STARTING FROM THE ROOF

ROOFTOP EXPANSIONS IN LOW AND MID-RISE HOUSING BUILDINGS

A report submitted to the faculty of graduate studies and research in partial fulfillment of the requirement of the degree of Master of Architecture.

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ABSTRACT

Space in cities has become similar to natural resources; it is scarce and limited. Today, more than half of the world's population lives in cities. Meanwhile, the UN projects that 7 out of every 10 people will live in urban settlements by 2050. To address this, people are developing cities either horizontally by expanding it into the periphery, or vertically, by sacrificing buildings. However, both alternatives have produced severe problems. Fortunately, there are areas in cities that could take part in the solution. These "lost spaces" range from abandoned lots and empty warehouses to a group of rooftops. Rooftops are considered lost space when they have built capacity available above them, a universal phenomenon in today's cities.

The author argues that we need to finish building the city that we already have by filling up the empty pockets of rooftop lost space. The supporting argument is that the environmental, urban, and economic benefits of repurposing these spaces outperform standard methods. The problem lies in identifying the tactics and design aspects to expand mid-rise and low-rise housing buildings vertically. Thus, the objective of this report is to assess and expose the techniques needed, based on literature reviews, documentation, and the analysis of case studies through drawings, photography, and observation. The former done using fieldwork in Barcelona with the outcome displayed at the end of this research, in the hopes of illustrating design and construction principles that enhance the adoption of rooftop lost space and provide housing in areas where land is scarce.

The main findings of this investigation reveal that the tactics needed are relatively simple, but the challenge comes when understanding and synchronizing all the necessary factors involved in the process. The report outlines that, to build rooftop expansions successfully, designers need to promote holistic building updates, exchange loads instead of implementing structural reinforcements, and use simultaneous construction operations. This paper aims to empower architects to use rooftop lost space as a means to create housing in the emerging the urbanization trend.

RESUMÉ

L'espace dans les villes est devenu semblable aux ressources naturelles; C'est insuffisant et limité. Aujourd'hui, plus de la moitié de la population mondiale vit dans les villes. Pendant ce temps, l'ONU prévoit que 7 personnes sur 10 vivront dans des agglomérations urbaines d'ici 2050. Pour résoudre ce problème, les gens développent les villes horizontalement, en les élargissant à la périphérie ou verticalement, en sacrifiant des bâtiments. Les deux alternatives ont de sérieux problèmes. Heureusement, il y a des espaces dans les villes qui pourraient faire partie de la solution. Ces «espaces perdus» vont des terrains abandonnés et des entrepôts vides à l'inventaire des toits. Les toits sont considérés comme des «espaces perdus» quand ils ont une capacité constructive disponible sur eux, un phénomène universel dans les villes d'aujourd'hui.

L'auteur fait valoir que nous devons terminer la construction de la ville que nous avons en remplissant «l'espace perdu» existant sur les toits. L'argument de soutien c'est que les avantages environnementaux, urbains et économiques de la réutilisation de ces espaces surpassent les méthodes traditionnelles. Le problème réside dans l'identification des tactiques et des aspects de conception pour étendre verticalement les bâtiments d'habitation de faible et moyenne hauteur. Par conséquent, l'objectif de ce rapport c'est d'évaluer et d'exposer les techniques nécessaires, basées sur des revues de la littérature, la documentation et l'analyse d'études de cas à travers des dessins architecturaux, de la photographie et de l'observation. La documentation est structurée par un travail de terrain à Barcelone et le résultat final est ce document. Le projet vise à illustrer les principes de conception et de construction nécessaires pour améliorer l'adoption des toits en tant qu'espace de développement et pour fournir des logements dans les zones où les terres sont insufficents.

Les principaux résultats de cette recherche révèlent que les tactiques utilisées sont relativement simples, mais le défi naît lorsque tous les facteurs nécessaires impliqués dans le processus sont synchronisés. Enfin, le rapport décrit que pour construire des expansions verticales, les concepteurs doivent promouvoir des mises à jour complètes des bâtiments, échanger des charges au lieu de renforcements structurels et utiliser des opérations de construction simultanées. Ce document vise à permettre aux concepteurs d'utiliser l'espace perdu des ponts comme un moyen de créer des logements à l'ère de l'urbanisation.

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CHAPTER 1 - INTRODUCTION

The intensity at which the world has evolved over the past fifty years is unprecedented. It marks the urban landscape as a central terrain for human development. Urbanization rates are higher than overall human growth which is creating a series of effects briefly described in Figure 1.1 (United Nations, 2010). Urbanization also varies among regions. For instance, although Latin America and the Caribbean have a smaller population when compared to other regions, they are surprisingly the most urbanized among them. In fact, with a 79 percent, they have already surpassed the world rate population projected for 2050 and exceeded the 73 percent of Europe. Furthermore, following the UN Study, Latin America's urban population will grow at a rate of 0.34 percent annually, North America at one of 0.28 percent, and Europe at 0.36 percent (all in the same period).

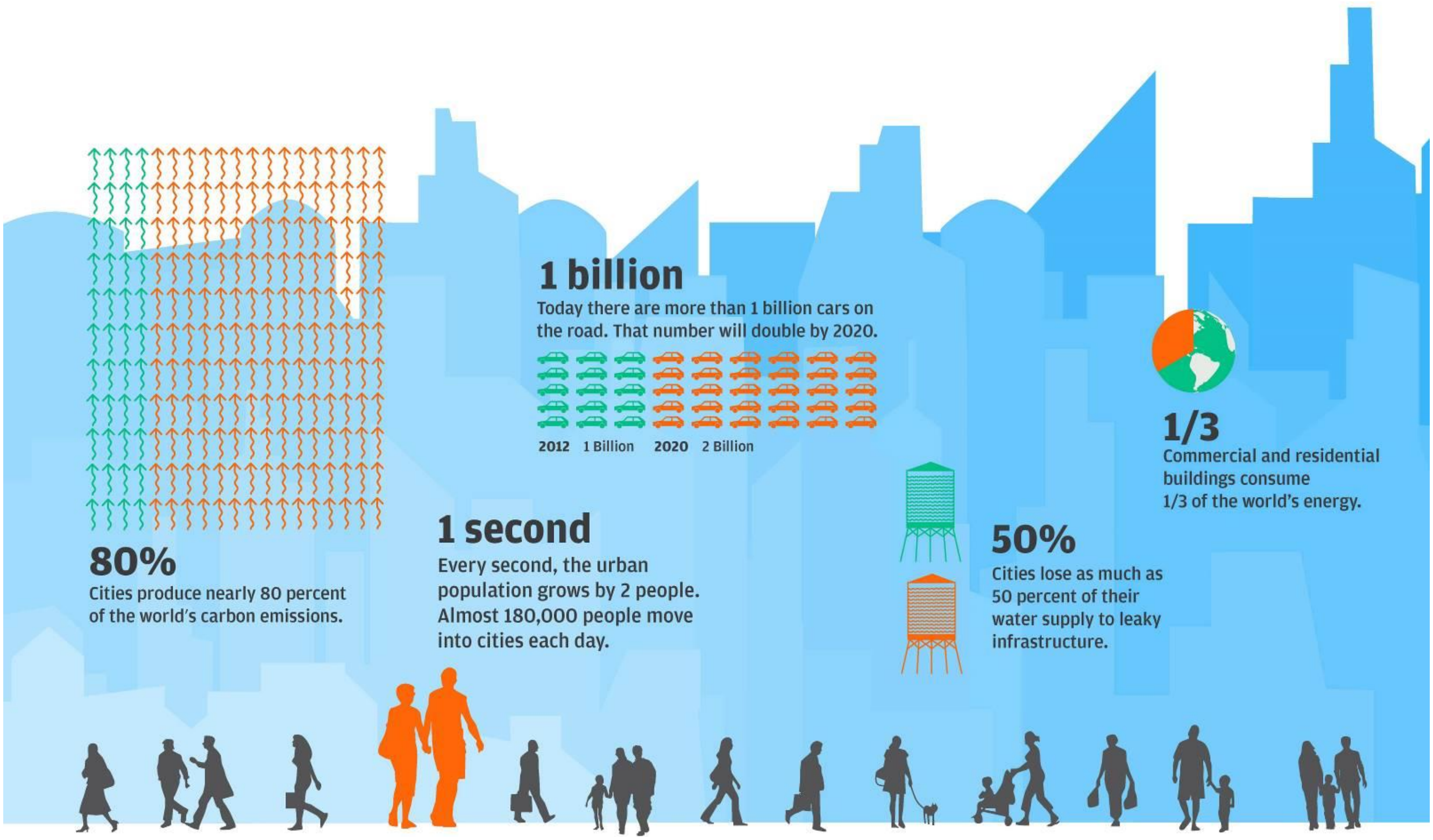


Figure 1.1 Effects of urbanization. Note the statistic where it is displayed the increase migration to urban settlements. Source: www.smartercitieschallenge.

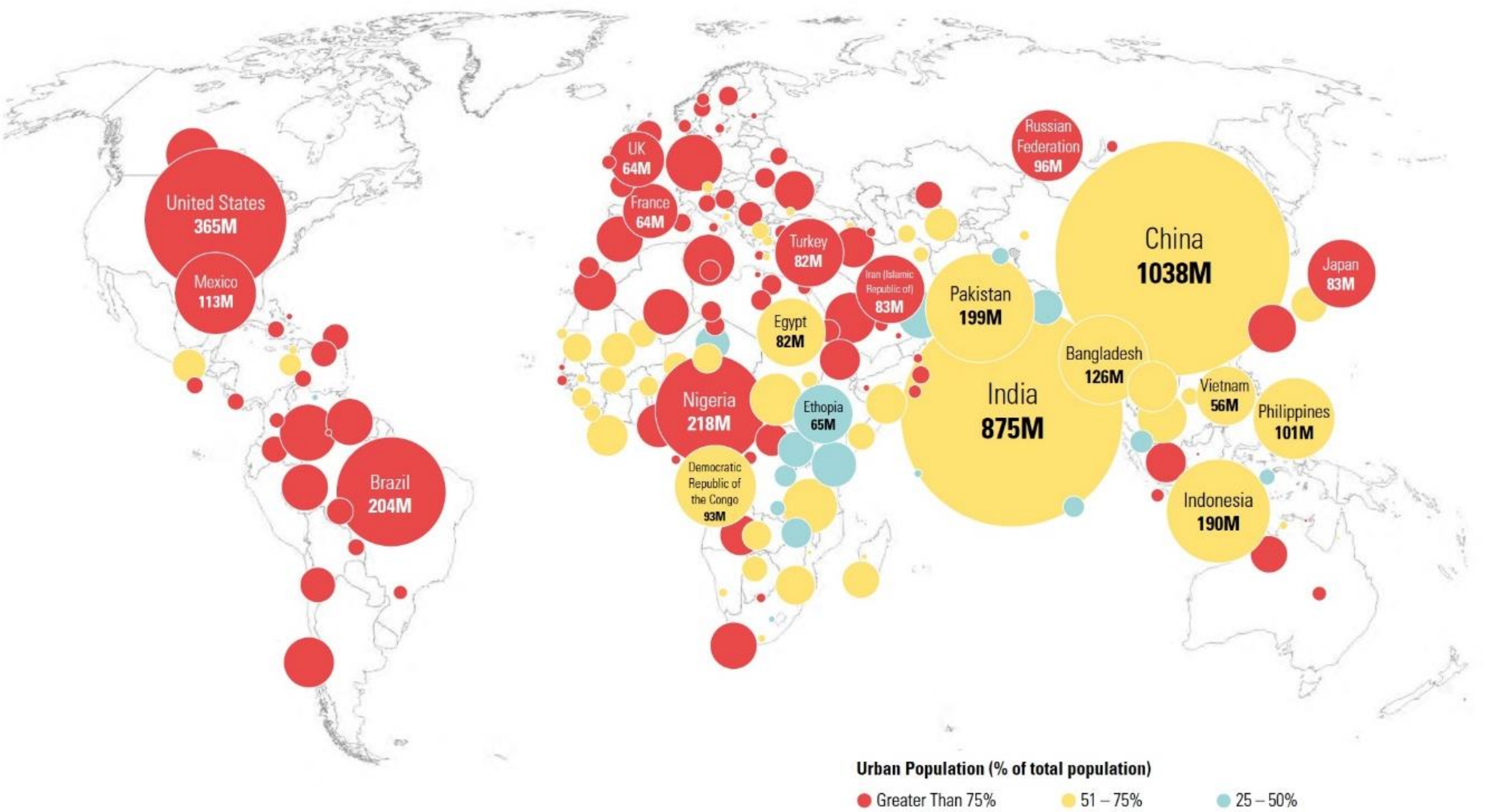


Figure 1.2 This map depicts the projected increase of people living in urban settlements by 2050. Source: www.unicef.org (urban maps tool)

Moreover, Africa and Asia, the two most rural populated areas in the world, will have an annual growth rate of 1.10 percent, making this trend a concerning issue (United Nations, 2010).

These migration patterns are better displayed

Figure 1.2 and Figure 1.3, where the existing urban population in the Western part of the world, including Canada and its increasing demand for urban living, is evident. Furthermore, it is critical to state the effects on the projected growth in other parts of the world, like Nigeria, China, and India that have yet to experience urbanization and may encounter several challenges, such as providing enough housing for its inhabitants in their respective urban cores.

Some of the main reasons to emigrate from rural areas to urban settlements include globalization, technological advances in food production, and the economic changes among countries. For instance, the agricultural activity in developing countries contributes less than 30 percent of their GDP. However, in developed countries, the technological progress and the improvement in production has resulted in limited access to jobs in rural areas. Therefore, people move to cities looking for jobs and better living conditions, given that rural areas have been disqualified in terms of development and amenities by cities (Pieterse, 2008).

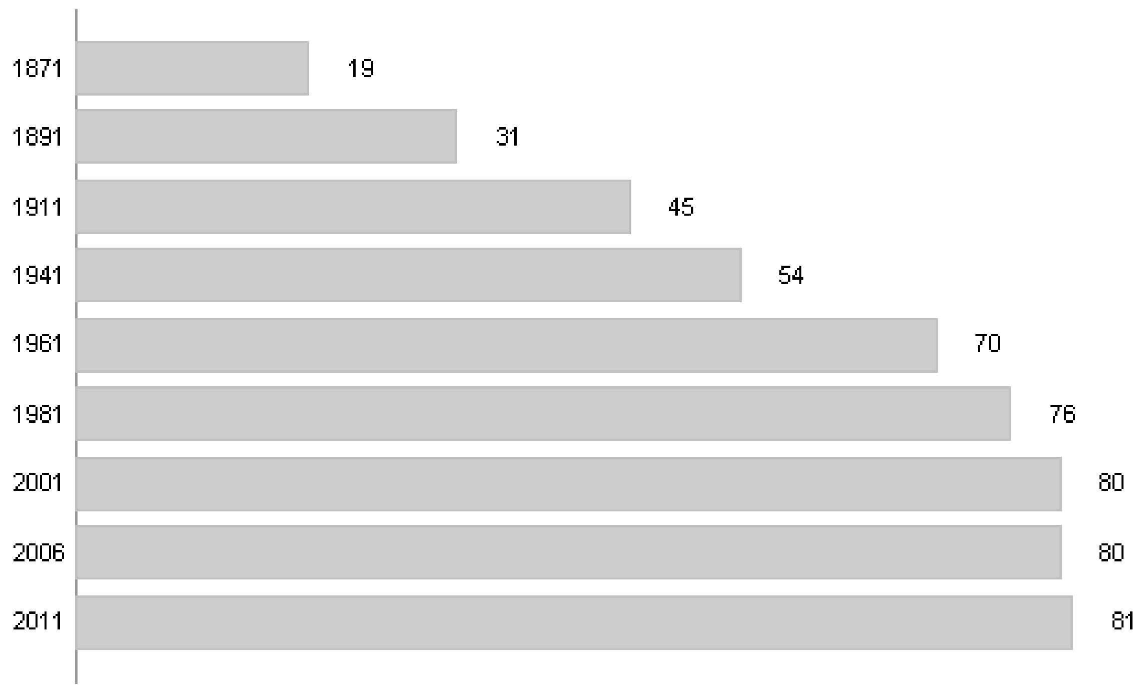
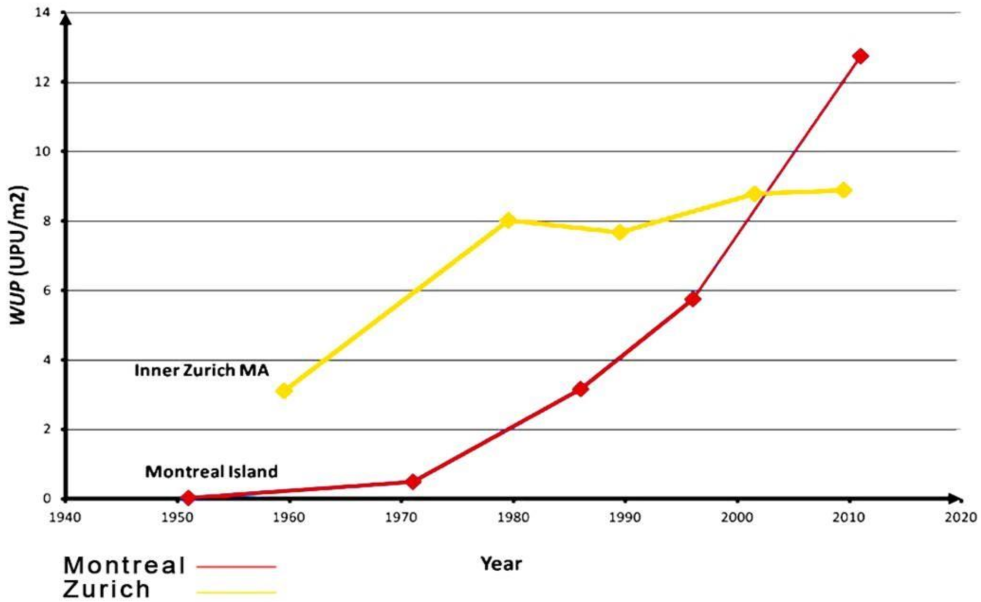


Figure 1.3 Population living in urban areas, Canada, 1871 – 2011 (in percent) Source: Employment and Social Development Canada 2014.

Urbanization has led to either the uncontrolled and unplanned growth inside the cities with the creation of new high-density buildings, or the spread of the cities along the periphery for the development of new suburbs (Bhatta, 2010). The effects of this phenomena are notable in Montreal where urban sprawl has grown extensively during the past 30 years (Figure 1.4).



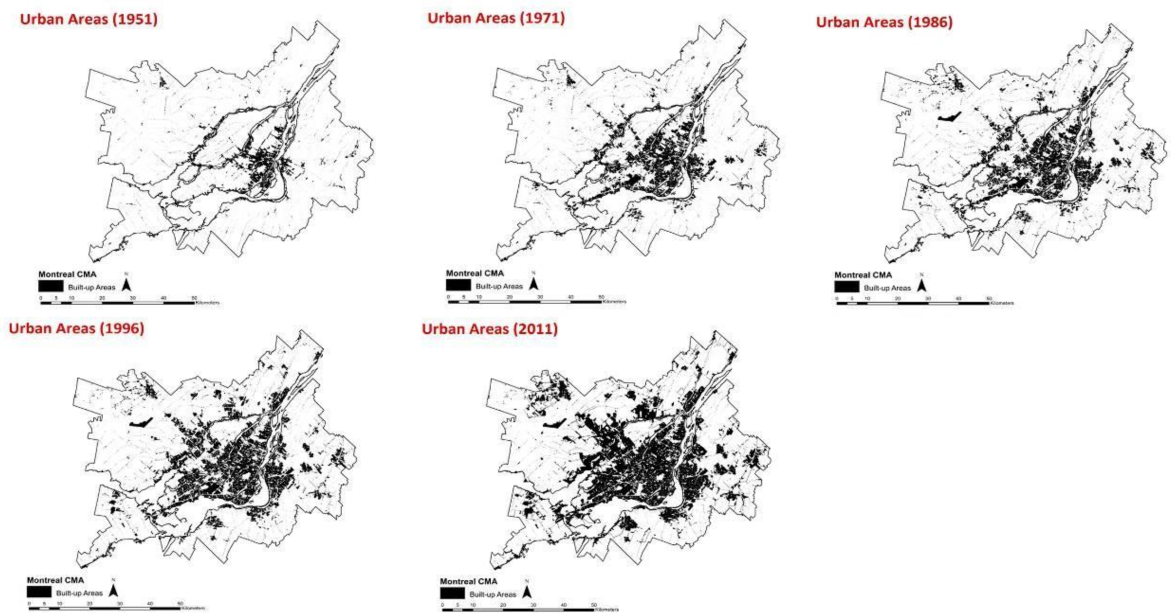


Figure 1.4 Above: evolution of urban sprawl in Montreal, 1950-2010. Below: Maps with the evolution of Montreal built area. Source: N. Nazarnia & A.G. Jaeger, Department of Geography, Concordia University. www.nrcan.gc.ca/earth-sciences/geography/topographic-infor

On one hand, the uncontrolled grow of urban sprawl the city results in an irrepressible occupation of land. This reduces the natural habitat for wildlife, promotes the use of transportation systems, and demands further extension of the urban infrastructure (Bloszies, 2012). Furthermore, this denies people from living in cities close to their work, recreational activities, and other conveniences. On the other hand, due to the rise in urban living, the demand for high-density dwellings in city centers has increased. Thus, apartment prices are soaring as developers compete for the increasingly hard-to-find land. Hence, in most of the world's urban centres, access to housing is beyond the reach of many (Friedman, 2013). For example, in Figure 1.5, the data from Statistics Canada shows a severely unaffordable area concentrated in the center of Montreal, where land is limited and in high demand. In short, both ways of developing have negative aspects for people's livability.

