fibers for existing buildings retrofitting. *Buildings*, *10*(1), 12.

[52] Dowling, D., Samali, B., & Li, J. (2005). An improved means of reinforcing adobe walls-external vertical reinforcement. *University of Technology. Sydney, Australia*.

[53] van Schagen, L. P. L. City Roofs 2.0–Making use of existing roofs to extend the urban green and user functions in the city. *Faculty of Architecture, Delft University of Technology, Delft, The Netherlands.*

[54] Dind, A., Lufkin, S., & Rey, E. (2018). A modular timber construction system for the sustainable vertical extension of office buildings. *Designs*, *2*(3), 30.

[55] Wang, W., Zhou, X., Wu, S., Zhao, M., Jin, Z., Bei, K., ... & Fan, C. (2024). Vertical Green Wall Systems for Rainwater and Sewage Treatment. *Sustainability*, *16*(17), 7593.

[56] Jassim, W., Madhat, M., & Ali, A. (2024). The Uses of Lightweight Material in Civil Engineering: A Review. *Al-Rafidain Journal of Engineering Sciences*, 300-318.

[57] Tighnavard Balasbaneh, A., & Ramadan, B. S. (2024). Integrating three pillars of sustainability for evaluating the modular construction building. *Construction Innovation*.

[58] Gijzen, R. (2017). Modular cross-laminated timber buildings. *Delft University of Technology*, *11*.

[59] Moran, C. (2015). *Raise the Roof*.

Website: https://www.barcelona-metropolitan.com/features/barcelona-raise-the-roof/

[60] Friedman, A. (2002). *The adaptable house*. McGraw-Hill, Inc.

[61] Rissetto, R., Pont, U., & Mahdavi, A. (2018). Performance comparison of timber-based assemblies and other construction solutions for rooftop extensions. *International Review of Applied Sciences and Engineering*, *9*(2), 153-161.

[62] Amer, M., Mustafa, A., & Attia, S. (2019). Conceptual framework for off-site roof stacking construction. *Journal of Building Engineering*, *26*, 100873.

[63] Papageorgiou, M. (2016). Optimal Vertical Extension: A study on costs and environmental impact for structural engineers. *TU Delft*.

[64] Rausch, C., Nahangi, M., Perreault, M., Haas, C. T., & West, J. (2017). Optimum assembly planning for modular construction components. *Journal of computing in civil engineering*, *31*(1), 04016039.

[65] Amer, M. (2019). *DenCity: A methodology for cost-optimal zero-energy lightweight construction* (Doctoral dissertation, Universite de Liege (Belgium)).

[66] Wadel, G. (2014). *Improvement and completion of buildings with vacant buildability*, la casa por el tejado, The weaver's House.

[67] Di Giulio, R. (2010). Sustainable roof-top extension: a pilot project in Florence (Italy). In *Sustainable Building Affordable to All* (pp. 255-263). iiSBE Portugal, University of Minho, Istituto Superior Tecnico.