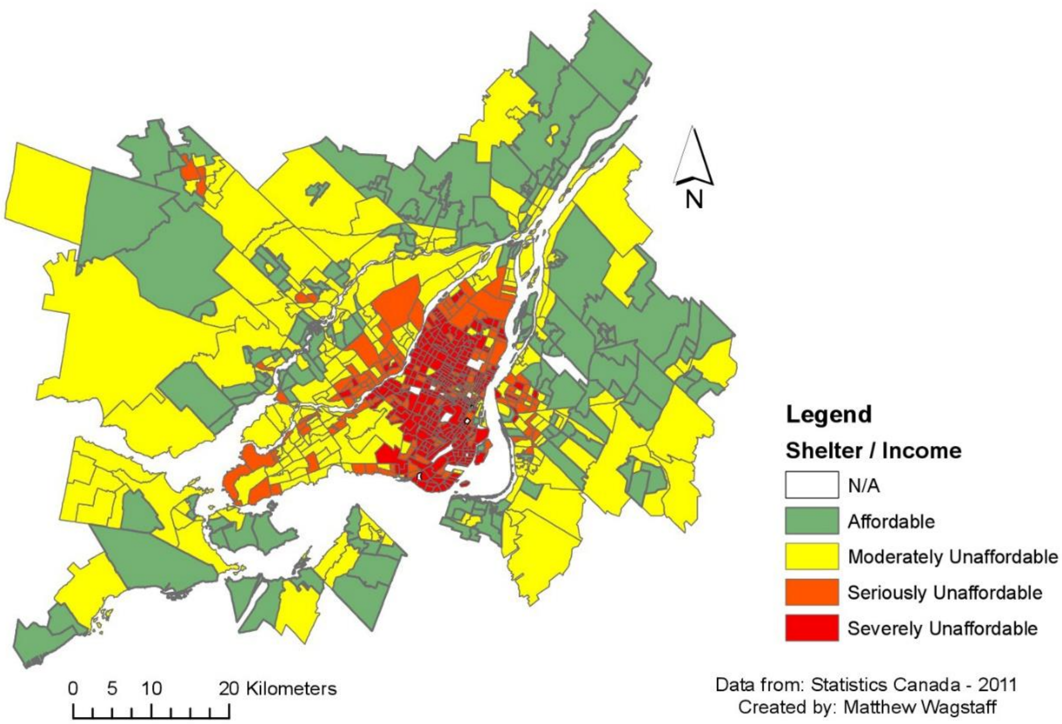


Figure 1.5 Affordability in Montreal, 2011. City center addressed as not affordable. Source: Housing Affordability Analysis: Vancouver vs Montreal. Retrieved June 5, 2018, from Wagstaff, Matthew website: www.blogs.ubc.ca/ mattwagstaff, 2011

In practice, the traditional way to create more housing in urban areas has been either to tear down the existing building and construct a new and higher building that occupies the envelope allowed, or to expand the city into the suburbs, as explained before. Such practices were customary in the past century because they efficiently delivered the space needed as people began to migrate into the city. However, they also carried many environmental, economic, and urban problems, which architects, urban designers, and politicians are constantly trying to solve. Nevertheless, some authors have proposed to use a stock of available spaces in cities to find the solution to these problems.

Trancik, who is one the most well-known architecture theorist, coined the term "*lost space*" in 1986. He described it as all the abandoned, obsolete, and unproductive spaces we find in urban landscapes. In his words, they are "no-man's-lands" that "nobody cares about maintaining, much less using". Usually, they are also inactive and alien to the urban fabric (Trancik, 1986). These spaces become an essential land resource in the 21st century-city due to land scarcity, high rate of urbanization, and the demand for housing space. Lost spaces include a wide variety of abandoned warehouses, oddly shaped plots of land, city alleys, and abandoned parks, among other obsolete spaces.

One of the most underestimated types of lost spaces are roofs. These fall into Trancik's terms when they have available buildability above them, which is a widespread phenomenon in today's cities. For many years, rooftop lost space remained unused due to the lack of technological development, high costs, and the easy access to vast plots of land, which were available to the government and private entities.

The human race is currently facing a world-scale urbanization trend that is testing cities to their limits. One of the biggest challenges cities face is to fulfill the demand for city expansion while preserving a safe environment for people's livability. It is recognized that some traditional methods provide an answer to this problem, however, it is also clear that these pose several difficulties, as it has been outlined in this chapter. In a nutshell, we have a limited amount of land and we are already reaching its limits. This is the case for Montreal and for many other urbanized cities in Canada that are struggling to find a solution to housing expansion in a 21st-century context. The problem lies in trying to solve housing expansion with the same traditional methods that have been used over decades. There is a need to recognize developing technologies and to use them to tap into the undiscovered parts of the city, like the available rooftop-landscape, to densify the existing city without destroying it. Ensuring the right space for city growth is imperative because this will allow it to flourish and create a healthy habitat for its future citizens.

1.1 Theoretical framework

This investigation argues that Above Rooftop Expansions (ARE) are a required source of housing-development in many cities across the world. Besides supplying housing in urban centers, rooftop expansions are a way to improve buildings' energy consumption, maintain their existing heritage value, and create a bottom-up market for a faster-developing housing process where land is scarce. There is a need to understand buildings not only as "unfinished artifacts" that could be expanded for future adaptability, as explained by Schmidt & Austin (2016), but also as a collection of elements that create an urban-platform that crafts an unconventional stock of space available for city growth. In other words, we need to finish building the city we already have.

On one side, Trancik introduced the idea of the city as an uncompleted fabric with several pockets of abandoned space that should be recaptured by the city (Finding lost space: Theories of urban design., 1986). On the other, Anderson argues that, during the past decade, there has been a massive transformation in the way humans build material goods (Makers: The New Industrial Revolution, 2012; The long tail, 2006). This micro-manufacturing trend is happening across different industries due to the combination of internet services and digital manufacture. The problem lies in the failure to recognize the combined value of both, the lost space addressed by Trancik (1986) and the developing technologies addressed by Anderson (2014), as a way to create more room for people without destroying the city or expanding it further horizontally.

The following research, relates to these concepts by addressing the notion of adaptable architecture, growth in time, and innovative technological advances to evaluate new methods that conquer lost space in the city (Schmidt & Austin, 2016; García-Huidobro, Torriti, & Tuga, 2010; Aravena, 2010; Friedman, 2001; Friedman, 2013). Practices in Europe, like LCT, are leveraging a method to make use of rooftops in city centres. For example, Artés *et al.* proposes an add-on expansion strategy which grows existing housing structures vertically by adding new prefabricated modules on top of Barcelona's roofs without demolishing the existing buildings (Vertical Extension and Improving of Existing Buildings, 2017). The methods addressed in this practice ensure that all additions do not exceed the maximum load capacity and comply with current urban codes. They also draw on concepts of adaptability, above-ground growth, and advanced prefabrication, to make use of lost space in Barcelona.

Although the idea of building on rooftops is not new as it has been done for decades in informal settlements, this phenomenon puts forward a close focus on bottom-up strategies to develop cities. Moreover, current practices, like LCT, are using manufacturing innovations that incorporate evolving technologies, like prefabrication, digital manufacture, and lightweight materials, to build a safe approach to progressive-housing in existing structures.

Drawing on top of previous work, this research uses a theoretical framework that includes adaptable architecture, growth in time, and prefabrication advances to inhabit rooftop-lost-space as an effort to meet the increasing demand for urban housing in the 21^{st}-century cities.

1.2 Research question

How effective is the use of rooftop expansions in addressing the needs for housing supply in low and mid-rise buildings in centric neighbourhoods?

1.2.1 Sub-question

- What strategies need to be considered in the design of a rooftop expansion of low and mid-rise housing that do not meet the maximum FAR?

1.3 Goals and objectives

The primary objective of this document is to assess the feasability of using rooftop expansions to meet the housing demands in urban dense areas and expose the required techniques needed to do this. From these results, it is possible to tailor the most effective strategy to improve access to such techniques and tap into these available plots of air.

- To create a set of criteria to develop rooftop expansions in city-centric low and mid-rise buildings.

- To define a solution for rooftop expansion that addresses the economic, legal, and construction constraints.
- To assess the influences of rooftop housing-expansion in the trend of urbanization.

1.4 Intended audience

The audience of this report resides in the scope of any professional interested in finding the techniques and concepts behind rooftop expansions, such as architects, planners, and urban designers that have access to available built-up space within their property. Moreover, the content of this research might interest other scholars who want to learn about the case studies and literature review on topics such as city planning, urban coding, and technological advances in architecture.

1.5 Methodology

The methodology combines a set of literature reviews, selected case studies, and a final guideline of strategies assessed through the investigation.

It starts by understanding traditional frameworks of city development of the 20th-century North American city. Then, it contrasts these views with the concept of *Lost Space* as a platform for city evolution, narrowing the research to rooftop lost space. At the same time, this paper draws conclusions based on the concepts of adaptable architecture, progressive growth, and fabrication advances to define possible strategies that make use of rooftop lost space and build the conceptual grounds of an alternative model for 21st-century city growth. The literature sources then outline prospective spaces and a technical framework.

Subsequently, this report evaluates the foundations outlined from the literature review with selected case studies that provide sufficient ground to form the proposed guidelines elaborated in Chapter four. The work developed by LCT provide the core reference studies due to the rich stock of built rooftop expansions they have done in a single city. In their published articles, the authors describe processes and conceptual frameworks of the work developed, however, the available sources are vague due to the lack technical specifications.

Thus, this report will document and assess them in depth to find their strengths and weaknesses, as well as to define the specific tactics one needs to consider when expanding vertically.

Finally, all the theoretical and technical conditions investigated form the body of the proposed guidelines. Within this framework, the investigation will outline specific guides to successfully design and build above rooftops in low and mid-rise buildings. This project will end in final remarks of the findings.

1.6 Scope and limitations

First, the scope of this project is limited to low and mid-rise buildings (between 4 to 12 stories) which have not met its existing floor square ratio (F.A.R.). This is to ensure that the proposed guidelines do not exceed existing municipal codes while making use of rooftop lost space.

As explained before, this study will rely on extensive fieldwork in Barcelona due to the vast conglomerate of rooftop expansions in the city. However, each selected case study project or manufacturing facility is conditioned to the previous approval of its owners or inhabitants. Similarly, to interview the designers and developers of such projects, their consent and approval is needed, which is why access to their information and or documentation may have be refused.

1.7 Research outline

The research is divided in four sections.

Chapter one focuses on laying down the rationale and general approach for the study.

Chapter two draws upon the theoretical framework. The first segment of the chapter inquiries about current preoccupations that can be addressed within this research context. The document investigates the historical evolution of the 21st-century North American city through the concept of Lost Space across different literature reviews. In the second part of the chapter, the research will study the concepts of adaptive growth in architecture. Finally, the chapter will draw conclusions based on the patterns in its findings to define a potential place for the expansion of Montreal's housing.

Chapter three contains the assessment of the case studies. This include the correspondent documentation, such as photography, drawings and site visits. The paper draws upon four contrasting case studies which will provide complementary technological information. The first case study inquiries about environmental opportunities in these expansions. The second case study focuses on the building restorations needed to acquire the aerial rights above the buildings. The third and fourth case studies explore structural strategies. The selected sample portrays valuable information to evaluate the strengths, weaknesses, opportunities, and threats of the existing condition of rooftop expansions in urban contexts.

Finally, Chapter four concludes with the criteria and guidelines required to develop such technique. Finally, it will address the conclusions and required discussions for the development of this subject.

CHAPTER 2 - LITERATURE REVIEW

For the first time in human history, cities have become a centre of attention for researchers because it is where the majority of people live most of their lives (United Nations, 2010). The city that is seen today is based on a series of pieces that change as they interact with each other. Each of these pieces is comprised by a sequence of layers that confluence all the present and past intentions of people in a physical space. One of the most significant challenges in architecture and urban design is the capacity to allow the city to adapt for future growth while keeping public well-fare that ensures the best livability for its inhabitants.

The current high peaks of urbanization have led to a discussion on the way cities are built. For the contemporary metropolis, it is no longer viable to develop the standardized and predetermined massive-projects (Figure 2.1) which were characteristic of the previous century (Eisenschmidt, 2012). Instead, the 21st-century architect needs to see the city as an ecosystem that is at "evolutionary state", where many relationships are happening at all times (Marshall, Cities design and evolution, 2009). Some theorist suggests that cities can find useful land within the existing city. The assertion is that the city's grit is a vital component of the city because, like a historical DNA, it stores and rules its

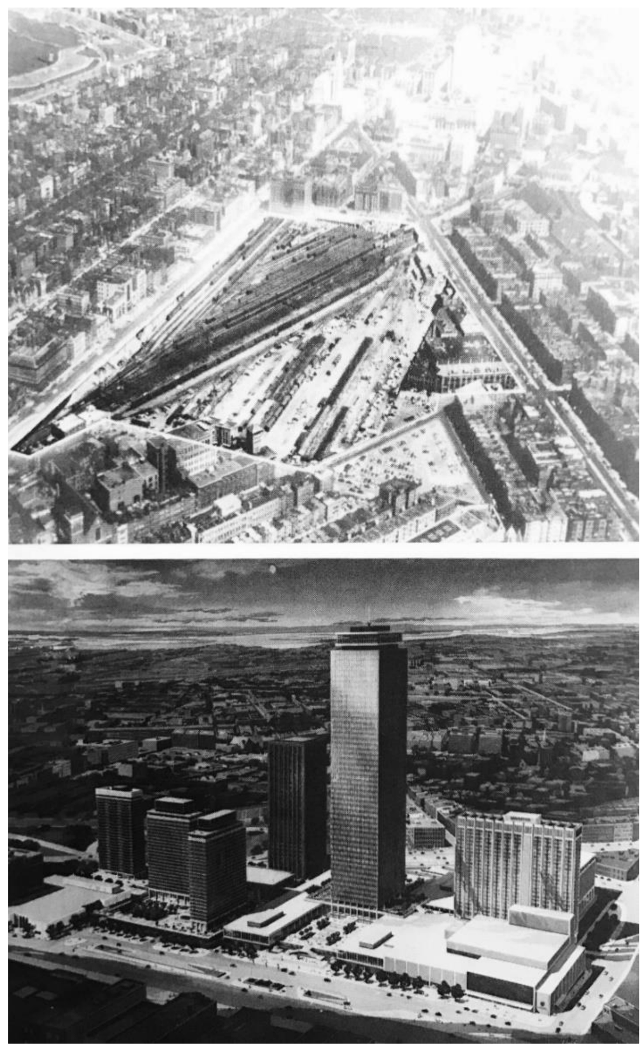


Figure 2.1 Up: before the intervention of the Prudential Center Bottom: After intervention of the Prudential Center by the Insurance Company of America in 1959. It represents an example of a totalitarian urban project. Boston, MA, Source: Finding lost space, Trancik, 1986

future expansions. In 1972, Martin argued that, if space was used "efficiently" architects could find the space needed in the already existent city. The author's idea explained that the grid needs to be re-configured in a series of huge geometrical changes where most of the built-up space needs to be destroyed (Figure 2.2) (Martin, 2007 [1972]). These ideas do accomplish the goal of developing more space in centric areas, but there is a missing part in Martin's argument and that is the scale.

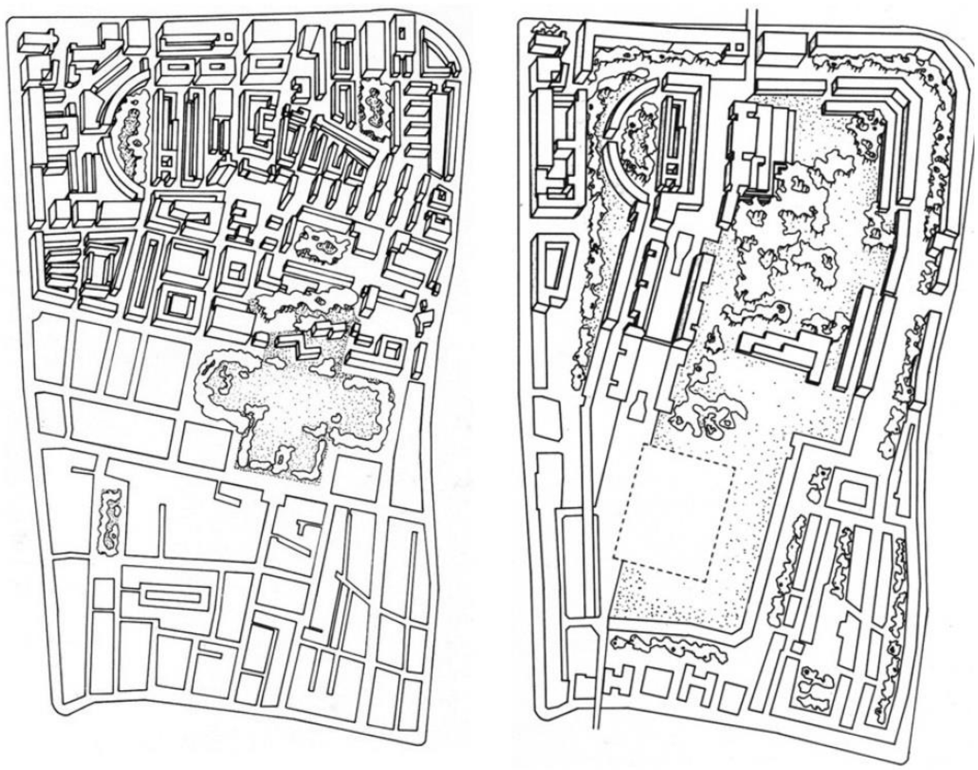


Figure 2.2 An example given by Martin on how to reconfigure the grid to 'make' space in the same area of a city Left: Before reorganizing. Right: After reorganizing. In this drawing the author also illustrates the classical 20th-century approach of rearranging the space through extensive redevelopments that destroy most of the existent city. Source: (Martin, 2007 [1972], p. 81)

2.1 Lost space

The problem with the previous school of thinking was that developers, either private or public, tend to focus too much on large scale areas by handling cities as a two-dimensional object to be developed. However, most of the built-up space available in contemporary cities is made-up of a grain of scattered small lots. In fact, large, single-owner sites are rare in 21st century cities (Moudon, 1991). A development exercise done in Toronto by the planning department's shows how a city could be developed by focusing directly on small-scale spaces around main streets, instead of the massive scale ones proposed by Martin (Finding buildings to fit Main Street, 1991). In the study, a set of micro-interventions are connected to the macro-vision of the city, punctuating the existing fabric to create a solution to city growth by introducing small built-up pieces that reccuperate space back into the city (Moudon, 1991).

As stated before, today, the city is perceived as a two-dimensional entity instead of the three-dimensional mass it is. As a result, cities have a massive stock of anti-space, also called *Lost Space* (Trancik, 1986). These areas are fragmented and detached from the city fabric. By perceiving it from a citizen's perspective, architects and developers can see the potential three-dimensionality of a city and, thus, include spaces that were otherwise undetectable. This standpoint offers remarkable opportunities to rediscover promising areas and create space in the 21st century-city. In this sense, lost space becomes a framework for city growth and, therefore, to housing development (Trancik, 1986).

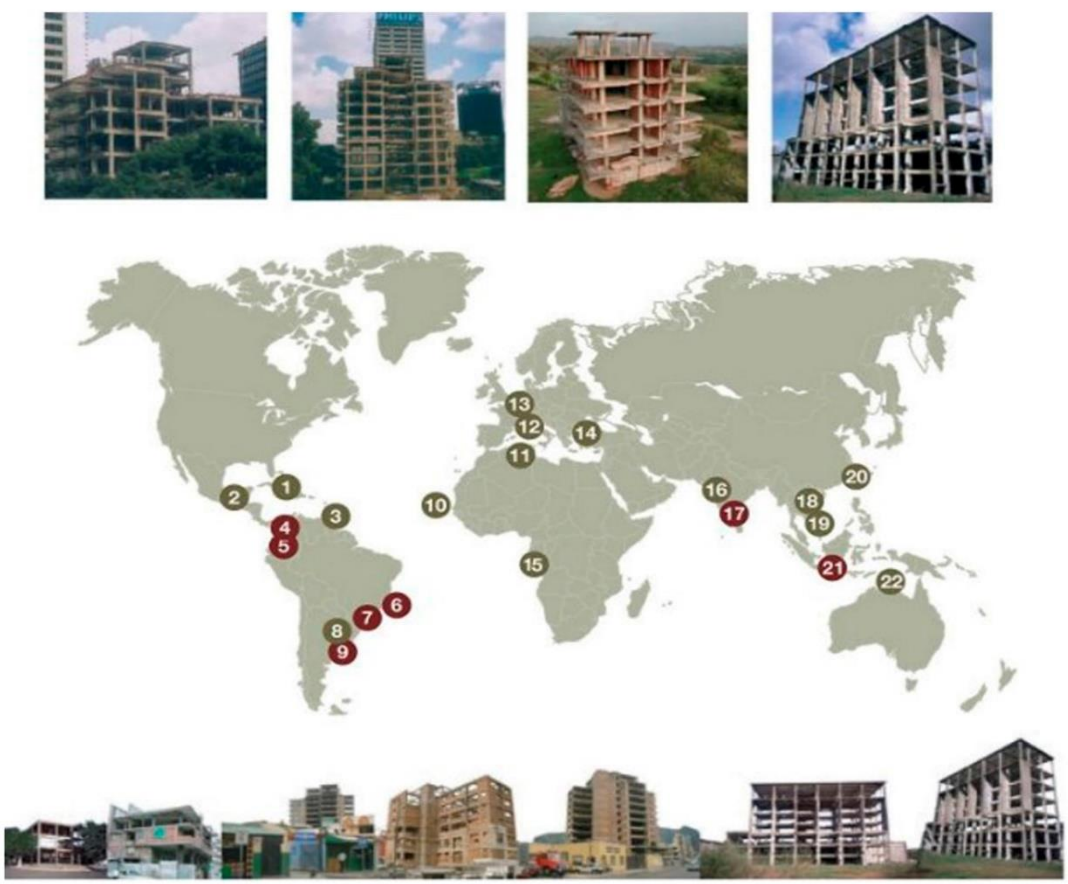


Figure 2.3 The map above depicts the locations where Coloco Collective have mapped the "Squelettes". The images above and below are a few examples of the structures identified. Author: Coloco Collective Source: www.coloco.org/projets/squelettes-a-habiter/

In the 20th century, lost space was left as a last resource for building because it was easier for the government and private developers to make massive urban renovations than to look after these small scattered places (Figure 2.1). This and the rise of prices, consequential to the lack of land, intensified the need for space within cities. Hence, the contemporary city is reinventing itself to make optimal use of space-resources within the city fabric. To illustrate this phenomenon, consider the work denominated 'Supercycling' by Coloco Collective, a strategy which uses abandoned buildings and gives back life and livability to them. Similar to the work of Tsukamoto *et al.* and Fabricius, Coloco has focused on mapping the '*Squelettes'* [abandoned buildings] available for recapture (Figure 2.3). This initiative seeks to bring attention back to abandoned structures by inhabiting and repurposing them through progressive growth done by its new inhabitants. The effect is a macro-scale solution that not only revitalizes the buildings and the cities, but also addresses the needs for housing space in central areas of these (Bonnenfant, Georgieff, & Georgieff, 2008).

As stated before, urban lost space needs to become a priority in the framework for city development in currently congested centres. Trancik structured lost space under five categories corresponding to the causes that produced them in the first place: Dependence On the Car, Modernism, Privatization of Public Space, Zoning and Urban Renewal, and Change of Land Use (Trancik, 1986). These five groups gather a diverse stock of "lots" available for development. Some examples include abandoned parks, vacant warehouses, or even vacant rooftops. The type of lost space investigated in this document falls under the categories of Zoning and Urban Renewal, and of Change of Land Use, defined as rooftop lost space. Rooftop lost space happens when the building

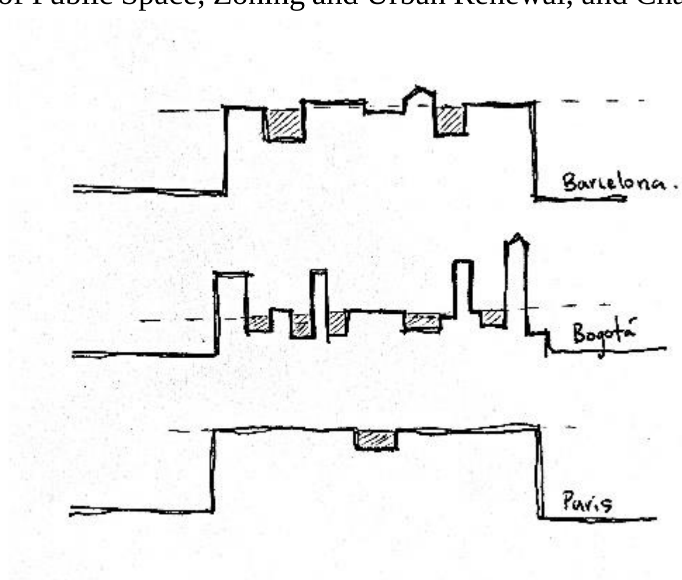


Figure 2.4 The hatch represents lost space in today's rooftops that do not comply with the maximum FAR capacity.

constructed does not meet its current FAR allowed by law (Figure 2.4). Left out by the change of land use and zoning renewal, rooftop lost space has become a widespread phenomenon in today's cities.

2.2 Rooftop's lost space as a development framework

Architects tend to mostly focus on buildable space, given that this is what people see and notice. It is known that, due to global urbanization, cities suffer from a lack of available space. Thus, the existing stock of lost space represents an instrumental land resource available to meet the demand for livable space in urban centres. Unfortunately, the stock of lost space lying in the surrounding areas of buildings remains in constant change due to its direct relation to the technologies available and the socioeconomic changes that the city encounters in a specific time period. Hence, it is essential to understand the conditions that each period represents in order to define which part of the stock should be developed. Based on Ford's work (The spaces between buildings, 2000), the following three sections will display the evolution of the backyard, alley, and rooftop lost space, correlating them with technological advances that triggered them as such.

2.2.1 Backyard lost space

In many European and North American older cities, the spaces between buildings, such as public squares, streets, and markets, were defined by decorative building façades, commerce, and the overall symbiotic relationship between these. The frequent use of row houses in the nineteenth century posed particular attention on the front façade. Buildings lavished with decorative designs while the rest remained secondary. At the end of the 19th century, modifications took part in the urban landscape as an effect of the introduction of demolitions and common fire incidents. Many of the side façades were colonized by advertisers and, as a result of the fragmented urban landscape, backyard use came forward (Ford, 2000). At the time, the backyards were usually a rather disorganized space that hosted most of the service elements of the row houses. According to the author, "the term yard comes from the world of work-shipyard, lumberyard, brickyard, and the true to form, backyards contained outhouses, laundry facilities, trash containers, and piles of building materials.” The previous quote portrays how the backyard was perceived at the moment in comparison to how it is perceived now.

2.2.2 Alley lost space

At the beginning of the 20th-century, the character of these cities changed according to the evolution of new technologies, such as the extensive use of the car, the use of steel in construction, and elevators. Alleys, in particular, were rare to the city until the introduction of specific technological advances such as heating, pipes, trash containers, ventilation systems, and fire exits, which incremented with the increasing building heights. “Alleys emerged as a behind-the-scenes landscape of the city,” by taking the job from backyards as the signature lost space of the previous century. In fact, alleys became such a signature space that they were often portrayed unpleasantly in many popular films and noir thrillers of the 1940’s (Ford, 2000).

Figure 2.5 Left: a typical alley from the 1940's Boston. Right: a restored alley from the 2000’s San Francisco. Source: Larry R. Ford (The spaces between buildings, 2000, pp. 183-184)

2.2.3 Rooftop lost space

Land value grew even more, thus, many building owners demolished and started building high-rises to supply the extra space demanded. As a result of the fast urban transformation, "…buildings of uneven height became the norm in the competitive laissez-faire American city" (Ford, 2000). Aside from the uneven height in the urban landscape, a new set of challenges was introduced as a result of the growing number of service elements and the various urban beautifications movements. Thus, the previous charming landscape, famous for its peached tiled roofs and chimneys traditional of older cities, morphed into the iconic landscape of service's rooftops we see today. As shown in Figure 2.6, "when water tanks, electric wiring, service sheds, and other types of machinery were piled on, rooftops, like alleys, came to epitomize the messy urban scene (…) Most rooftops were never meant to be seen and therefore were rarely given careful attention. Today, even in residential areas where the picturesque roofline has held on, the tops of houses are often graced with such unattractive devices as cooling fans, television antennae and satellite dishes" (Ford, 2000, pp. 31,32)

Figure 2.6 Typical service rooftop in Atlanta, Georgia. Source: Larry R. Ford (The spaces between buildings, 2000, p. 73)

It is evident that the evolution of lost space is directly related to the introduction of different elements such as technologies or sociopolitical changes. In the case of rooftops, it seems as if the building only possessed four façades and architects pay no attention to its fifth façade (rooftops). The rooftops we see today on top of our cities are a result of the evolution of this way of thinking through the past hundred years. Only until recently, cities have noted the value on rooftops through the lens of sustainability, with the introduction of rooftop farming and energy collection using solar panels, solar water heaters, and water collectors. Despite the significant value in these current efforts, the possibilities that lie within the use of rooftop lost space expand beyond them.

Like any other type of lost space, rooftop lost space can also serve as a solution to the lack of buildable space in the city. Fortunately, there is an excellent source of rooftop lost space in centric areas where old buildings currently possess floor area ratio (FAR) available. This could be due to the high cost of developing a new building, the owners' desire to keep the existing building, or to heritage codes. In either case, the challenges with rooftop lost space include finding the technological advances needed to expand vertically without compromising the existing building, the affordability of the new unit, and the current municipal bylaws. In other words, its success depends on "incorporating appropriate structural considerations" to avoid larger costs (Friedman, 2013). Thus, the purpose of this research is to find the means needed to transform rooftop lost space into a space that has high value for the city.

In an era of increasing urbanization, this approach is imperative for the city because it can become the site of future building development. Similarly to the introduction of the car, the elevator, and steel construction in the previous century, emerging technologies like prefabrication are making it possible to introduce a new space to the built environment. Hence, building guidelines that tackle economic and structural difficulties are crucial to explore rooftop-lost-space.

The purpose here is to open a new platform of development for the public and private developers by recapturing the space left out by the buildings that do not comply with the

FAR allowed and reconnect them to the city fabric. This type of lost space is often densely condensed in city centres and it is a recurrent phenomenon in many cities around the world. For example, in Figure 2.8, red and black represent the number of underdeveloped properties, both as rooftop lost space or as empty lots. However, contrasted with Figure 2.7, it is noticeable that many of these units also host existing buildings. The landscape that lies on top of the built city is what this project aims to research.

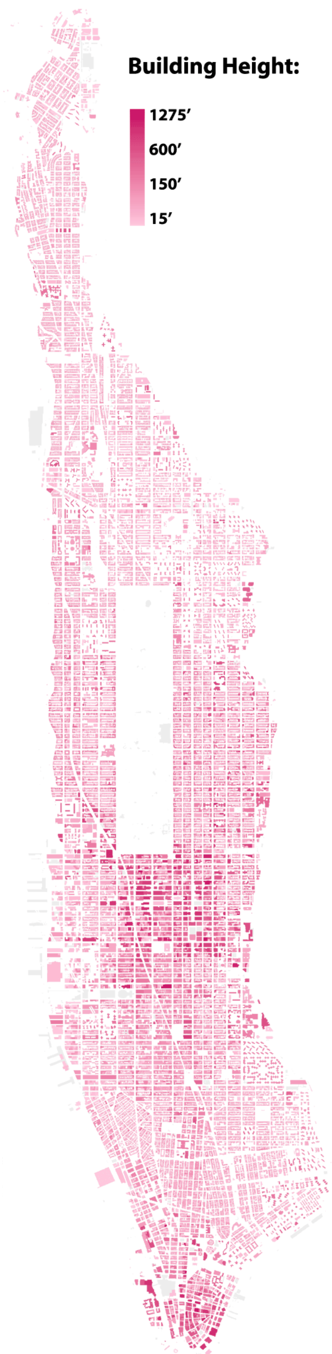


Figure 2.8 Far left: The map depicts the relation to the maximum zoning allowance: percent of allowed Floor Area Ratio (FAR). Starts from deep black with less than 20% to red with 90% of the maximum allowed FAR.

Figure 2.7 Left: These maps depicts the building's heights of Manhattan. It confirms that many of the properties with available FAR are already built. Meaning that the FAR available sits above the built units.

The challenge here is that architects need to include this space as part of the interest on their designs. Rooftop lost space needs to be treated the same way open lots are. Furthermore, they need to be mapped, measured, and defined with precision so that a new stage of usefulness is given to them and a new platform for development is given to us.

2.3 The growing city

It is clear that cities have a lack of developable land as a result of uncontrolled urbanization. Traditionally, design adopts frameworks that concentrate in a “rather solitary product of the mind” (Aravena, 2010), where architects coincide meticulously every piece of the end product. However, the built environment is a rather particular subject because it resides in a state of dynamic change and it is not static as traditional design works are (See Figure 2.9). Some buildings die, some transform, and others grow. Therefore, design needs to accommodate, instead of restricting the dynamic conditions buildings have so that users can make the best out of the existing space we have in cities.

Figure 2.9 Documentation by Camilo Vergara, Evolution of a building, 10828 S. Avalon Blvd, Los Angeles from 1980 to 2012 Source: Vergara C. Archive. /camilojosevergara.com/Los-Angeles/10828-S--Avalon-Blvd--L--A/8

Aravena argues that, despite the popular do-it-yourself culture and off-the-shelf tools and materials on the market, growth in architecture has “disappeared from contemporary building cultures in most parts of the developed world” (Perspecta, 2010). In effect, places with an increasing demand for urbanization, like Japan, Singapore, and Hong Kong (See Figure 2.10), choose to use standardized and rigid designs for the majority of their developments because fast timing and efficiency is preferred over other architectural aspects (Hooper & Nicol, 1999; West & Emmitt, 2004). Due to the adoption of this practice by most public and private developers, projects do not meet the increasing demand for growth and change (Sullivan & Chen, 1997). Thus, building owners need to demolish existing buildings to meet the demand for space and accomplish new spatial requirements. Buildings in cities are designed as disposable units, creating an “immediate obsolescence” (Wong, 2010). The existing framework does not correlate with the standing push towards a sustainable world where resources are preserved, and goods are given another life. Adaptability and growth provide a solution to this problem given that the existing owner(s) can meet their new spatial needs with the use of progressive growth in a way that the current building is not destroyed (Wong, 2010). Naturally, specific components of the building may require to be adapted to meet new ways of inhabiting it, but structural elements that include valuable resources such

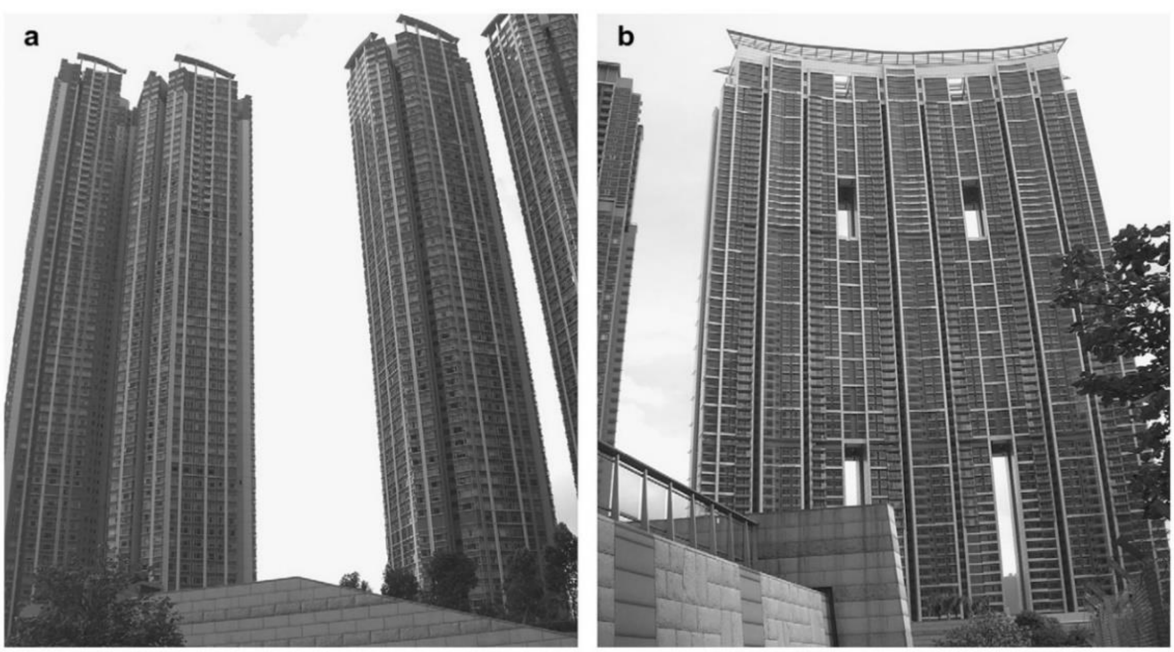


Figure 2.10 New high-rise development in HongKong, Kwoloon station. Source: Wong (Factors affecting open building implementation in high densitymass housing design in Hong Kong, 2010, p. 175)

as the use of materials, human labour, and energy consumption can be cut as shown in this section.

The concept of adaptive growth understands growth as an ongoing process rather than as the delivery of an end product. This strategy capitalizes on the needs for space in cities and it is based upon the existing practice of extensions and changes that people make over time. To achieve this, many authors propose that each development should contemplate guidelines for expansion and future customization through the provision of correct structural components and the use of empty spaces so that its inhabitants can make extensions later (Friedman, 2002; Aravena, 2010; García-Huidobro, Torriti, & Tuga, 2010; Habraken, 1962; Tiuri, 2000; Schmidt & Austin, 2016; Brand, 1994).

The key to implementing adaptive buildings is the understanding of time and the vision that buildings will always remain in a constant "flow" of change (Brand, 1994). Habraken was a pioneer in the identification of this idea (Supports: An alternative to mass housing, 1962). His argument was based on the theory that buildings should be deconstructed into different sections to be susceptible for future adaptation. Habraken's approach not only divided the building among physical components as *support* and *infill* (Figure 2.11 and Figure 2.13**),** but he was also interested in the way different users participate in it (Figure 2.12). Habraken introduced adaptability through different levels of scale which come hierarchically as: Urban Structure, Tissue, Building, Partition, and Furniture (Habraken, 2002). The main idea with his concept is that the components developed in each level should create enough support for the

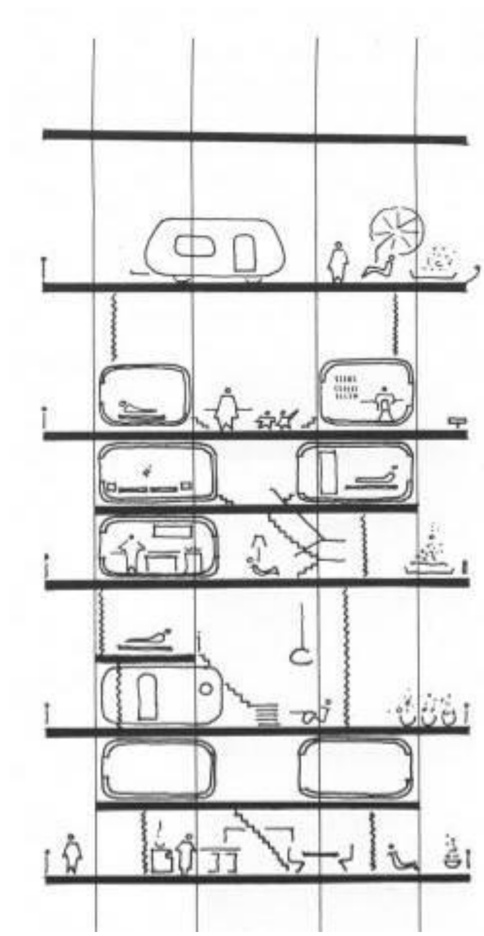


Figure 2.11 Concept of Support and infill. Source: Habraken J. Archives, 1962

adaptability of the consequent level. Meaning that, at any level, the framework set by the previous level will have control over the additions done at the next level. For example, if a certain apartment layout has an irregular form, it is more difficult for the final user to have flexibility in configuring the same space in different forms with furniture or with small wall demolitions.

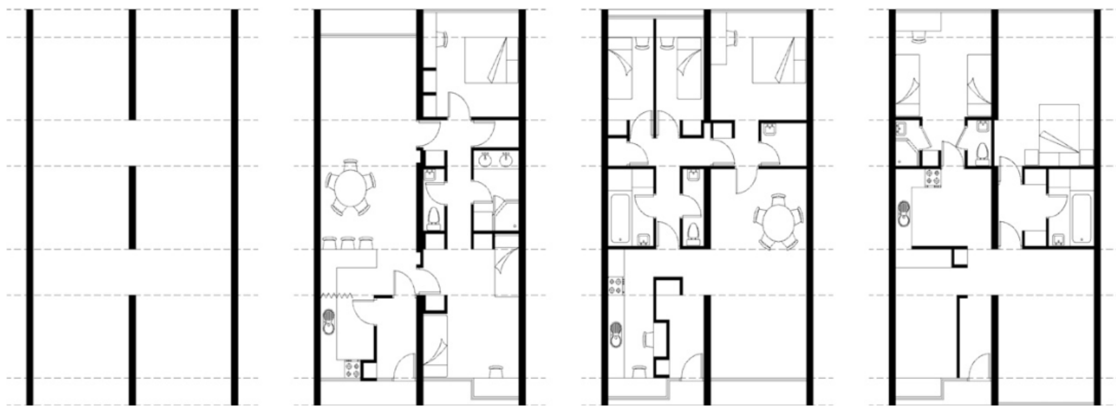


Figure 2.13 Habraken's supports and different types of infills for the same unit Source: Habraken J. archives, 1962

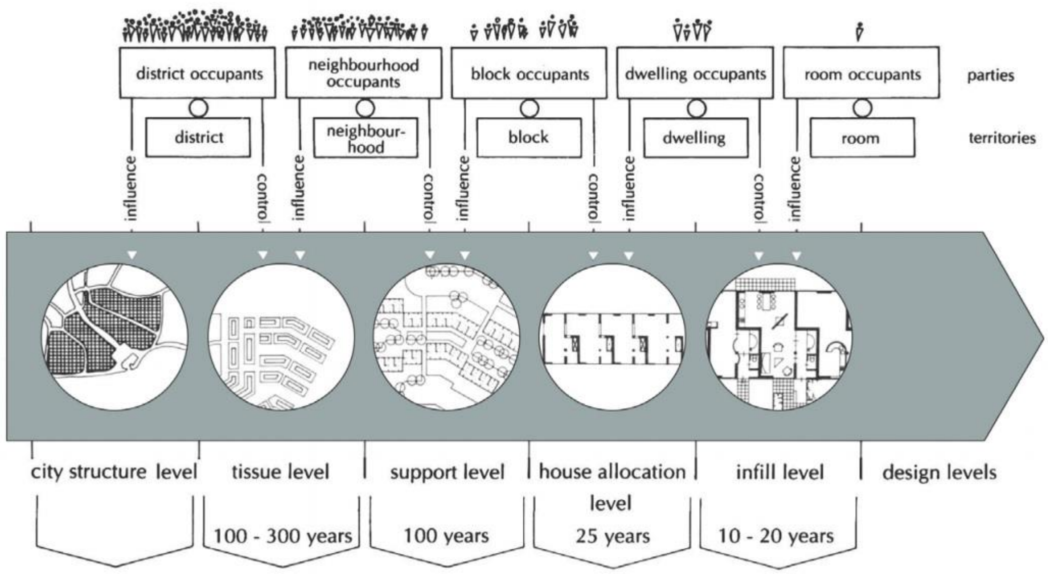


Figure 2.12 Levels of control as defined by Habraken. Source: The Structure of The Ordinary: Form and Control in the Built Environment (Habraken, MIT Press, 1998).

The claim here is that, due to the economies of scale and increase in urbanization, the numbers are prioritized, and the role of the user is deficient. As a result, public and private developers are attaching buildings to a short-term economic basis along with other disposable goods (Schneider & Till, 2005). To resolve this, adaptability and growth provide an alternative because they allow for making changes over time without destroying the existing building.