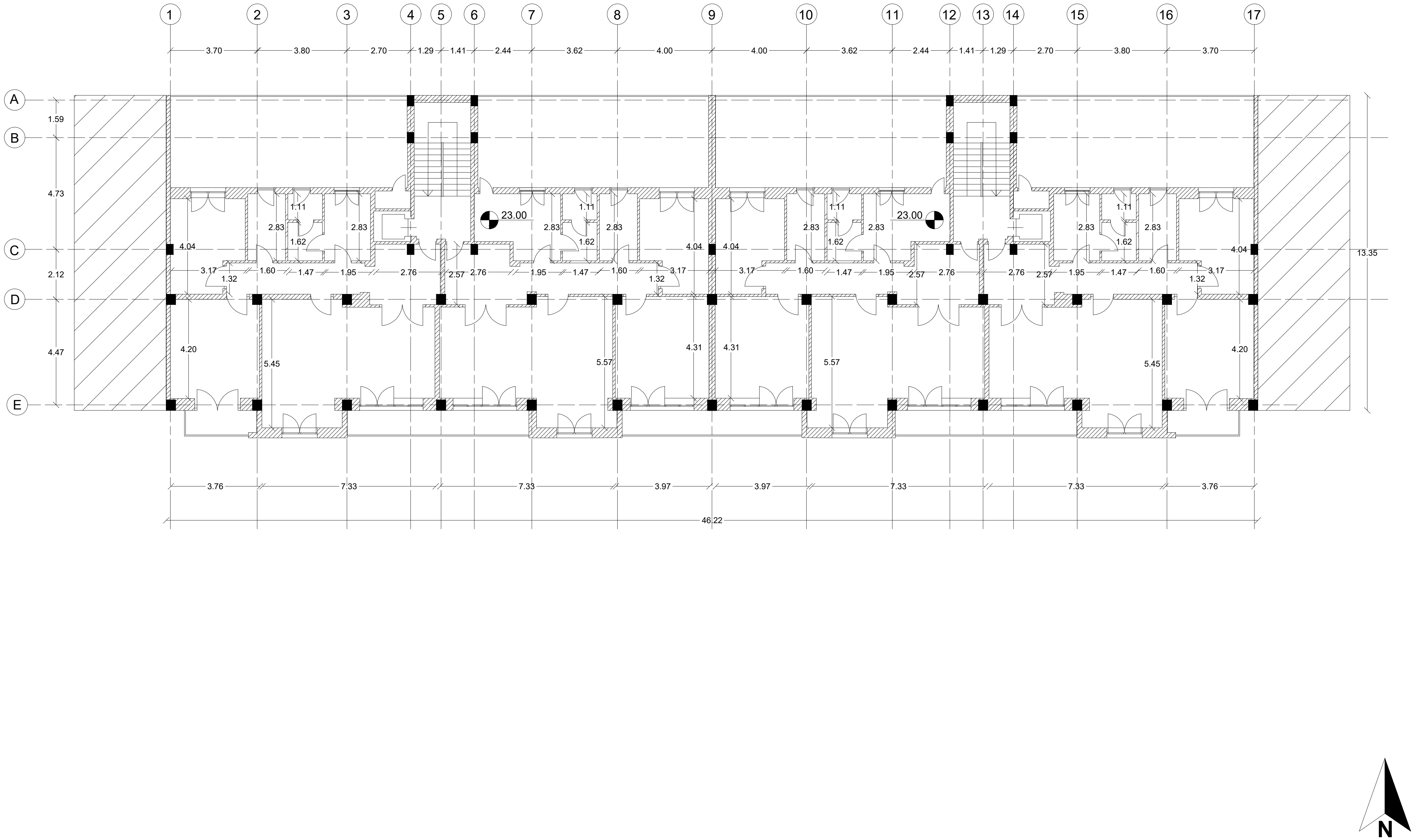
[68] Gudkova, T. V., & Gudkov, A. A. (2017, November). Spatial modernist architectural artistic concepts. In *IOP Conference Series: Materials Science and Engineering* (Vol. 262, No. 1, p. 012152). IOP Publishing.

[69] Carnieletto, L., Ferrando, M., Teso, L., Sun, K., Zhang, W., Causone, F., ... & Hong, T. (2021). Italian prototype building models for urban scale building performance simulation. *Building and Environment*, *192*, 107590.

[70] Ellena, M., Melis, G., Zengarini, N., Di Gangi, E., Ricciardi, G., Mercogliano, P., & Costa, G. (2023). Micro-scale UHI risk assessment on the heat-health nexus within cities by looking at socio-economic factors and built environment characteristics: The Turin case study (Italy). *Urban Climate*, *49*, 101514.

[71] Li, Z. (2024). *Innovative Interlocking Connection System For Mediumrise Timber Modular Structures* (Doctoral dissertation, University of Leeds).