Along with these ideas, Stuart Brand studied architecture in its state of post-occupancy, where money, time, effort, and living were considered. Based on the work by Frank Duffy, Brand suggested a way to decompose buildings in a set of six layers (Figure 2.14). Brand claims that these layers should be studied in its accordance with time as they mature so that they can easily be adapted by its users and not disposed due to the ageing of a single element.

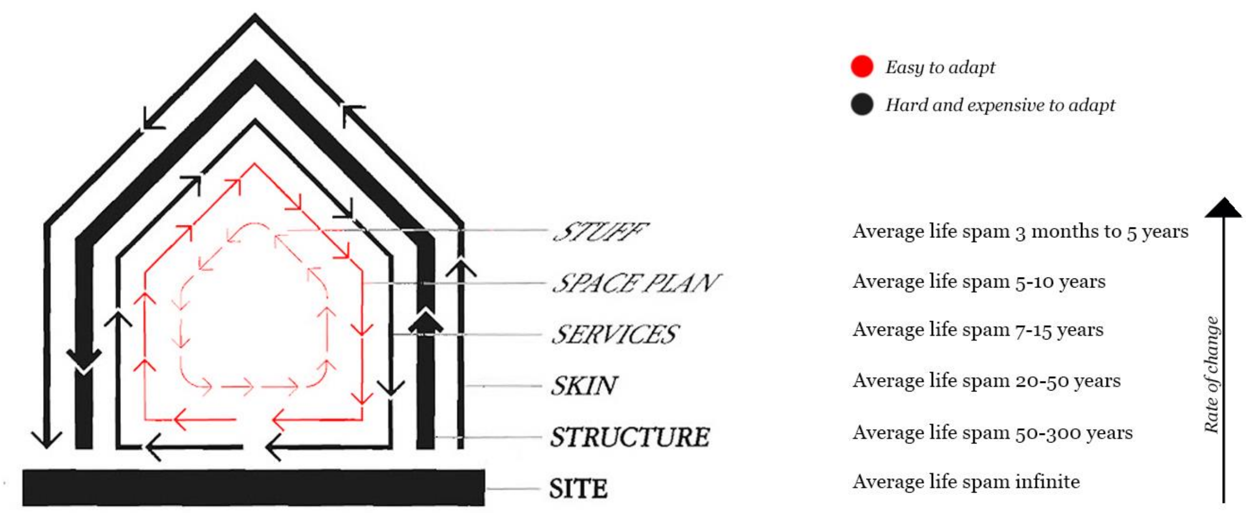


Figure 2.14 The 6 shearing layers of a building, adapted from Brand's diagram. Adapted by the author from: Stewart Brand (How buildings learn: What happens after they're built., 1994)

To understand further the theory of growth and adaptability, it is crucial to understand how it happens in practice; therefore, it is vital to base research where it occurs commonly. Building practices of low-income housing developments tend to be heavily criticized. Some claims may be valid, but the truth is that they have remarkable growth and adaptability embed in their DNA. Growth occurs very often in low-income housing in many third world countries due to the scarcity of land and the low amount of resources (Aravena, 2010; García-

Huidobro, Torriti, & Tuga, 2010). Based on these claims Garcia et al. documented the Proyecto Experimental de Vivienda (PREVI) in Lima to understand growth in architecture. The authors synthesized growth in housing in a 3 stage process. The first stage is installation, where the users settle through minimum modifications to establish themselves in space. The second stage is densification, where the user expands the base unit either for economic profit or for personal needs (Figure 2.15). Ultimately, a consolidation and diversification stage happens when the building changes internally to create a new subdivision of spaces to accommodate for the inhabitants' needs or for rent.

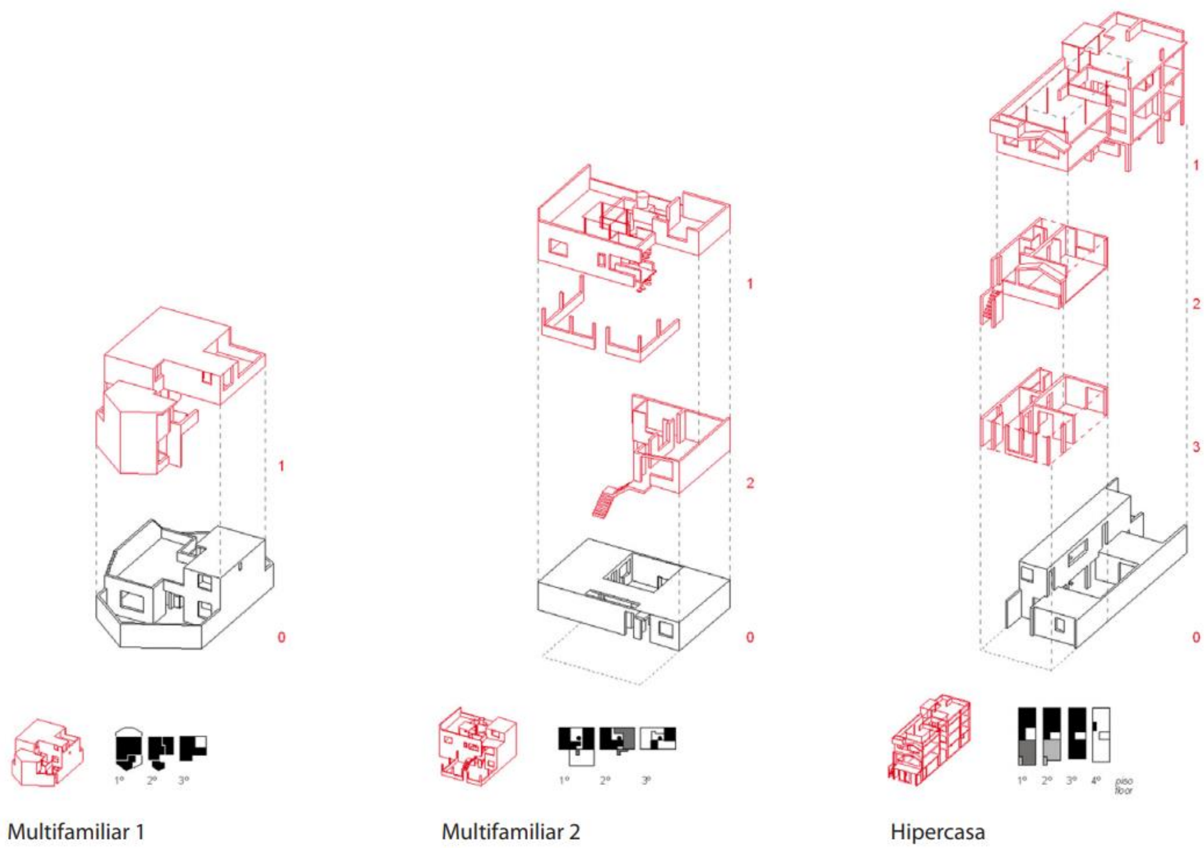


Figure 2.15 Adaptive growth in PREVI, Lima. The diagram shows growth in different housing typologies through time. Source: García-Huidobro, Torriti, & Tuga (PREVI Lima y la experiencia del tiempo., 2010)

The types of expansions described by Garcia *et al* correlate with the findings of Friedman in the "Add-on" and "Add-in" expansion methods. Firstly, the add-on method deals with the process of adding a new structure to the existing unit. These added pieces range from horizontal expansions, like backyard units, to vertical expansions, like the addition of an extra floor on the rooftop, as seen in Figure 2.16. Secondly, the Add-in method is a process that modifies the interior of a shell, favouring unfinished interiors, so that the user can do the interior work themselves (Friedman, 2013). Both of these techniques fall under the category of the *Grow Home* due to their ability to increase space either internally or externally (Friedman, 2001). A benefit of this practice is that it is a more affordable approach that takes advantage of the do-it-yourself trend (Friedman, 2013). Additionally, due to the life extension of the existing structure, the present carbon investment is fully expoited, creating a lower carbon emission when compared to a newly built building (Sturgis, 2017). Finally, in an age where individual customization is crucial, allowing for adaptability over time leaves the door open for more vibrant spaces accommodating the user needs.

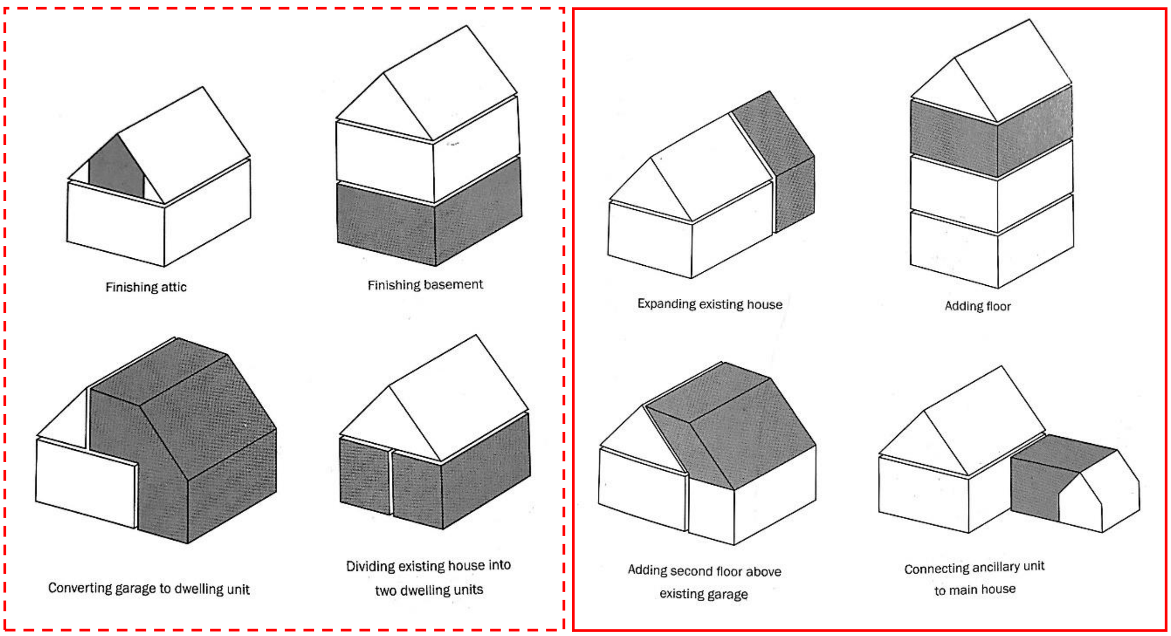


Figure 2.16 Add-in on the left and Add-on expansions on the right. Source: (Friedman, Innovative houses: concepts for sustainable living, 2013, pp. 68-69)

The success in either of these techniques is measured by the way the fixed components are arranged and the technology is used so that they allow for expansion without the need for extensive demolitions or large expenditures that make the process unfeasible (Friedman, 2013). Other authors also suggest that the elements of the house need to be segregated in order to provide enough adaptability among themselves (Habraken, 2002). This is done through the implementation of lateral supports and an open floor plan, or internal supports that are concentrated next to a cluster of wet spaces (Friedman, 2013). Additionally, the form of the spaces needs to be designed based on standard measurements that allow for different configurations of the space (Friedman, 2002).

2.4 Conclusion

The initial aim of this chapter was to understand growth in a holistic way to find new potential areas for development as well as a series of strategies to do it. The conclusions of the work are grouped into the following segments.

First, the research concluded that lost space is the 21st-century source of land for cities. Initiatives, like LCT in Barcelona, portray a new platform for city development in using the gaps we have left over the past years. The actions explained here seek to bring awareness of this projects to architects who believe that there is no longer available space for people in cities. Undeniably, their assumption has led to urban sprawl, damage to the environment, and a lack of affordability and livability in cities, exacerbating the consequences of urbanization. In fact, if the rooftops suitable for this practice are mapped, there would be a new understanding of the extensive area still available and cities could afford to build new housing in centric areas (Maier & Fadel, 2009). Moreover, it is conclusive that the use of such unconventional spaces presented here is reasonable due to the current circumstances of (1) the lack of buildable space, (2) the desire to live in city centres, (3) the gaps in urban codes, (4) and the construction innovations that make this possible. It is important to state that rooftop-lost-space is not understood by this research as a panacea, but rather as a starting point to use up the cities' lost space.

Second, this project found that much of the ideas presented were scattered through a series of literature sources which were disconnected from each other and unlinked to the 21st-century urban situation. The argument constructed suggests that the cities' evolutionary patterns are not only related by their social, economic, and political changes (Arntz, 1998), but that they are also directly connected to the technological advances introduced, which dramatically modify the built environment (Dufaux, 2000). On the one hand, some architects are discussing the introduction of new architecture which focuses on the aesthetic side and not on its full perception. To this investigation, this is a subject that remains highly subjective to the city's particular desires at a certain time and, therefore, it is out of the scope of this research. On the other hand, scholars, like Jacobs and Alexander *et al.* (Alexander, et al., 1977; Jacobs, 1961 [1997]), argue that we also need to expand our discussions to the way we build our cities. So far, the theoretical framework and its relation have been extensively discussed, but the way this gets built remains secondary. Thus, there is a need to create a system which organizes the 'evolutionary perspective' of buildings so that they adapt on time according to its dynamic changes by making use of the space we have at our disposal to refine urbanization problems like housing expansion (Marshall, 2011). Two things were outlined to create "more" space in cities where land is scarce and in high demand:

1. Identify rooftop-lost-space. This is the starting point to induce the use of this scattered landscape and finish building the city.
2. Conquer lost space in the city. At the very least, we should take advantage of new methods of construction, like digital manufacturing and prefabrication. These solutions become the new input that place the 21st-century city apart from previous generations because it eases the building process and empowers developers to build on top of these small lots in a scale that fits the task.

Ultimately, it is clear that the way of production in architecture affects the city including those individuals that shape them. In 2018, the influence of internet-based technologies in everyday-life is radical and marked (*e.g.* Uber: Public transportation; YouTube: Broadcasting; Airbnb: Accommodation. Anderson introduced the theory of the Long Tail as a way to describe the effects of this trend (The long tail, 2006). The internet has made it easier to interconnect people. Now, we can use digital manufacturing systems powered by high-performance prefabrication and the Open Building movement to make a difference in the way we tackle housing growth on a large scale (Habraken, 1962). This trend, defined by Anderson, is already starting to change major industries around the world. Perhaps, architects can make use of this trend in favour of cities and create a technique that is safe to build and that solves the massive problem of housing expansion. Both, lost space and construction innovation, might be the key to integrate a cohesive solution that harvests the stock of rooftop lost-space we have lying in our cities.

The next chapter will explore two contrasting case studies which take place in two very different locations in order to harvest sufficient data and address rooftop housing expansions in low and mid-rise buildings. The methods for each case-study evaluation compromise fieldwork, photo and video documentation, and mapping to create a holistic understanding of the subject.

CHAPTER 3 - CASE STUDIES

3.1 Introduction

The effects of expanding the city to the periphery are well known, and to confront its negative consequences, cities must densify its existent fabric. The usual response to this issue is to tear down existing buildings in order to create new, higher ones. Although this can indeed achieve the goal of vertical densification, it also carries an array of environmental, economic, and urban problems previously identified in this research.

The past five decades sought an urban explosion in the majority of cities around the world (United Nations, 2016). Most of these cities pushed their boundaries to the periphery in search of additional land to develop upon. However, "when it comes to property development in Barcelona, the only way, quite literally, is up," reads an article from a Spanish magazine (Moran, 2015). Barcelona's geographic location is clustered in between the Mediterranean Sea, the Collserola mountainside, and two rivers, making non-vertical expansions problematic. At the same time, these urban-centred spaces are becoming unattainable due to their high cost and the overwhelming amount of architectural heritage within the city.

The standard, low-density development strategies –representative of North America- have been criticized due to the high cost in their infrastructure, their destruction of the natural environment, the high cost of their maintenance, and their extensive use of transportation that, in return, create energy waste and pollution (Birch & Wachter, 2011; Artés, Wadel, & Martí, Vertical Extension and Improving of Existing Buildings, 2017). Public entities around the world have warned about these consequences. In 2010 the European Union and the Ministry of Spanish Housing addressed the need for a compressed city that improves efficiency from the heavy use of cars to the construction and maintenance cost of expanded infrastructure, which also promotes ecological preservation and social inclusion (Libro Blanco de la Sostenibilidad en el Planteamiento Urbanístico Español, 2010). This multiuse urban model where cities are densified vertically creating shorter distances and better access to services has its challenges, but it can be achieved relatively simply when there is abundant land available and a top-down approach. Still, doing it in an already established city with a shortage of space, like Barcelona, is difficult. First, a considerable amount of construction waste and heritage demolition is unavoidable when many of the buildings need to be sacrificed for densification. Additionally, finding open-air lots for development is rare, given that most of them are tiny scattered lots spread across the city (Moudon, 1991). Furthermore, as a consequence of the lack of a market offer, the cost for open-air lots in cities has sky-rocketed during the past decades, making them inaccessible to most people (Friedman, 2013).

Some argue that, in such cases, developers should intervene in the existent built-form in search of a solution. The argument is that the urban, economic, and environmental benefits of repurposing and expanding rooftops outperforms the traditional method of development (Artés, Wadel, & Martí, Vertical Extension and Improving of Existing Buildings, 2017). As a result, initiatives like La Casa por el Tejado (LCT) can recover the embedded energy in the existent building by regenerating it, and reduce costs by using the already-built infrastructure instead of building a new one.

Chapter 3 presents four in-depth case studies of rooftop expansions, each representing its own strategies and processes. The methodology is based on the outlines from the literature, such as adaptable growth and rooftop lost space. The first factor in choosing the case studies was the need for four projects that were in line with the primary research question – specifically, that the projects incorporated a consistent rooftop expansion. The second factor was that there were sufficient primary and secondary sources on the development process to assess. The final factor was that they were as close as possible to make feasible the fieldwork required to collectively asses and create a better understanding of the case studies.

3.2 Methodology

The methodology of this chapter includes literature reviews, documentation, and analyses of these through the use of architectural drawings, photography, and observation. The last three processes were done through fieldwork in Barcelona, and its final result is presented in the following two sections.

Section one begins with a general analysis of LCT's developmental system. It includes the logic behind the structure, its utilities, its vertical circulation, its heritage preservation, its economics, and the social response to the expansions. This opening presents essential information crucial for the understanding of the analysis of the case studies.

Section two follows a five-step process which evaluates each of the four case studies. First, it presents the project description, where introductory information like site location, year of construction, cost, and demography is analyzed. Secondly, it presents the architectural strategies which comprise specific types of construction documentation, including plans and sections. Thirdly, it displays construction strategies which include the typology of construction, the materials, and other particular architectural interventions done to the building as it concerns to circulation, utilities, aesthetics, and heritage conservation. Fourth, it comprises the assessment of particular characteristics of each case study. For example, Case Study 1 (Enric Granados 69) explores environmental strategies. Here, the project is analyzed for its environmental innovations used to minimize its carbon footprint. Case Study 2 (Letamendi 29) shows the refurbishments of an existent building. Here, the case study presents the renovations needed to acquire aerial rights. Case study 3 and 4 (Aragó 259 and Girona 81) involve structural strategies which feature specific types of tactics used to produce rooftop expansions, such as upper slap typology, foundations, bearing walls, among others. Aragó 359 exposes a scenario where the building's overall weight increases, whereas Girona 81 portrays a scenario where it decreases. Finally, each project is summarized in a conclusion that correlates and contrasts factors to be identified for further exploration in the following section.

The work of La Casa por el Tejado (LCT) was selected as the primary source of this research due to its extensive practice in this specific field of construction in the past decade. It is important to mention that rooftop expansions are not new as they have been part of formal and informal architecture for centuries. However, LCT has built a particular structure that enables them to industrialize the process of rooftop expansions building and makes an unusual case for a scalable citydevelopment system.

The project began as a Ph.D. research project, at the University Ramón Llull in Barcelona, with the aim to preserve the city by filling up the empty pockets of rooftop space in Spain (Interiores Minimalistas, 2016). Therefore, LCT focuses solely on rooftop expansions on developed housing across Barcelona, San Sebastian, Pamplona, and Madrid. In fact, in an article by *Artés et al.*, the authors show seven samples already completed by LCT (Vertical Extension and Improving of Existing Buildings, 2017). They also outline relevant processes and conceptual frameworks of the work developed, both of which are assessed in this chapter.

Case study approaches tend to include many different examples in order to compare them and draw interpretations based on the similarities and the differences among the projects. This research uses La Casa por el Tejado as the primary source but selects 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. Hence, although the projects presented here may be from the same developer, they undertake the rooftop expansions through different methods. The sample projects chosen from LCT were based according to the following limitations with the goal of providing enough variety in the case studies.

- Located in Barcelona.
- Differ in the size of expansion (small and medium scale).
- Differ in structural and architectural strategies.

The first case study is Aragó 359, an ambitious 300 m^2 rooftop expansion of six new housing units distributed in two added floors, finished in May 2015. The second case study is Enric Granados 69, a 200 m^2 wood-structure expansion where two new floors and housing units were added. The third case study is Letamendi 29, a 200 m^2 expansion where one new floor was added and the existent top floor was refurbished. The last case study is Girona 81, the smallest expansion at 100 m^2, with one added floor and one housing unit (Figure 3.1).

These analyses aim to evaluate the current state of the ARE technique, and outline problems and patterns to develop specific guidelines for this type of constructions. This research will focus mainly on architectural and construction techniques used in these case studies. However, if necessary, it will introduce concepts of sustainability and a social dimension, which are essential to propose the guidelines required to tap into this devalued space and empower the city to finish building its existent fabric.

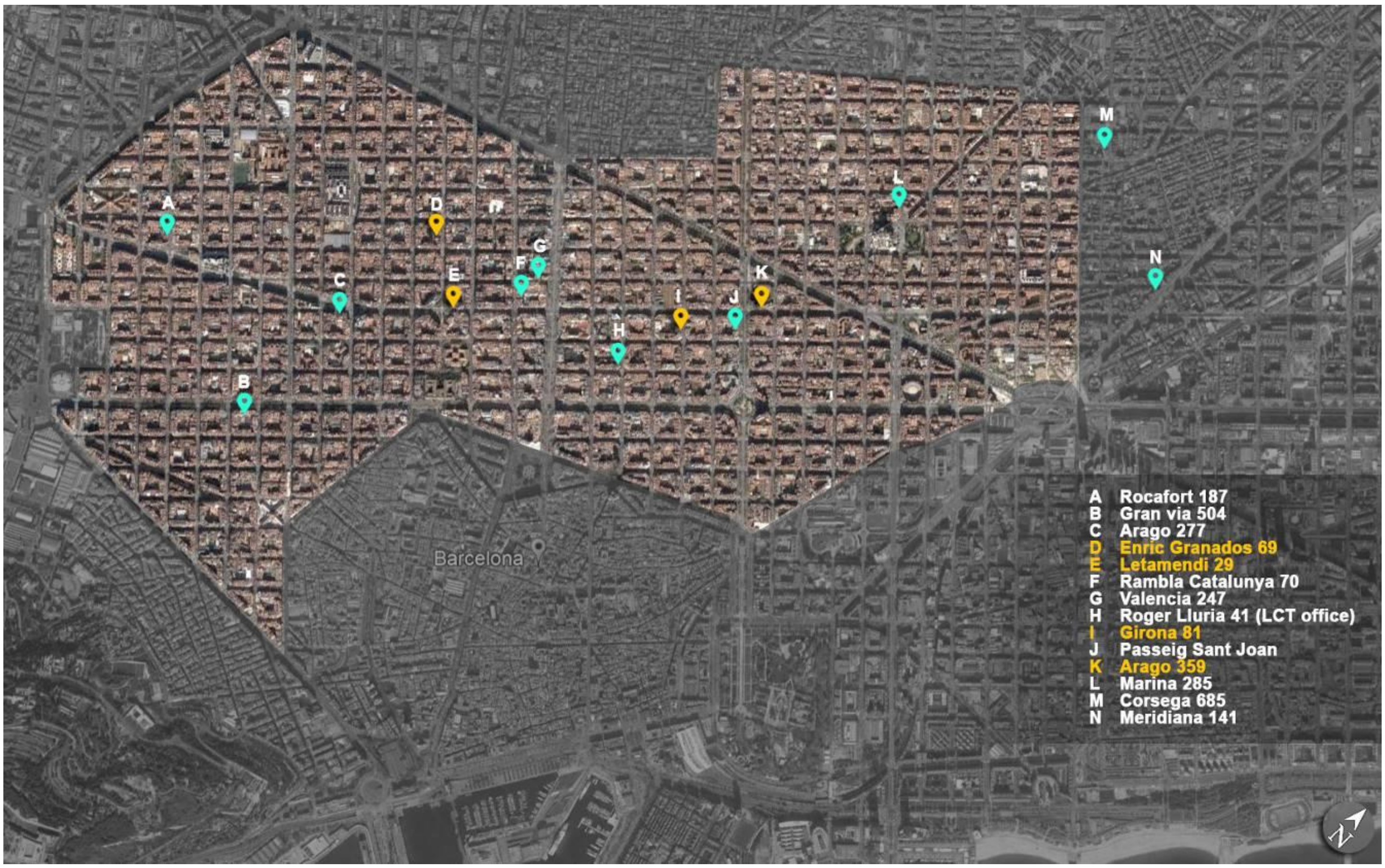


Figure 3.1 2018 localization of LCT projects in Barcelona's Eixample. The yellow corresponds to the four case studies selected for this report. Aerial view retrieved from Google Earth, 2018

3.3 Why Barcelona?

Figure 3.2 Proposed plan of the Eixample (Colored version published by Francesc Carreras Candi to Geografia General de Catalunya, 1912) by Ildefons Cerdá, 1858.

After the elimination of the city walls in 1841 and the introduction of Cerda's Eixample in 1858 (Figure 3.2), an era of robust building codes and regulations emerged to increase the quality of the built form in Barcelona (Paricio, 2001). Along with the expansion of these policies, new masonry technologies for industrial quicklime, the mechanization of brick production, and improved workmanship emerged. As masonry construction was established, its load-bearing and interlocking walls became a standard system that featured increased structure optimization, permitting to bear more weight than before (Artés, Wadel, & Martí, 2017). Following these construction advances, the mid-19th-century sought an increase in vertical growth due to the incrementing absence of large empty lots. Thus, urban planners and policymakers outlined the Land Plot Ordinance (1860 to 1890) that set regulations for a maximum height of 20m per building. At the time, construction loans used to construct housing as a commercial product were not frequent and, therefore, property speculation did not occur as it does now. People built housing for personal purposes, with each building meeting the requirements of the owner at the time of construction. For example, if an individual needed a workshop on the ground floor and three more upper floors for housing, that's what the person built. Thus, growing to the maximum height was unnecessary for some people, given that the upper floors were the least appreciated. This worldview led to the occupancy of most lots, but also led to the creation of an uneven collection of buildings with residual buildable capacity that remains to this day. As consequence, The City Block Ordinance (1891 to 1941) increased the land occupation to 73.6%, and the depth of the buildings to no more than 24.24m. Moreover, in 1942, building heights increased to 24.4m and patio buildings to a maximum height of 5.5m. However, in 1976, the Metropolitan General Plan Ordinance lowered these heights to 20.75m and 4.5m correspondingly.

The previous analysis was a condensed introduction to Barcelona's city development over the past centuries. It is possible to draw a direct relationship to Arntz's, Potsdam's and Dufaux's work in Montreal, where the constant argument is that the socio-political or technological novelties in the cities affect profoundly the way in which they are built (Arntz, 1998; Dufaux, 2000). For example, in Barcelona, it was the introduction of a new typology of masonry construction; in Montreal, it was the introduction of new construction techniques by the British, such as the flat roofs; and in Potsdam, it was the dissolution of the monarchy which brought a laissez-faire practice to the city. Barcelona has collected a particular unfinished-landscape which is an opportunity in itself. The combination of these dynamic roof variations with its unused buildable space on top of buildings, and the unnecessary and heavy structures product of previous construction technologies, could be an occasion to redesign and conquer the city, in an effort to create a more habitable space within the already built city. The historical pattern shows that, with the introduction of technology, a new era of city-development can emerge. In Barcelona's 19th-century it was new masonry techniques, the question is, what next technology will disrupt city development as it is now?

3.4 La Casa por el Tejado

Figure 3.3 LCT's 'rooftop-lost-space' map in Barcelona's Eixample. The red dots represent the buildings with remaining buildable space, and the outlined dots represent the ones already built as of June 6, 2018. Adapted by the author using the base research-map from: (Artés, Wadel, & Martí, Vertical Extension and Improving of Existing Buildings, 2017)

La Casa for el Tejado (LCT) is a company located in Barcelona that entertains a new understanding of buildings. They see buildings as unfinished-artifacts, which could be densified without demolishing existing ones (Schmidt & Austin, 2016). LCT was established in 2012, after the economic crisis of 2008, to create new housing developments. Artés, the architect and founder of LCT, developed the concept of using the remaining buildable spaces as part of his doctoral studies[1] at the School of Engineering and Architecture La Salle, at the University Ramón Llull, in Barcelona (Interiores Minimalistas, 2016).

In his research, Artés argued for a city that extends vertically, taking advantage of the already built infrastructure. His research identified the buildings that had remaining buildable space and compiled a detailed study of each unit, including ownership, expansion area, and technical difficulties, among other characteristics (Moran, 2015). This proved to be a phenomenon present, not only in Barcelona, but also in other major cities covered in his study, such as Madrid, San Sebastian, and Pamplona. Thus, in the last decade, LCT has capitalized on rooftop lost space and used it as an opportunity for housing development in

[1] The 4-year-research mapped the buildings that do not meet the maximum FAR and building height. The research discovered 800,000 square meters of available extension-space within the current urban code of Barcelona. Source: La Casa por el Tejado website (LCT)

their building of prefabricated penthouses on the roofs of Barcelona. His research remarked the extensive stock of rooftop-lost-space (Figure 3.3) in one of the most desired areas of the city: the Eixample of Barcelona, including La Dreta de l'Eixample, also known as the Quadrat d´Or (Golden Square). The former was established by wealthy families of the late 19th and early 20th-century Barcelona. The Golden Square presents an incredible stock of houses produced by legendary architects, such as Lluís Domènech i Montaner, Josep Puig i Cadafalch and Antoni Gaudí. A walk through the area is enough to recognize that it is an exclusive zone where the past lavish architecture coexists with contemporary indulgence, which is seen in both the old buildings and the new luxury stores that have opened to meet the needs of the new Catalan society.

LCT's idea of building over roofs correlates with the Social and Economic Committee and the Ministry of Spanish Housing's initiative to create compact cities which make the best out of their existent infrastructure. The purpose of this initiative consists on reducing environmental impact, avoiding social segregation, and improving economic efficiency by using the existing buildings and refurbishing their architectural heritage. Thus, the idea to tackle lost space in the city has been developed for decades under various forms with rooftop-lost-space being one of them. LCT's approach contrasts with the traditional techniques of repurposing existent buildings because it incorporates a combination of construction technologies, like wood prefabrication, light-weight materials, and environmental techniques, as an effort to overtake the undervalued rooftops (Artés, Wadel, & Martí, Vertical Extension and Improving of Existing Buildings, 2017).

The Add-on expansion strategy uses a Tetris-like system of modules (Friedman, 2001). These are prefabricated in a factory using steel, timber, or a mixture of both, as construction material. Prefabricating the modules allows for quick, precise, low weight, and tailor-made modules, with simultaneous on-site and off-site work. LCT follows a precise approach that ensures all additions do not exceed the bylaw limitations, such as setbacks, maximum height, and the allowed Floor Area Ratio (FAR), while preserving the structure safe for vertical development (Sullivan J. , 2011).

3.4.1 Development process

In basic terms, LCT's applied methodology is based on a two-way intervention (Figure 3.4) that consists on refurbishing the existing buildings, preserving their existent heritage, and updating them to new living standards, in exchange for the remaining buildable space which LCT uses to develop housing.

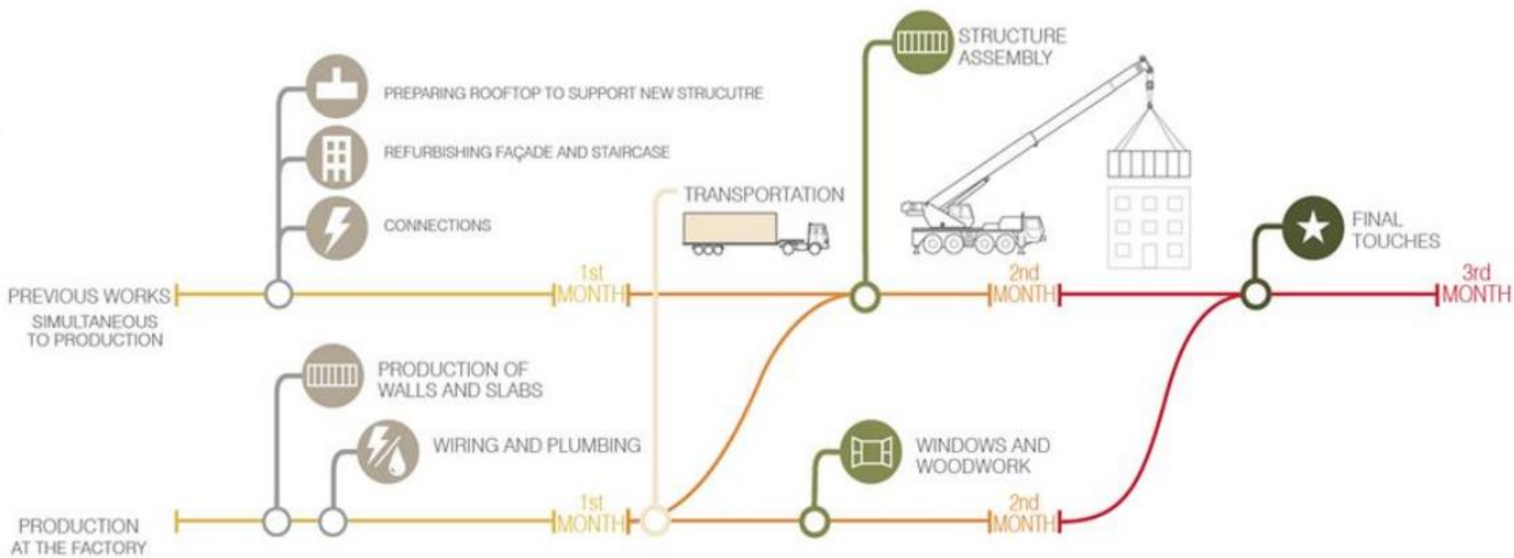


Figure 3.4 Enric Granados 69 simultaneous sequence of building intervention. Diagram author: Miba architects.

The complete process can be divided into five phases (Artés, Wadel, & Martí, Vertical Extension and Improving of Existing Buildings, 2017):

The first phase involves the study of the building's history, its relationship with the environment, the architectural style, and its structural and technical components. At the same time, LCT identifies the elements that could be replaced to extract weight with the new low-weight expansion in order to preserve the same loads that the structure can bear without retrofitting much of it.

In the second phase, the architects and outsourcing professionals elaborate a Building Evaluation Report which summarizes the results of the study and the possible approaches for the intervention. At this stage, the development team values the price of the aerial rights and meets with the co-owners of the building to buy it, allowing LCT to use the above space to use the buildable space. As mentioned before, LCT pays for this right by refurbishing the existing building. If there is money left after the intervention, it is paid in cash to each co-owner in a corresponding ratio. This strategy has proved to be efficient because the whole building is preserved, the inhabitants improve their living conditions, and the city gets is renovated.

In the third phase, architects make specific observations on the refurbishment. They study which utilities must be modified or replaced or if the structure must be reinforced, as well as the condition of the bearing walls, the façades, and the woodwork of common areas.

Throughout the fourth phase, observations are made about the vertical extension. The team analyzes the social, economic, and environmental impact of the proposed intervention within the existent context of the building and its surroundings. This includes, not only the aesthetic conditions, but also the environmental strategies that could be incorporated to reach a better level of sustainability that benefits the city, the existent building, and the future expansion.

Finally, the fifth phase corresponds to the construction of the modules in a factory and the refurbishment of the building, which take place simultaneously. After the construction of the extension is done in the factory, the panels and/or modules are transported to the building and fitted on site in 24 hours. Subsequently, the finishes are made, including windows and interior woodwork (Artés, Wadel, & Martí, 2017). The average construction time of the process can be outlined as follows:

1. Prefabrication of the new modules: Three months.
2. Building improvements: Three months.
3. Installation: One day or, in the most complex situations, two days maximum.
4. Finishes: Three months after the installation of the modules on the rooftop.

3.4.2 Structural strategies

Before considering a rooftop expansion, a particular question stands out: will these century-old buildings withstand the weight of the new units? LCT's leading solution is to strive for removing as much weight as possible before investing in retrofitting their core structures. These buildings "…tend to carry various additional structures, such as storerooms and laundry outhouses, and the roof construction itself known as Cubierta Catalana, a weighty brick construction" (Moran, 2015). In average, the projects done by LCT remove approximately 1000 kg/m^2 and add just 300 kg/m^2 (Moran, 2015). To confirm these estimates, LCT does an extensive structural study to reiterate that there is no need for reinforcement.

This tactic is essential because it is easier and cheaper to do than retrofitting the whole structure. In the beginning, the project based its structural efforts on removing a common item in buildings from the early 20th-century Eixample: the *Catalan Roof (*

Figure 3.5). This roof is made of a double brick-slab designed to have a ventilated air chamber that traps rain and heat as well as providing a walkable deck on the top floor. 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 (Figure 3.6).

Figure 3.5 Picture of a model representing the Catalan Roof. Source: Universidad Politécnica de Madrid (2015, April 9). Aula-museo de construcción. ETSEM. DCAC. Retrieved June 8, 2018, from Flickr Oficial de la Universidad Politécnica de Madrid: https://www.flickr.com/photos/universidadpolitecnica/17860736216/in/photostream/

Figure 3.6 Image of a demolition of a Catalan roof. Source: Aparajadores Mataró, Retrived June 8, 2018, from https://www.aparejadoresmataro.com/ayudas-a-la-rehabilitacion-energetica/rehabilitacion-integral-modificacion-cubierta-catalana-1/

Besides this structure, LCT also aims to reduce the following items to take off as much weight as possible before making any modifications:

- *Trasteros* or small brick storage-rooms located on the rooftop.
- Brick laundry outhouses located on the rooftop.
- Non-structural vaulted ceilings located on the existent apartments.
- Non-load-bearing walls from the existent apartments. These are changed from brick to drywall system.
- Rooftop exits made out of brick.

The load replacement allows them to not intervene in the main structure of the building and to make the structural terms of the project feasible without major expenses. In some cases, and only if necessary, the following structural reinforcements are done:

1. Enlarge the brick foundations through manual excavation. This is also done to verify the condition of the brick foundations before the intervention.
2. Improve the continuity of the structure when there is a sudden change in the columns or beams. This includes repairs in cracks or small defects that the structure may have.
3. Make an exoskeleton encompassing the new pillars and foundations that run independently from the existent structure. This happens only when the work is unusually large, as it is in a project with three added floors, six restored floors, and a new garden rooftop, currently under development in Pamplona.

Moreover, the anchoring system (Figure 3.7 and Figure 3.8) is made out of a chained beam with steel plates, which are embedded using screws and welded to the modules. When the span of the chained beam that sits on top of the building's bearing walls is too wide, the upper slab structure also incorporates a series of transversal steel beams to support the module evenly.

Figure 3.7 Images of the anchoring system at the rooftop expansion Roger Lluria 41 (LCT central office). The brick wall at the bottom is the old bearing wall; then, a chained concrete beam which is merged with transversal steel beams screwed. These two level and support the modules that sit above it as it can be seen in the black and red structure. May 29, 2018.

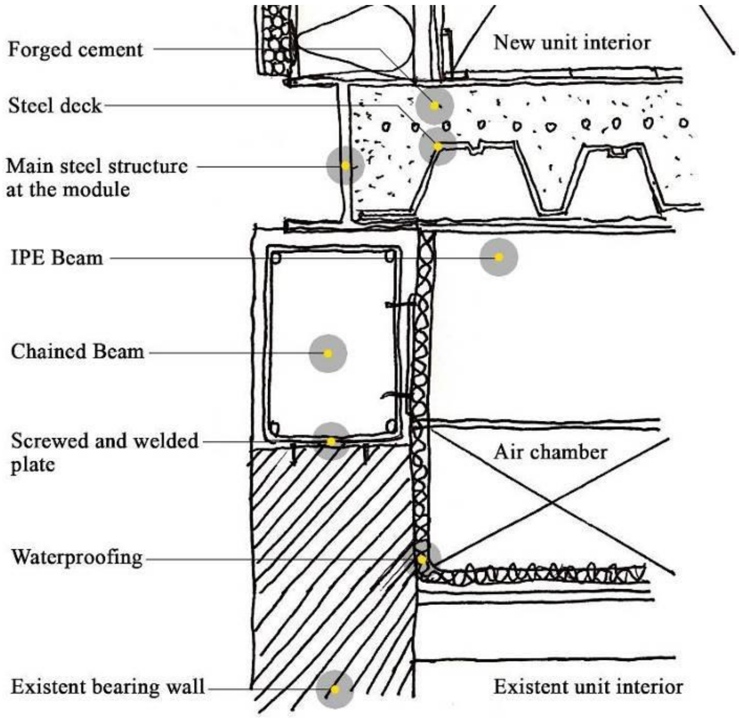


Figure 3.8 A sketch developed by the author representing the anchoring system between the building and module.

The walls of the modules are composed by (from exterior to the interior) a layer of plaster for exteriors with the required mesh, followed by a layer of 1 inch of extruded polystyrene, then a layer of ISOPAN Sandwich Panel (Insulation), a layer of drywall, and a final layer of plaster for the interior finish (Figure 3.9).

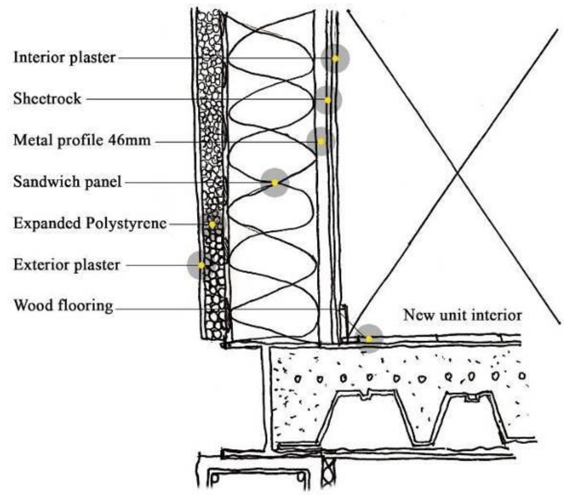


Figure 3.9 Left: Image of an exterior wall under construction at Gava's factory. Right: Sketch developed by the author with all the elements from the wall. May 30, 2018

As it will be noted in the following case studies, the majority of buildings do not require major structural reinforcements. Even in the worst scenario (Aragó 359), where the additions make the load higher than the previous one, there is no need for major reinforcements. However, if the building is in a condition that requires reinforcements for several structural elements like foundations, bearing wall, wood beams, or top slab, the project is discarded altogether.

3.4.3 Utilities and vertical circulation strategies

When expanding vertically, utilities are another challenge. This is the case for various buildings in North and South America, which have pipelines in hidden ducts embedded in their walls. However, the old buildings in which LCT intervenes in Barcelona have *Patilejos*, or small open-air patios that allow the networks to go down on the building's façade. As it is for most decisions in these processes, everything depends on the state of the networks in place.