[72] Li, Z., Tsavdaridis, K., & Katenbayeva, A. (2024). Reusable timber modular buildings, material circularity and automation: The role of inter-locking connections. *Journal of Building Engineering*.



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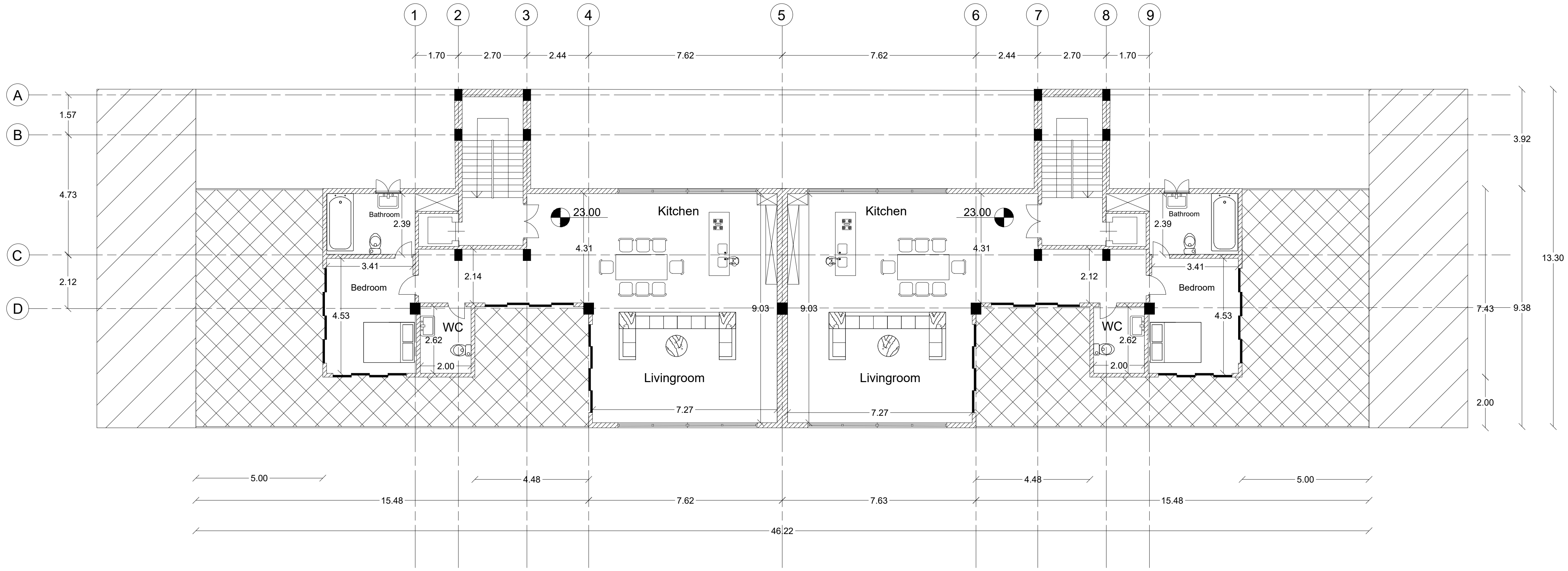
Supervisor :