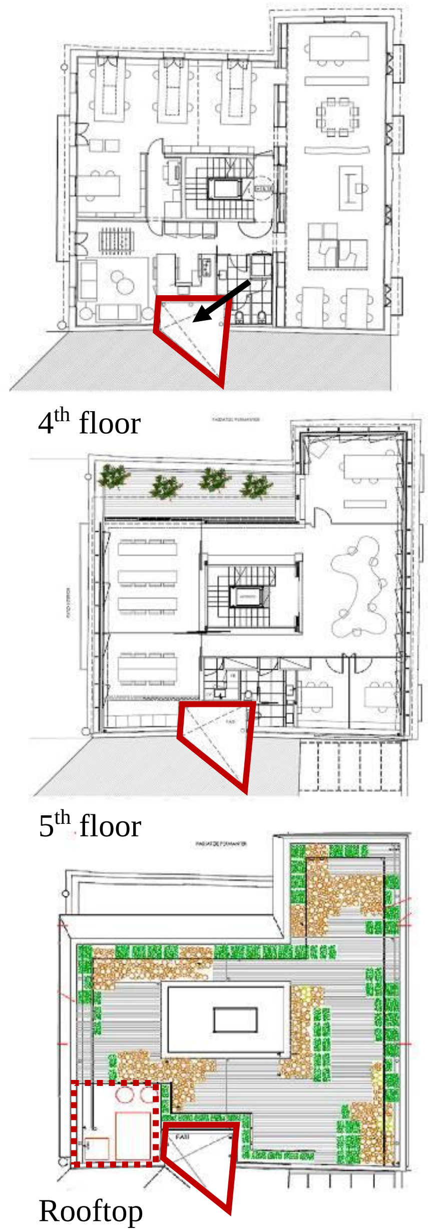


Figure 3.10 Left: Image from the bathroom to the Patilejo at Roger Lluria 47. May 28, 2018. Right: floor plans of Roger Lluria 47 indicating the patilejo (pictured on the left) where the hydraulic, electric and gas utilities are extended. The dotted square indicates the location on the rooftop of all the equipment part of the utilities like heat pumps and kitchen extractors. Source of the drawings: Interiores minimalistas (Nueva Sede en Barcelona de la Casa por el Tejado, 2016)

3.4.3.1 Hydraulic network

In most cases, there is an effort to reuse the building's existing hydraulic network in but, before doing it, an extensive review is made as well as the required reparations. As for the capacity of the pipes, the existent pipe has to provide enough flow capacity. If not, it is replaced by one of higher capacity that connects all the networks from the other apartments. It is important to mention that one of the most significant challenges in this typology of buildings is the connection to the city's sewer system, since some of these buildings are not properly connected and excavations must be made to fix this.

Figure 3.11 View from the air chamber between the new modules at Aragó 277 and the existent building. It illustrates the hydraulic network that comes from the modules and goes to the Patilejo on the far left. May 30, 2018.

3.4.3.2 Electrical networks

The electric cables are passed through square channels that also run through the patilejos. Regardless, it is necessary to make improvements to the main electrical box (also called general protection box). This means installing a new box with a higher capacity so that it resists the charge of the new penthouse and the new devices, like heat pumps, intercom, or elevators that are going to be installed.

Figure 3.12 Left old electric box. Right: Updated set of boxes with a higher electric capacity. Pictures taken at Aragó 277. May 29, 2018

3.4.3.3 Gas networks

Gas network extensions are not necessary since the appliances only use electric outlets.

3.4.3.4 Vertical circulation

Vertical circulation corresponds to the communal staircase and elevator. The staircase is extended using low-weight steel plates which follow the same path as the existent staircase. The roof of the staircase is removed to expand and connect the new modules to it. This void is covered with a temporary structure to keep water out of the building's interior while the construction takes place. The elevator depends on existence of a previous one on site. If the building did not have a lift before, the refurbishments include a small unit which fits in the staircase's central void. The refurbishments demand the creation of an elevator pit and small foundations for steel pillars, which sizes depends on the lift specifications. However, if there is an elevator in place, the cabin is fully restored and the mechanics are updated to increase its height capacity and to improve energy consumption. In general, the void and the elevator car are reused, but the system and the structure are updated to a newer one in order to raise its capacity and reach higher levels.

Figure 3.13 Upper left: Temporary structure and installation of the new elevator's mechanics. Bottom left: New steel flight of stairs being installed. Right: Elevator ground floor entrance inside the void of the staircase. Pictures captured at Valencia 247, May 29 2018.

Finally, utilities and structural components like foundations are particularly hard to visualize without doing invasive explorations. The best tactic is to rely on information from previously surveyed buildings of the same time and area, and which have similar architectural and structural characteristics. Despite the established processes described in the Development Process (Page 40) and further detailed in Girona 81's case study (Page 106), the method could be defined as *logistics on the fly* given that the path for building these items is not precisely defined and improvisation has to take place.

3.4.4 Heritage preservation

Rooftops expansion are not new to Barcelona. They were promoted extensively in the 1960’s by Barcelona’s mayor at the time, Josep Maria Porcioneles, as an alternative for the rapid city-growth at the time. However, a recent newspaper article from El Periódico recalled the high criticism against these (See Figure 3.14). “The strategy got out of hands, expanding the courtyard houses illegally up to two stories and creating disastrous projects that overhang the 19th-century buildings. In 1971 the major was forced to remove the policy” (Andreas González, 2014). This coincided with the high peak in real estate speculation of 1958, Eixample. In face of this, the reaction from Barcelona’s citizens was to criticize these developments given that most of them were developed without clear restrictions to protect the city’s heritage. Due to this precedent, many locals recognize LCT’s work as a new type of “Porciolismo”.

Figure 3.14 These images (taken in the same blocks where LCT has expansions) represent the vast number 'Porcioles Hats' developed through the 60's in the Eixample. They are easy to identify since most of them have a signature step back structure and a prominent change in architectural style. The condition at the moment of construction was to build until the maximum permitted height and then to follow a 45° angle from the top of the building to create the setbacks as seen in the images. May 31, 2018

Certainly, this is an issue that needs to be prevented by authorities. The city's heritage must be preserved but it must not impede the development of construction innovations. Precise and eloquent rules should be followed that allow to build new space in urban areas while protecting the set of old structures. The point of view of the authorities, represented by Deputy Head of Urban Planning for Barcelona, Antonio Vives, is that "[…] the rooftops of Barcelona are effectively a hidden façade, and the transformation of these into usable space, particularly if it is green, makes the city more livable for its inhabitants." (Moran, 2015). This statement shows the particular interest of the current governmental entities to work with companies like LCT to develop these expansions.

Furthermore, LCT is obliged to follow existing regulations and to mediate with the heritage authorities what they can and cannot remove from the building. When the proposal is presented to the authorities, LCT has to consider landmarks and/or urban conditions that exist in the surrounding areas of the expansion. These may include respecting special setback-lines, or the conservation of specific architectural elements in the façade, like colour pallets and carpentry, etc. It is important to note that the Eixample has a particular set of bylaws due to its location and history. Regulations are strict as it regards to the building envelope and occupation limits but, in most cases, they allow for a feasible expansion. If the bylaws are beyond restrictive, LCT dismisses the project and continues onto another building.

Finally, as part of the permits required, LCT pays municipal construction taxes which are used by the city to improve the neighbourhood infrastructure and support new inhabitants. It is important to note that most of their projects not only fulfill all the energy-bylaws requirements, but they go above and beyond current standards.

3.4.5 Economic approach

LCT's economic model provides renovation work and money in exchange for the rights to build additional stories. The renovations are agreed upon negotiation with the building owners and they depend on the conditions of each building. These usually include communal areas like the façade restoration, woodwork, entrances, hall retrofit, new telecom system, and the installation of a new lift. In case these renovations do not meet the price of the aerial rights, a monetary offer is made on top of the renovations which is divided among the owners correspondingly.

To assign the cost of the aerial rights, LCT calculates the estimated market value of the penthouse minus:

- The direct cost of construction of the expansion.
- The direct cost of the building improvements.
- The interest on the money invested (around 12%).
- The cost of structural, environmental, and utilities' studies.
- Taxes.
- Profit.

The result of the calculation is the cost of aerial rights.

The development of the economic strategy is crucial because it increases the overall state of the building and, therefore, the value of the existent and new units. Additionally, the building's heritage is amortized, and the cost of running the building is lowered for its inhabitants.

3.4.6 Social response

The building owners' initial reaction to the proposal is of skepticism because it seems too good to be true. "Imagine a building with no lift, a dilapidated façade, and a bunch of neighbours who can't agree on carrying out essential maintenance. Along comes a company that offers to fix it all up at their own expense and give each owner a financial payout too" (Moran, 2015) . Being dubious is a natural reaction. However, Joseph, a neighbour of one of these expansions, outlined that the main struggle is valuing aerial rights and agreeing on a fair monetary compensation for them. Joseph's building agreed on LCT's development proposal after the city hall's Inspección Técnica de Edificios or ITE (Building Technical Inspection) was performed. The official survey, done every few years to buildings over 45 years old, expressed serious repairs had to be done for safe habitability. Thus, LCT's proposal seemed like the right opportunity to carry out these repairs. Joseph added: "I am not expecting much in monetary compensation, but I do expect high-quality work to be carried out on the building" (Moran, 2015).

It is smart for LCT to target buildings that are already in need of repair to get their extra buildable space. Furthermore, LCT's offer is also beneficial to the inhabitants because they get their building fully renovated and their monetary compensation. It is a win-win situation.

3.4.7 Final remarks

According to Artés *et al.*, seven projects were finished during the project's first three years of operation, from 2012 to 2015 (Vertical Extension and Improving of Existing Buildings, 2017). Furthermore, a total of 1,380m^2 of housing units was developed using the technique described above. Some of their LCT's renewed rooftops retail for over € 700,000 ($ 1,066,045)[2] for a 106 m^2 apartment (Enric Granados 69), while the renting price of an average apartment goes for as little as €1,200 ($ 1,827) per month, making their high value undeniable. Furthermore, an economics article on La Vanguardia newspaper marks LCT's annual revenue at € 17 million ($ 25.8 million) in 2017. This enabled them to build a new €6 million ($ 9.1 million) 10,000m^2 factory with an annual prefabrication capacity of 60,000m^2 (equivalent to 600 housing units a year), in the industrial cluster of Consorci de la Zona Franca, close to Barcelona. Additionally, this commercial expansion will enhance the other two factories LCT already has: "Gavá", with an annual prefabrication capacity of 35,000 m^2, and "Cornellá de Llobregat", with one of 20,000 m^2. Artés, CEO of LCT, remarked that the objective of this company expansion is to get closer to the annual production capacity of 115,000m^2 by 2019, which amounts to 1,200 housing units per year (Sandri, 2017).

[2] All the conversion rates are done at the current exchange rate of 1 EUR = $1.52255. Retrieved from www.xe.com re, June 5, 2018.

Figure 3.15 Interior view of Gava's factory. In the image, several projects under different stages of prefabrication are seen. On the far left it is possible to visualize how the stacked modules used to check dimensions and manufacturing details before they land on the rooftop. May 30, 2018

Figure 3.16 Interior view from the back of Gava's factory. May 30, 2018

3.5 CASE STUDY 1: ENRIC GRANADOS 69

3.5.1 Project description

Figure 3.17 Frontal façade of Enric Granados 69. May 28, 2018

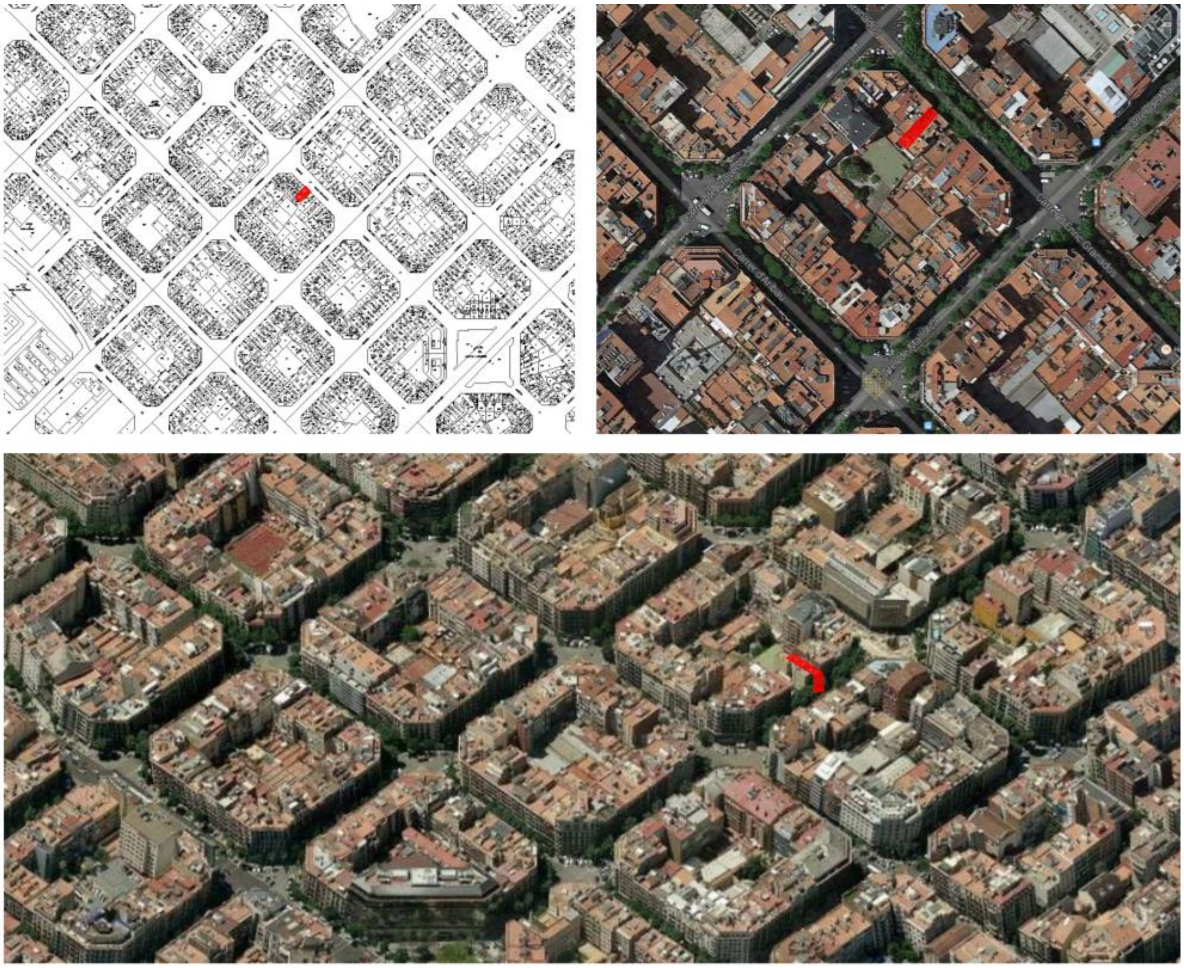


Figure 3.18 Enric Granados site plan. Source: Casa Ático (Dossier Enric Granados 69, 2015)

Close to the location of the previous case, is Enric Granados 69. The middle-block is approximately 164 m^2 with an elongated shape. It is located in front of the busy streets of Carrer d'Enric Granados (See Figure 3.20) and Carrer de la Provença, and it is only 500 mt (7 min. walking distance) to the Diagonal Metro Station.

Apt Number	Area	Terrace	Bedrooms	Bathrooms
Ático 1	86,94 m2	14,97 m2	2	2
4-1	102,31 m2	7,53 m2	3	2

Figure 3.19 Enric Granados 69's table of areas. Adapted by the author from: www.lacasaporeltejado.eu/wp-content/uploads/2016/02/InterEmpresa-22012016-baja.pdf

Figure 3.20 Streetscape in front of Enric Granados 69. Source: Casa Ático (Dossier Enric Granados 69, 2015)

The project was developed by LCT and designed by the architectural firm MIBA. As it is discussed in the following sections, this project is the most advanced regarding environmental sustainability. This was designed and tested in cooperation with LCT's partner and environmental consultant Societat Orgánica. Further, Atres 80 was commissioned as the construction company, and Novadomus habitat as the manufacturer of the mass timber panels used in this extension (Casa Atico, 2018).

The prior multifamily building had four floors in total, with a store on its ground level. Each of the existing housing floors had an individual dwelling per level. The two floors added by LCT make up two dwellings of 161m^2 of net area. As it can be seen in Figure 3.17 and Figure 3.21, the frontal façade of the vertical extensions is aligned with the planes and a pallet of materials inspired on the building below. This particular detail was done to enhance the old façade of the building facing Eric Granados, improving the urban landscape of the area. The rear façade of the extension is also aligned on the fourth-floor, but the penthouse's façade was moved back 1.7mt to create an open terrace which overlooks the inner courtyard of the block (Delgado, 2016).

Furthermore, the prefabricated units have an expanded interior courtyard that allows for natural cross-ventilation and natural light. Finally, this plan also allowed for a private open-air space for the owners.

Figure 3.21 Left: Render of front façade. Right: Render of rear façade. Source: Casa Atico (Dossier Enric Granados 69, 2015)

3.5.1.1 Demography

From a demographic standpoint, it was not possible to determine the profile of the user. Regardless, according to a Construction 21's report, the upper unit was inhabited, but the lower unit was vacant at the moment of publication (European Union - IEE project, 2016). The existent owner reported to be "…pleased to have found a home of this type, of which there are no more in the city, similar to a house because it has a terrace, sun, and views, but with the wealth of being part of a historic building in a central urban area, with all amenities within walking distance." (Delgado, 2016).

3.5.1.2 Cost

According to the same publication, the total cost of the project, including the added modules and the required refurbishments, was € 402,027 ($ 614,211), including the € 4,200 ($ 6,415) from the costs of structural studies (Delgado, 2016). Additionally, Casa Ático published the selling price of Enric Granados’106.48 mt^2 first-floor unit at € 740,000 ($ 1,130,730), valuing the square meter at € 6,949 or $ 10,618 (Casa Atico, 2018).

3.5.2 Architectural strategies

Figure 3.22 Left: Front façade. Right: Rear façade. Source: Casa Atico (Dossier Enric Granados 69, 2015)

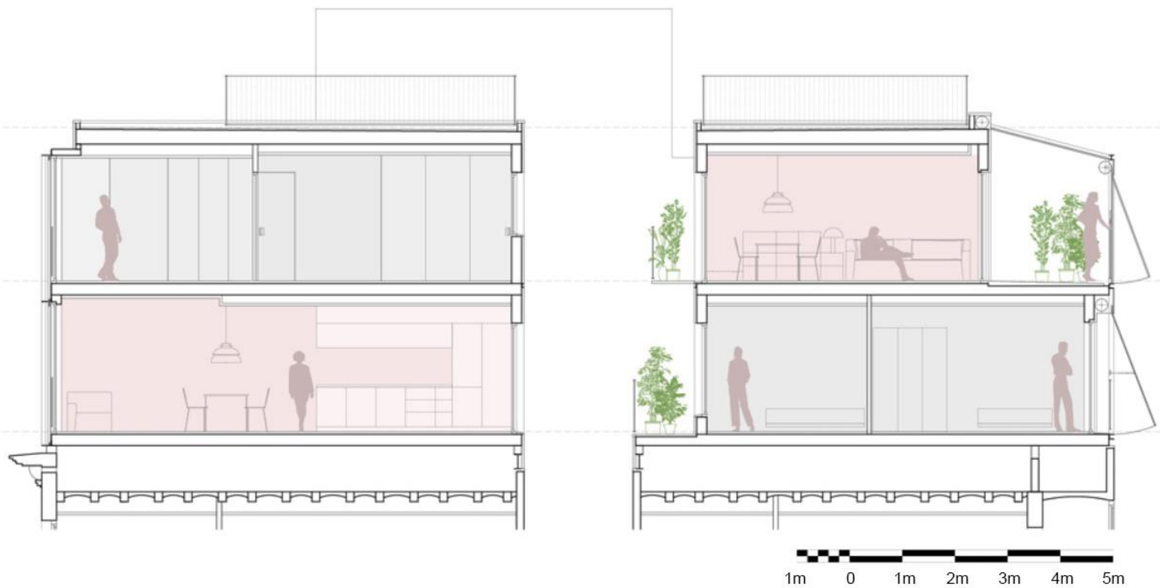


Figure 3.23 Cross section of the project. Grey color represents private areas and red areas represents social areas. Source: (Miba Architects Website, 2016)

Figure 3.24 Floor plan of the two-level expansion. Source: (Miba Architects Website, 2016)

3.5.3 Construction strategies

Enric Granados 69 is the first project developed by LCT using "[…] 2D assembly light laminated wood frame system, and semi-passive house insulation, achieving an A level in energy efficiency rates" (Miba, 2016).