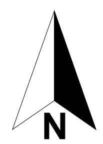
Marika Mangosio

Lungo Po Niccolò Machiavelli 25

State of The Art
Sixth Floor

Scale : 1:200





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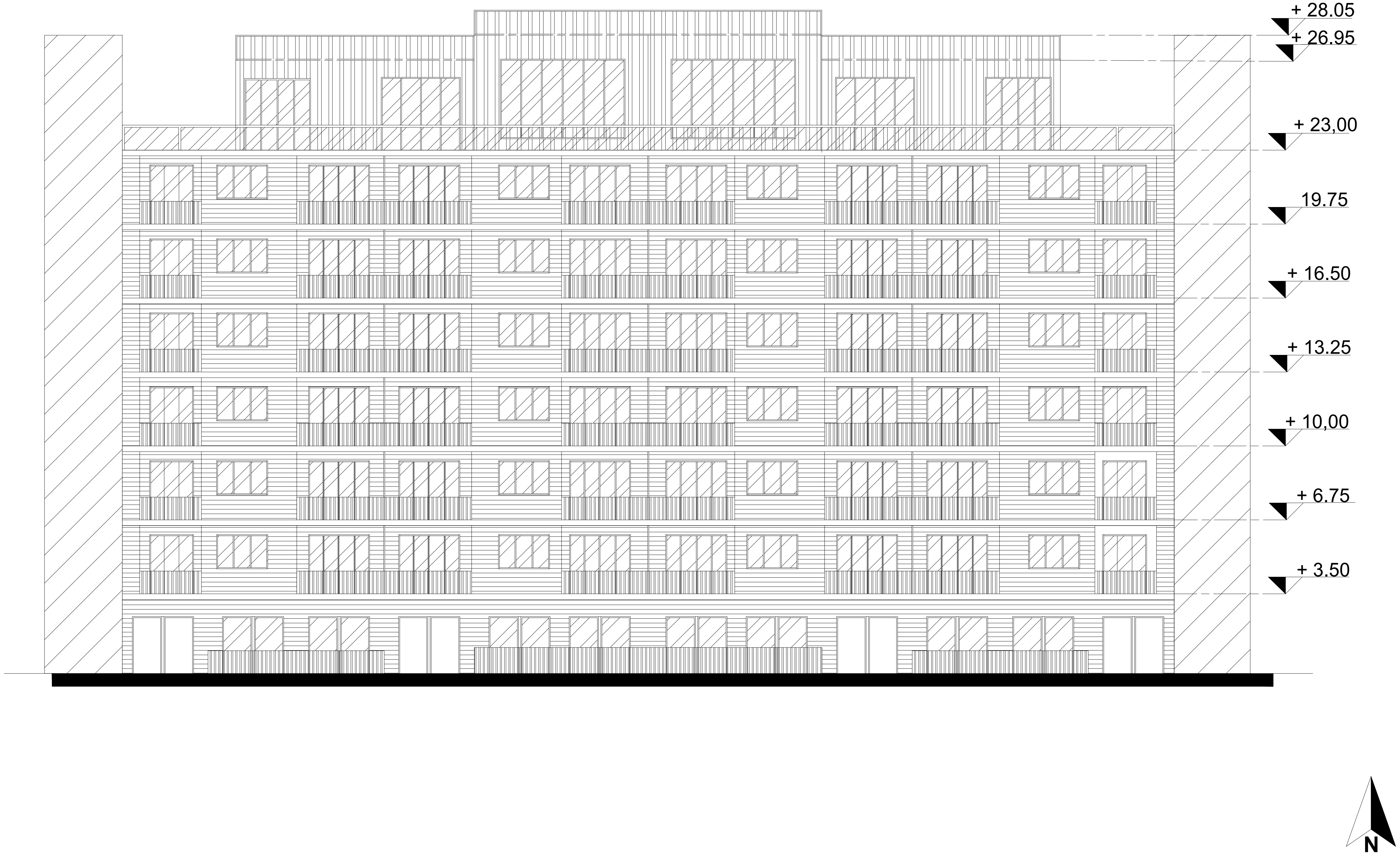
Project Proposal