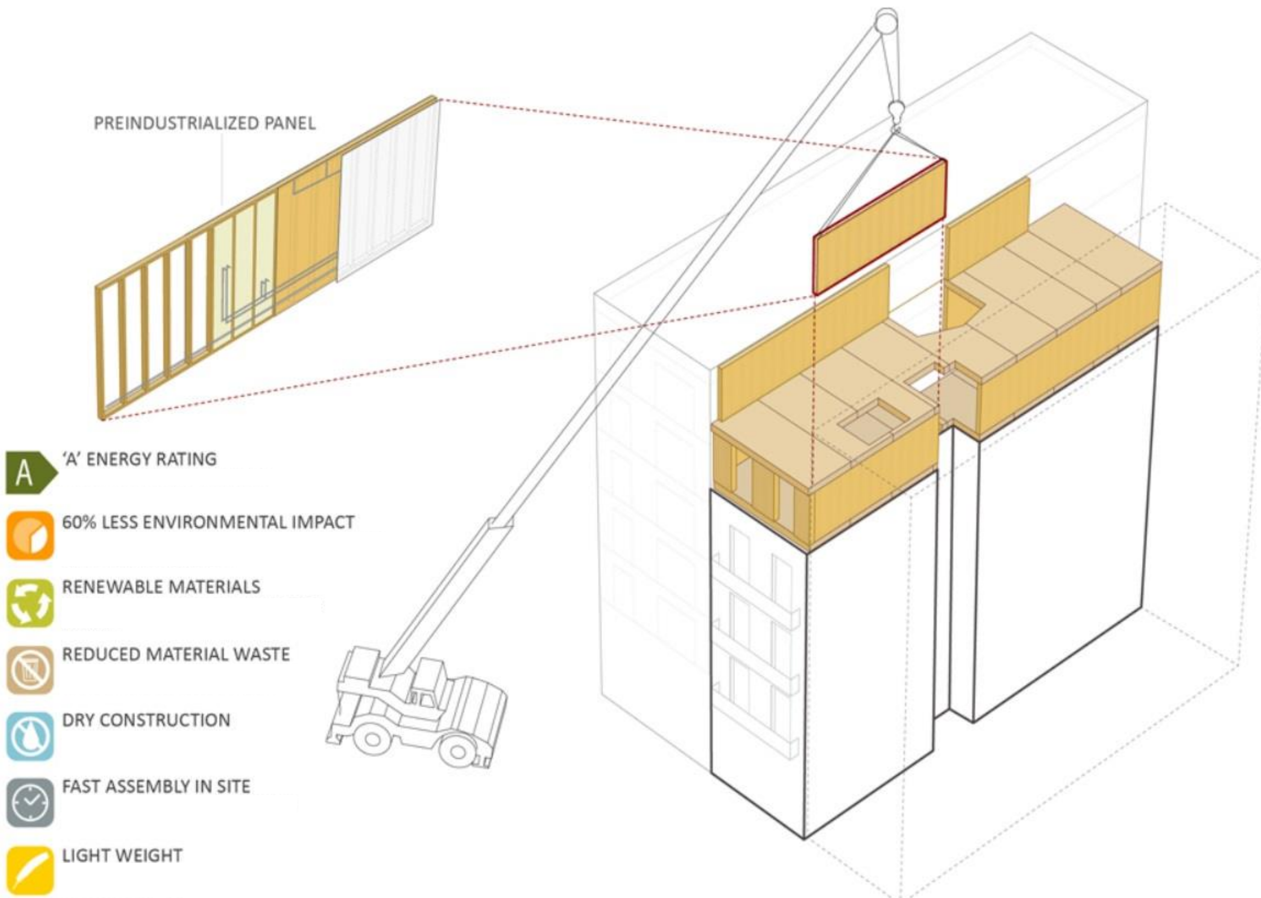


Figure 3.25 Diagram of construction system. Installation of the prefabricated mass wooden panels. Source: (Miba Architects Website, 2016)

The prefabricated wood panels used for the bearing walls and the slabs were manufactured by Novadomus habitat, and they were put in place in only two days using a crane system. Thus, the construction of the expansion is not only highly industrialized but also environmentally sustainable. The construction on-site happens in separate sets, as seen in Figure 3.25. First, the industrialized wooden panels are used to erect the slabs and the walls.

The rest of the components, such as windows, façades, and finishes, arrive prefabricated and are lifted with a crane in single sets. In the following months, these elements are installed in their correspondent location.

Enric Granados' envelop is built using prefabricated wooden panels. However, the frontal façade comprehends a "ventilated façade with expanded metal panels of transparent red". This system allowed the project to seamlessly integrate into the street's pallet with a contemporary view. The interior façade holds a less high-tech approach with cedar wood louvres retractable enclosures (Delgado, 2016).

Similarl to the other case studies, LCT used a system of reorganization of loads were they replace the overweight objects on the top slab with lighter finishes and with the new prefabricated unit. In this particular case, the modules were not 3D steel prism, but 2D mass wooden panels. Although the manufacturers Novadomus habitat mention a "Nucleus Klimark System", it was impossible to find its technical specifications (Novadomus Habitat, 2018). Nevertheless, the author addressed a system called die.modulfabrik, from the Austrian company KLH Massivholz, that resembles the one used at Enric Granados 69.

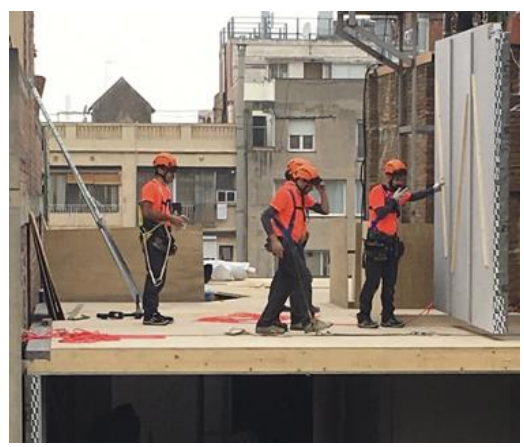


Figure 3.26 Left: Location of Novadomus' prefabricated slabs. Right: View of the walls being installed. Source LCT (Enric Granados 69, Clase Energética A, 2015)

Figure 3.27 Wooden panels fabricated by Novadomus.. Source LCT (Enric Granados 69, Clase Energética A, 2015)

Figure 3.28 On-site installation of the mass wooden panels developed by Novadomus. Source: LCT (Enric Granados 69, Clase Energética A, 2015)

The panels are enclosed by three different layers of hardwood sheets which differ in structural and density levels. Their dimensions vary from 2.42 to 2.95mt in width, to 3 to 8mt in length. At 506.83 Kg/m^2, these panels are also lighter when compared to traditional concrete and steel constructions, which go from 2,000 to 15,000 Kg/m^2 (Wadel, 2009).

Besides the mass wood panels, two other materials were used in this project. First, steel and wood composite beams with epoxy resins (Figure 3.29) were used to protect the steel from fire heating and to provide better flexural strength to the mass wooden panels (Delgado, 2016). Second, a layer of Fermacell Aestuve (Figure 3.30) was added as a fire insulator and interior finish, providing a dry solution with the thickness needed (Delgado, 2016).

Figure 3.29 Steel and wood structural beams. Source: LCT (Enric Granados 69, Clase Energética A, 2015)

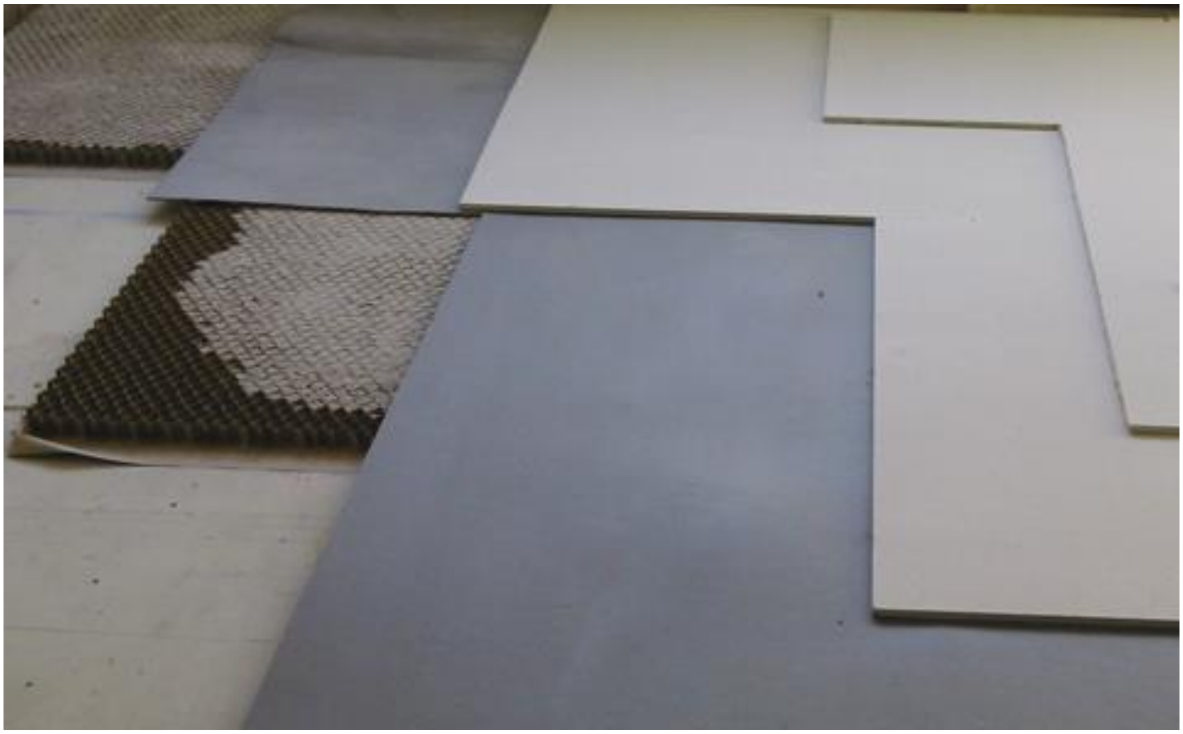


Figure 3.30 Complementary acoustic and fire insulation Fermacell Aestuve: Gravel board and plasterboard. Source: LCT (Enric Granados 69, Clase Energética A, 2015)

3.5.4 Environmental strategies

From the materials used to the construction and design, which combined passive strategies creating a highly sustainable and lightweight development, Enric Granados 69 stands above all of its sibling extensions in its performance on environmental sustainability.

The roof of the new penthouse holds only the required telecommunications facilities, air extractors, and a solar-powered water-heater. The rest of the space is covered with crushed pine to decrease the heat island effect.

Testing the environmental standing of these projects is challenging in itself because it defers significantly from traditional projects. Thus, Societá Organica developed a tool called SENDA which is used by LCT in projects located in Barcelona, Madrid, Pamplona, and Bilbao. The tool was developed for testing this specific type of construction (new rooftop expansions) and it complies with the requirements of the environmental certification (Certificación Energética de Edifícios) by the Spain Ministry of Industry and Tourism. The tool ensures that all of its additions hold environmentally-sustainable construction parameters. For example, the tool analyzes effects in “biodiversity, consumption of non-renewable energy, deterioration of drinking water, impacts caused by materials, and generation of pollutants” (Delgado, 2016). As it was addressed in the same report by Delgado, SENDA has shown remarkable distinctions when set side by side with the standard way of building housing.

The environmental results of Enric Granados 69 intervention are summarized in the following table:

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%

Figure 3.31 Summary of environmental strategies at Enric Granados 69. Adapted by the author from: “Vertical Extension and Improving of Existing Buildings” (Artés, Wadel, & Martí, 2017).

3.5.5 Conclusion

Enric Granados 69 is a particular project among these case studies due to its environmental accomplishments. First, expanding vertically is sustainable in itself because the existent building is restored and preserved by giving it a new life which fits today’s living standards. Furthermore, due to the high levels of insulation, the vertical extension preserves the energy from one of the most significant sources of energy loss in buildings, roofs. Thus, it improves the energy consumption to the apartments below.

Secondly, creating a specific tool for environmental analysis shows LCT’s efforts to create environmentally sustainable developments. Despite its achievements, it is important to test this expansion with a tool developed by a company that has no conflict of interest with LCT.

Another significant factor to consider is the high cost of these units which, by default, are not within the reach of most people. Moreover, if the market value is not controlled and the price keeps increasing, it may lead to social issues, like gentrification where the original inhabitants are forced to move due to the high cost of living.

Despite all the criticism, Enric Granados 69's environmental and construction innovation remains remarkable. Mass plywood panels and steel-wood beams could be an innovative solution that fits the restrictions posed by tall constructions and sustainable development. Its environmentally friendly, lightweight, prefabricated, dry construction outperforms many past technologies which did not allow for vertical growth. Perhaps, as the mass wood panel technology evolves and becomes a more standard construction system, it becomes an accessible way to preform vertical expansions in existent buildings.

3.6 CASE STUDY 2: LETAMENDI 29

3.6.1 Project description

Figure 3.32 Frontal view of Letamendi 29. May 28, 2018

Placa del Dr. Letamendi 29 is located in the Eixample of Barcelona, just in front of the well-known Letamendi Plaza. Various media sources show the prefab floors being placed in July 2014, which is why it is estimated that the unit was finished in late-2014 (Artés, Montaje módulos Letamendi 29, 2014). The one-floor extension sits on top of a neoclassic six-floor building. The irregular shape of the existent building is extraordinary, making this project puzzling not only as a rooftop expansion, but as any type of architectural development. The architects aimed for a project that recreates the attributes of the old building and creates a piece that adds to the composition of the building cornice (Casa Atico, 2018). However, the rooftop expansion contrasts drastically with the existent building's shape and materials palette when compared to projects like Enric Granados whose expansion seamlessly integrate with the building.

Figure 3.33 Letamendi 29 site plan. Source: Casa Ático (Dossier Letamendi 29, 2015)

This project is part of the first cohort of rooftop expansions developed by LCT. Therefore, it is highly documented by both public media and themselves.

Apt Number	Area	Terrace	Bedrooms	Bathrooms
Ático 1	83,85 m^2	9,46 m2 / 3,37 m^2	2	2
Ático 2	91,15 m^2	10,80 m2 / 3,30 m^2	2	2
4-1	105,54 m^2	0 / 3,36 + 2,48 m^2	3	2
4-2	107,37 m^2	0 / 3,36 + 2,48 m^2	2	2

Figure 3.34 Letamendi 29's table of areas. Adapted by the author from Casa Ático Website (Dossier Letamendi 29, 2015)

The intervention was divided into two parts: a renovation of the existent fifth floor, and the extension of a new prefabricated one. The fourth floor has two apartment units. The first apartment (4-1) has three bedrooms and two bathrooms with a total area of 105.54m^2, plus a terrace space of 5.84m^2. The second (4-2) one has two bedrooms and two bathrooms, with a slightly higher enclosed area of 107.37 m^2 and the same terrace space (5.84m^2). On the fifth floor (added expansion), the project has two housing units; both of them with two bedrooms, two bathrooms, and a large private terrace. The first one, Ático 1, has 83.85m^2 of enclosed space and a total open-air area of 12.83m^2. The second unit, Ático 2, is slightly bigger at 91.15m^2 and an overall open-air area of 14.1m^2.

Figure 3.35 Interior view of Ático 1. Source: LCT Website (Mejora y Completamiento del Edificio - C/ Letamendi 29, 2015)

Figure 3.36 Terrace view of Ático 1. Source: LCT Website (Mejora y Completamiento del Edificio - C/ Letamendi 29, 2015)

Figure 3.37 Rooftop view, facing the inner courtyard. Source: LCT Website (Mejora y Completamiento del Edificio - C/ Letamendi 29, 2015)

3.6.1.1 Demography

It was not possible to determine the demographics of its inhabitants. However, one of the new owners of Letamendi 29 was interviewed on TV. He was a 30-40-year-old, single man who works as a furniture curator at a design store close in Barcelona. He described his first impression of the apartment in saying that he did not notice that it was an extension until he was told about the construction system. The individual also described the nice view, natural ventilation, and sun exposure in the apartment, as well as its central and convenient location (TVE Channel, 2015).

3.6.1.2 Cost

The cost of the units was not documented in any of the published sources, though one could expect a luxury real-estate price like most of LCT's projects in that area. Furthermore, the finishes applied to unit one appear to be upscale, which accord with LCT's target buyer. The uniqueness of the apartment is worth mentioning as it is rare to find a new penthouse sitting on top of a century-old building.

As a reference, the Enric Granados 69 106.48 m^2 unit, only three blocks away from Letamendi 29, was listed at € 740,000 ($ 1,129,682), with a square meter of € 6,949.66 or $10,600 (Casa Atico, 2018). However, it is important to note that Enric Granados uses an outstanding eco-friendly technology which possibly elevates the overall price. It is impossible to determine the cost per unit, but a mark-down of 25% is a safe estimate to get the overall price. This would leave Letamendi 29's square meter at € 5,212.2 ($ 7,950) and a valuation for its biggest apartment of 91.15m^2 (Ático 2ª), at € 475,092 ($ 724,678).

3.6.2 Architectural strategies

Figure 3.38 Left: Frontal elevation. Right: Rear elevation. Source: Garcia, Javier (Proyecto de Ejecucion Remonta e Incorporacion de Ascensor, Letamendi 29, 2014)

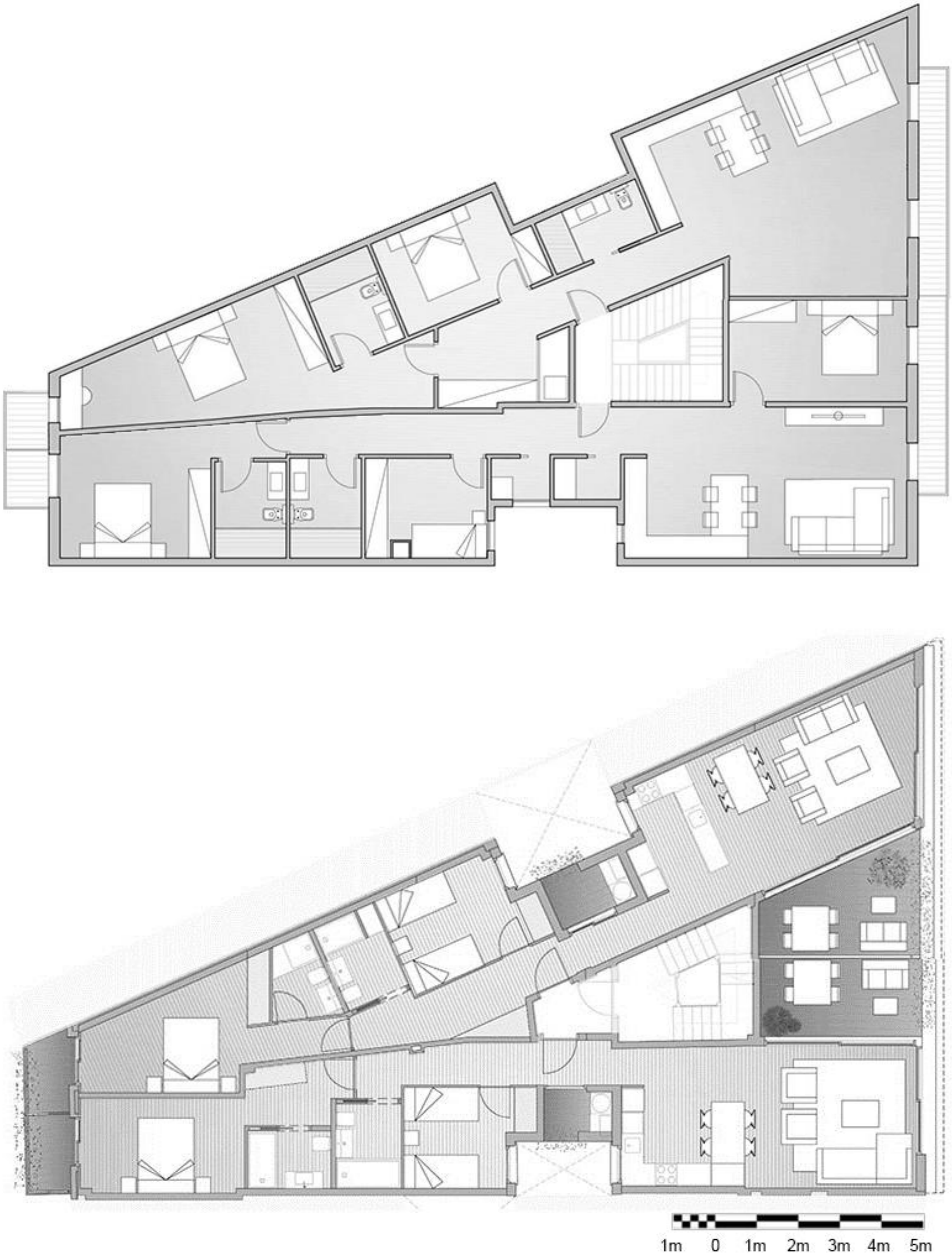


Figure 3.39 Top: Floor plan of the existent refurbished fifth floor. Bottom: Floor plan of the added expansion Source: Casa Ático Website (Dossier Letamendi 29, 2015)

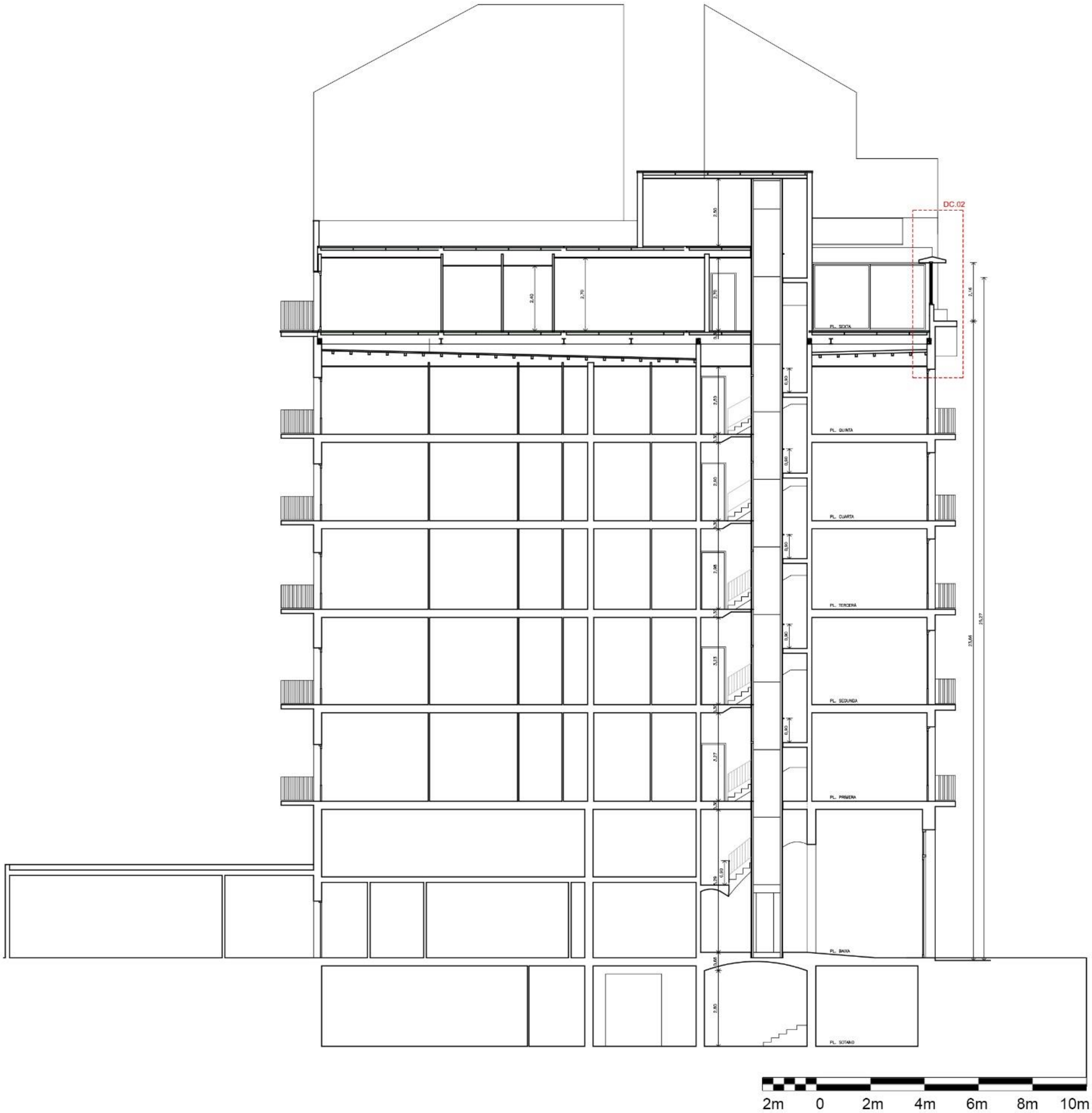


Figure 3.40 Cross section of the building including the added elevation See Figure 3.36 for the outlined-red detail of the connection between the existing building and the added module. Source: Garcia, Javier (Proyecto de Ejecucion Remonta e Incorporacion de Ascensor, Letamendi 29, 2014)

3.6.3 Construction strategies

Like many of LCT earlier projects, the units in this case study were prefabricated using a three dimensional steel structure. The main steel frame is enclosed on the sides with an insulated wall panel. The modules are composed (from the outside to the inside) by a layer of mineral mortar, then a sandwich panel with sides of thermal insulation, followed by an inner space that serves to pass the electrical lines and, finally, a sheetrock layer on top of which the desired finish is applied.