Scale : 1:200



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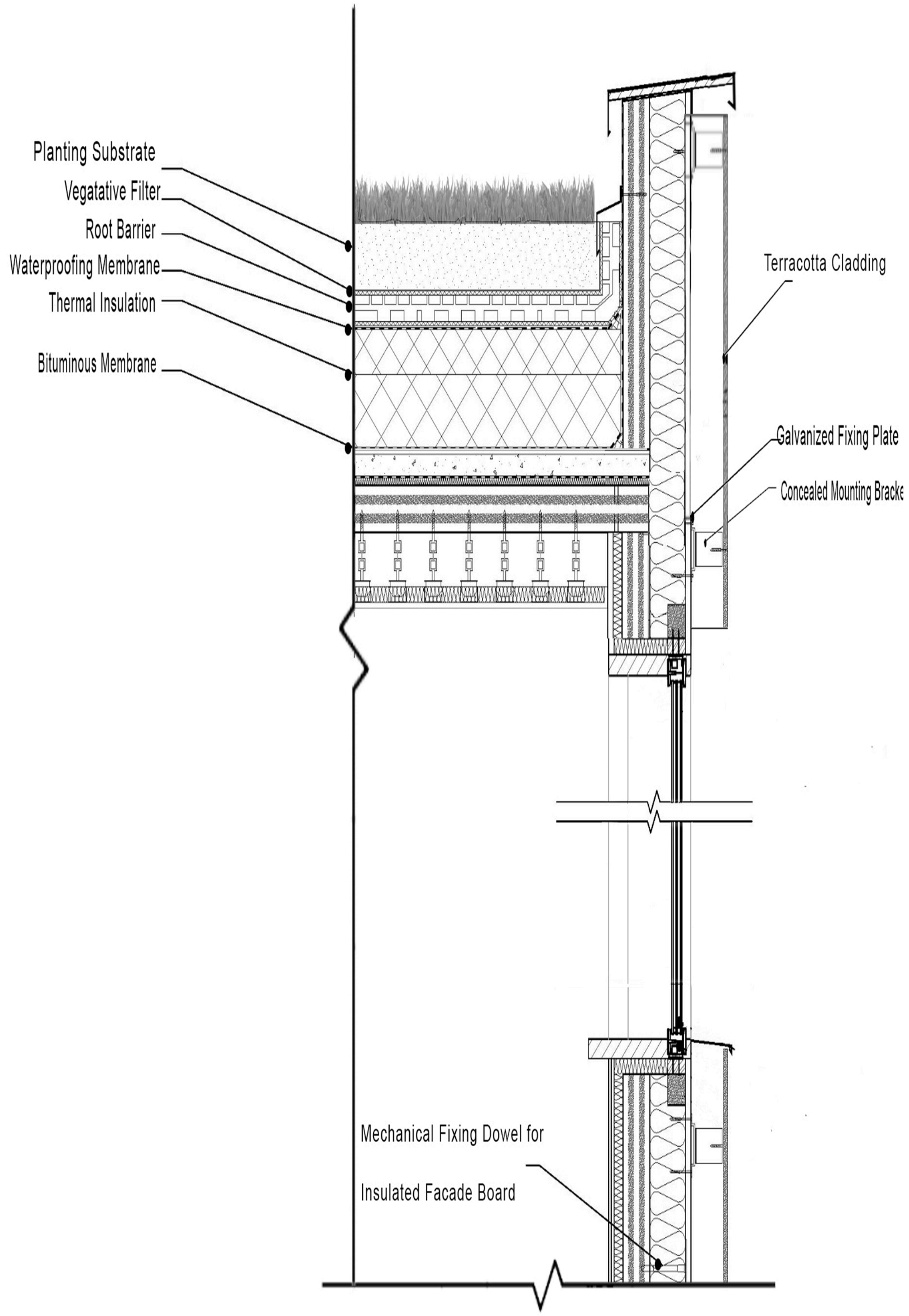
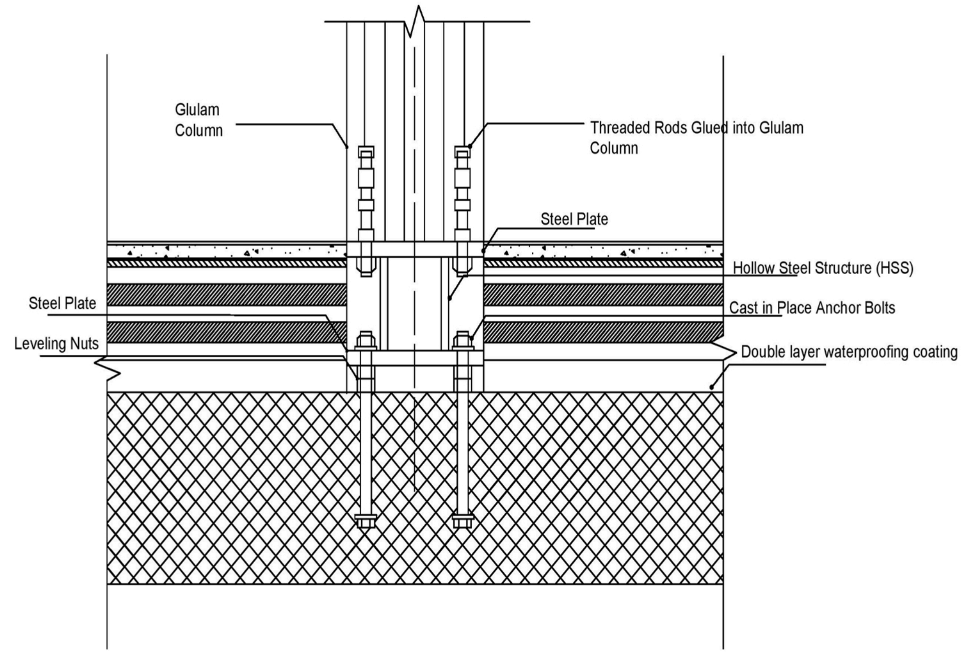
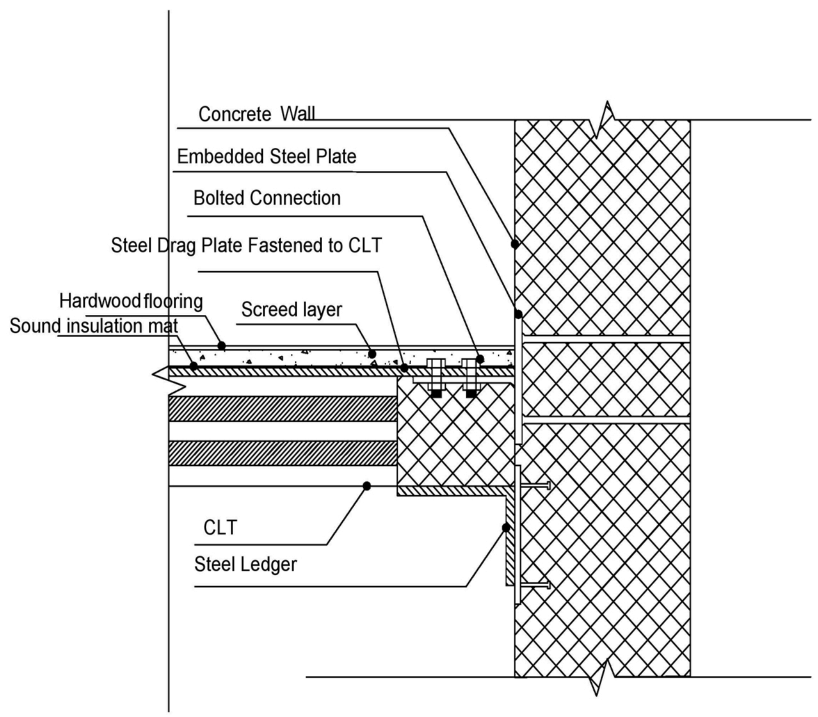
SouthElevation

Scale : 1:200







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Wall Section , Connectio Details

Scale : 1:10 , 1:5