Figure 3.41 Images of the process of transportation and installation of Letamendi 29's prefabricated modules. Source: LCT & Perea, Rafael (Áticos Nuevos en Finca Antiguas, 2014)

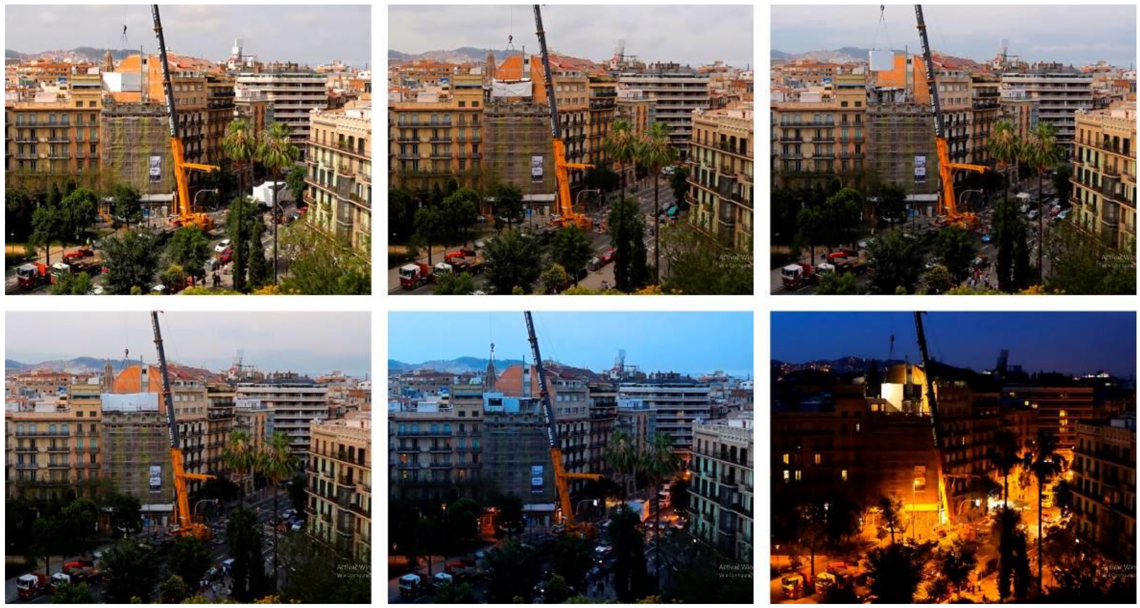


Figure 3.42 Images from the time-lapse of installation at Placa del Doctor Letamendi 29. Adapted by the author from the video by Artes. (Montaje módulos Letamendi 29, 2014)

Letamendi 29 uses LCT's standard structural strategy. The project eliminates or improves unnecessary existent structures from the rooftop of the building as well as from the top layer of the existent roof (Moran, 2015). Then, 1/8 of the weight of the new expansion is calculated and added to the existent weight of the building to test its effects on its different structural components, and, if required, a new reinforcement is designed.

Compared to Aragó 359, Letamendi 29 did not require major structural reinforcements because it did not add as much stress on the existent structure.

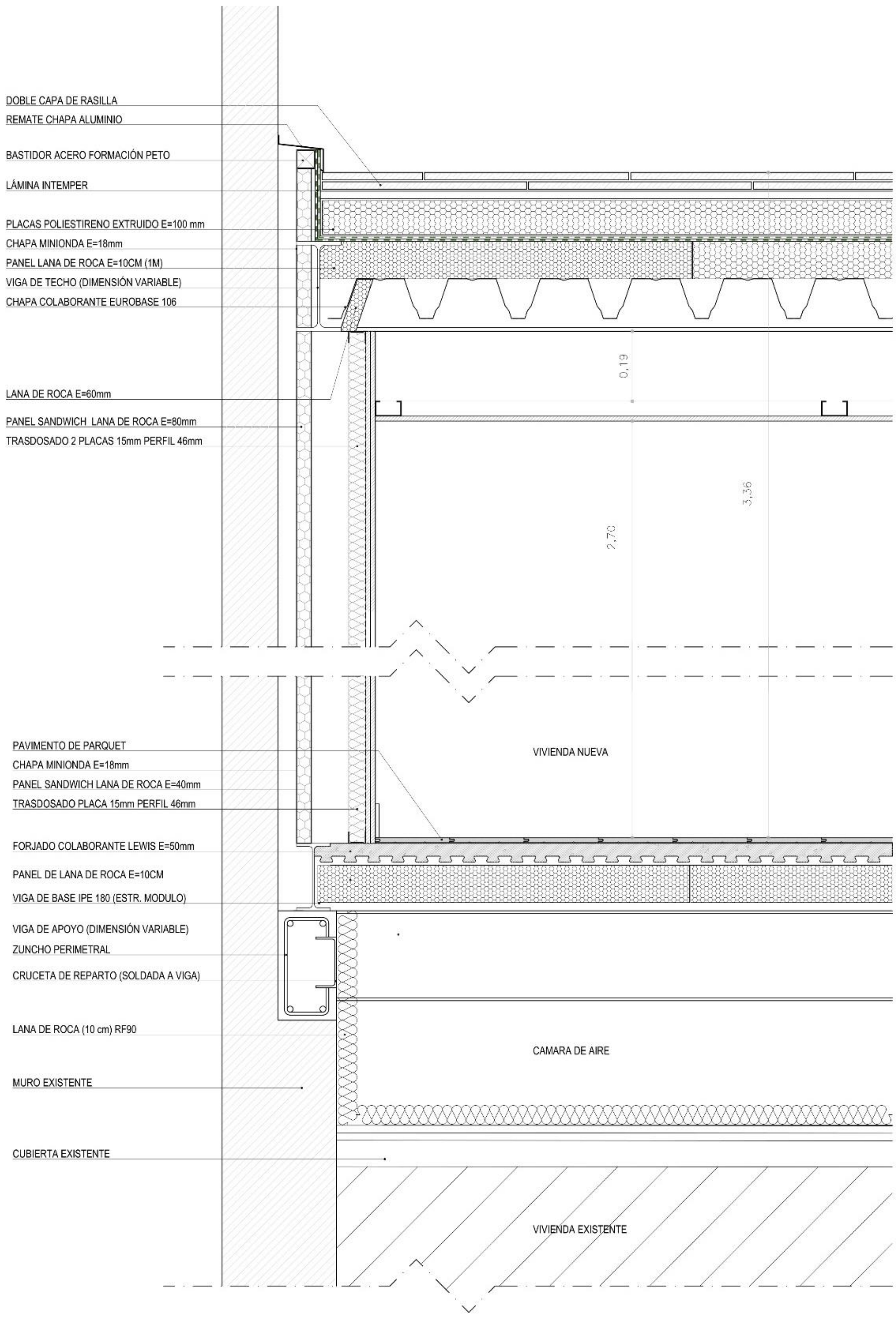


Figure 3.43 Detailed cross-section of the connection between the existent building and the added module at Letamendi 29. Source: Garcia, Javier (Proyecto de Ejecucion Remonta e Incorporacion de Ascensor, Letamendi 29, 2014)

3.6.4 Building refurbishment strategies

As it was mentioned before, Letamendi 29 was intervened almost entirely. The refurbishments include not only the standard common areas, but also interior work of the apartments. This practice enabled LCT to perform a comprehensive restoration of the building, including: functionality, structural improvements, heritage conservation, improved accessibility, improvements in energy consumption, and a decrease on its communal expenses (Artés, Wadel, & Martí, 2017). At the same time, the construction team had the opportunity to make a detailed survey of the building to have a better picture of its state and use it as an indicator of the surrounding buildings' state.

The following table is a summary of the renovations performed at Placa del Doctor Letamendi 29:

	Before	After
Functionality: Existing flats, Terrace	Four homes in a state of deterioration with deficiencies, obsolete installations, and high side walls.	All homes refurbished and in use. New penthouses, green roof, reduced side walls.
Accessibility: Vertical Mobility, Communication	The stairway was the only way to ascend (5 floors). Deficient telecommunication installation	Renovated stairway and incorporation of an elevator. New intercom system and telecommunication installation.
Safety: Structures, Installation	Slabs between floors with affected materials. Residual water pipes with cracks and leaks.	Repair and reinforcement of slab and load-bearing walls. Replacement of pipes and new connections.
Heritage; Main Façade, Interior Spaces	Deteriorated, discoloured, or missing closures. Walls, ceilings, and carpentry in poor conditions or modified from their original state.	Refurbishment of walls, carpentry, and decorative elements. Restoration of walls and woodwork to their original state.
Sustainability: Existing Building, New penthouses	Skin without insulation; inefficient installations; lack of comfort.	Insulation in façades, efficient climate control, and better waterproofing. Superior thermal quality in walls and woodwork
Economy: Current Expenses, Revaluation	High expending, but insufficient to maintain and refurbish the building.	Minor due to the new inhabitants of flats and penthouses. Estimation: 35% decrease for sale and 70% for rental.

Figure 3.44 Summary of refurbishments at Letamendi 29. Adapted from (Artés, Wadel, & Martí, Vertical Extension and Improving of Existing Buildings, 2017)

3.6.5 Conclusion

As we have seen in the previous analysis, Letamendi 29 is a project that successfully conquered a piece of rooftop-lost-space that would have otherwise remained unoccupied in a city where the demand for housing keeps rising. Design-wise, Letamendi 29 had a standard procedure in which the extension loads were balanced with existent structures that can be removed. Additionally, as compared with the other case studies, Letamendi 29 outperforms the others in its building preservation level. This tactic is particularly crucial, not only because the project creates a new demand for this type of developments, but also because it ensures that buildings update to current living standards. In some cases, improving the building infrastructure increases the cost of acquisition and even makes the development process of the building more complicated. However, the improvements made in accessibility, decrease in energy consumption, and preservation of architectural heritage improved the overall valuation of the building and city. In Letamendi 29's case, LCT estimates a 35% increase in sale price and a 70% increase of the housing units (Artés, Wadel, & Martí, 2017). Thus, it is a win-win situation for all: the existent neighbours, the new inhabitants, the developer, and the city.

Admittedly, there are lots of disagreements within the community about aesthetically contrasting projects like Letamendi 29. On the one hand, the exaltation among some Barceloneses might be due to the uncontrolled development of rooftops in the 1970s in Barcelona's Eixample, which destroyed the urban landscape with "monstrous" rooftops. (Andreas González, 2014). On the other hand, some developers argue that replicating century-old buildings with current technology does not make sense and might result in an almost cartoon-like city, foreign to the 21st-century reality. Both of these positions have valid arguments. The decision of how this is handled lies in the governmental entities that control architectural heritage and city expansion. These two institutions need to balance heritage and no-heritage bylaws to preserve the city's architectural landscape while also allowing for innovation on city development.

3.7 CASE STUDY 3: ARAGÓ 359

3.7.1 Project description

Figure 3.45 Aragó 359 before and after the intervention. Left picture source: (Casa Ático, 2015) Right picture by the author. May 29, 2018

The project was developed by La Casa por el Tejado (LCT) and designed by Tesgat Architects (Ártes' architectural firm) in 2014. It has a total area of 551.79m^2, divided in 449.04 m^2 of private area and 102.75m^2 of balconies and terraces. Located in the right-centric area of Eixample in Barcelona, the extension lies on top of a neoclassic building in front of Carrer d´Aragó 359. The architectural goal was to develop an integrated solution between the existent four-stories building and the proposed two new levels (Casa Atico, 2018).

Figure 3.46 Aragó 359 site plan. Source: (Casa Ático, Aragó 359 dossier, 2015)

Figure 3.47 Aragó 359 plot location. Source: Google Earth, 2017

As it can be seeing in Figure 3.45, the new fifth floor takes four flats (5-1, 5-2, 5-3 and 5-4), each with average area of 60 m^2, a single room and one bathroom. The sixth floor comprehends two new units (Ático 2 and Ático 1) with an average area of 100 m^2. One apartment comes with two bedrooms and the other one with three (Casa Atico, 2018).

Apt Number	Area	Terrace	Bedrooms	Bathrooms
Ático 1	103,82 m^2	38,06 m2 / 8,47 m^2	3	2
Ático 2	85,78 m^2	38,20 m2 / 4,91 m^2	2	2
5-1	73,22 m^2	0 / 8,34 m^2	2	2
5-2	54,06 m^2	0	1	1
5-3	77,07 m^2	0	2	2
5-4	55,14 m^2	0 / 4,77 m^2	1	1

Figure 3.48 Enric Granados 69's table of areas. Adapted by the author from: Casa Ático (Dossier Aragó 359, 2015)

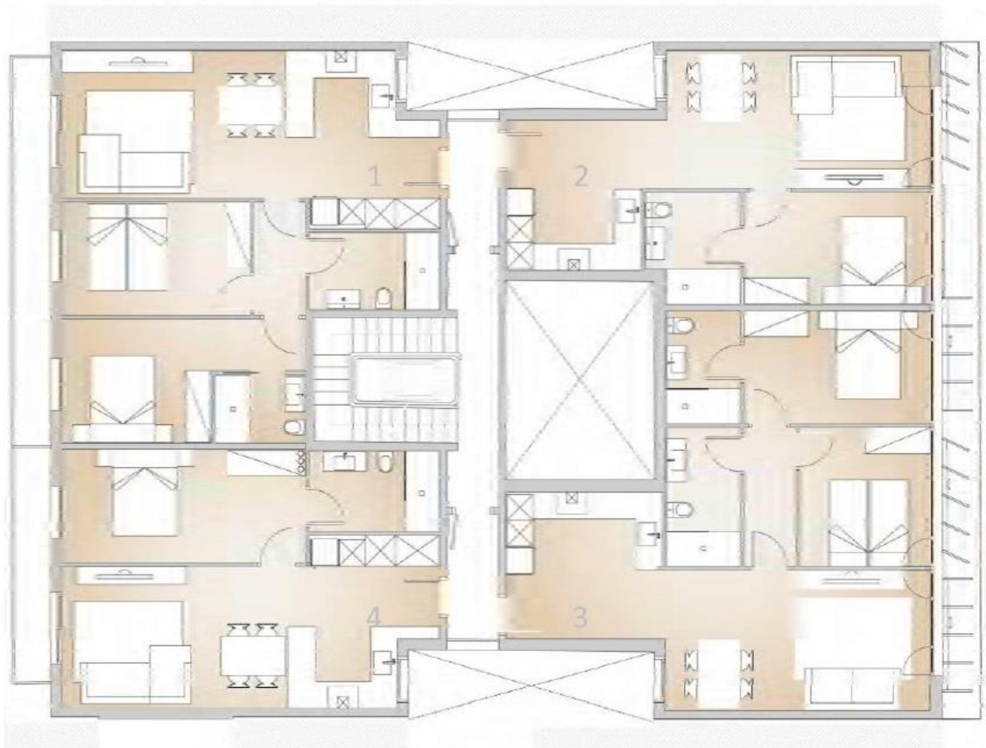
The project is in a prestigious area next to the newly renovated pedestrian avenue Passeig de Saint Joan, in between Arc de Trionf and Ciutadella Street. The project was finished in May 2015.

3.7.1.1 Cost

According to LCT's commercial branch, Casa Ático, Aragó 359's starting price was € 317,000 ($ 485,673). If divided by the smallest apartment without balconies in the project (54.06 m^2), the selling price per square meter would be € 5,863 ($ 8,983). It is said that the developers argued for the selling price of their apartments to be below the market price at the moment of listing (Casa Atico, 2015). They made clear that this was due to their particular construction method that outperformed traditional real estate standards, thus, lowering the overall cost of production, allowing them to compete with a better price (Casa Atico, 2018). However, these claims are not confirmed.

3.7.2 Architectural strategies

Figure 3.49 Left: Frontal façade. Right: Rear façade. Source: Casa Ático Website, (Aragó 359 dossier, 2015.)



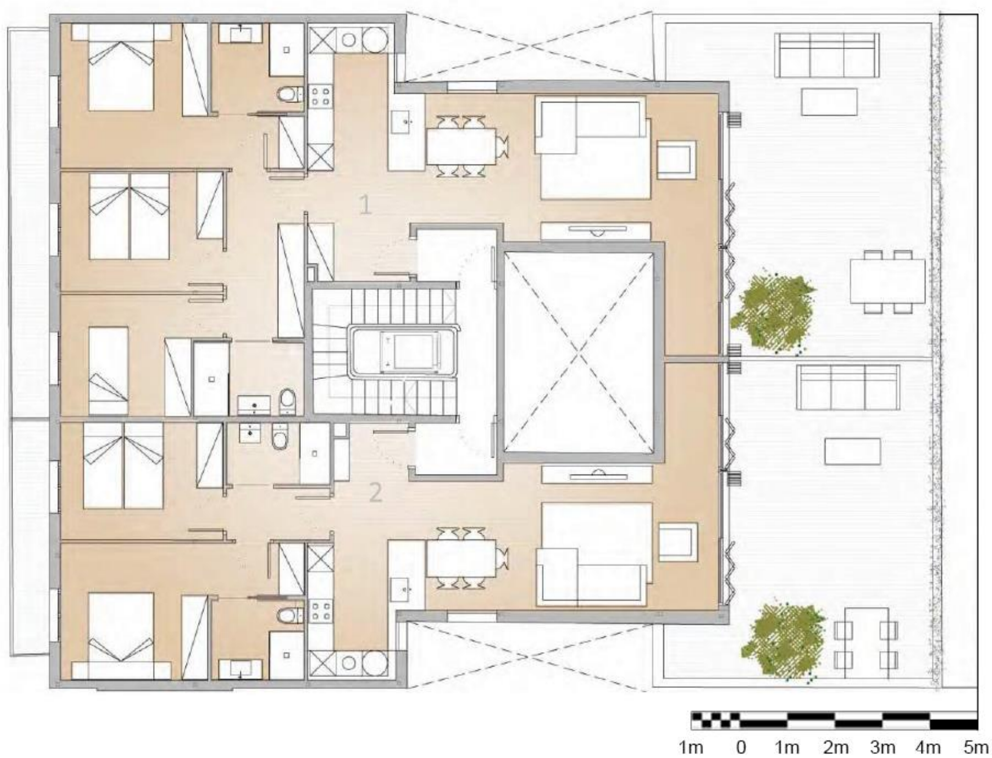


Figure 3.50 Above: Floor plan of the fifth-floor extension Right: Floor plan of the sixth-floor extension Source: Casa Ático, Aragó 359 dossier, 2015.

3.7.3 Construction strategies

As all of LCT's projects, Aragó 359 was built using off-site, prefab techniques. This tactic is essential for the projects' success because it lowers the overall time of construction., thus, not affecting neighbours' daily activities.

Figure 3.51 Pictures of the process of transportation and installation of Aragó 359's prefabricated modules. Source: LCT Website (Aragó 359 y Roger de Llúria 41, 2015)

Online media sources depict the use of a main three-dimensional steel structure, and insulated walls in a sandwich structure that encloses the building and keeps the weight low (Casa Atico, 2015). The floor and top covers of the modules can be either made out of a steel deck system with poured concrete, or with structural wood beams for a lighter and a more ecofriendly alternative. The choice depends on the available budget and structural needs of each project (LCT, 2015; LCT, Yanina Mazzei, 2015).

Figure 3.52 Images of the finished units at Aragó 359:.Source: LCT & Mazzei (Espacio, luz y confort, C/ Aragó 359, 2015)

3.7.4 Structural strategies

From the structural standpoint, LCT aims to create a balance between the weight they remove and the weight they add. In the majority of cases, the removed loads are larger than the one placed, including the weight of the expansion.

However, in some cases (*e.g.* Girona 81 case study), the loads removed are lower than the new additions, which is when structural tests and reinforcements are needed to for the construction to be safe.

3.7.4.1 When the new building's load are increased

Structure-wise, Aragó 359 is a special case study because after the project was completed, the overall weight of the building increased. However, the structural tests proved that despite having a slight increase in the foundations of the party wall and the stress applied in the most unfavorable part of the bearing walls, the numbers were still acceptable after the safety coefficient (Artés, Wadel, & Martí, 2017). Meaning that the building was able to sustain the loads without any type of big structural reinforcement. The following table summarizes the structural strategies used by LCT at Aragó 359:

Name	Description	Obervations	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 regultations	Supports standard use, transport and lifting	Not applicable

Figure 3.53 Summary of structural strategies at Aragó 359. Adapted from: "Vertical Extension and Improving of Existing Buildings" (Artés, Wadel, & Martí, 2017).

3.7.5 Conclusion

One of the most significant challenges when designing for vertical growth is the proper development of the structure. Therefore, structural stability is at the forefront of rooftop lost space. Indeed, architects need to be aware of its challenges. Some professionals reject using rooftop expansions because, from a traditional construction practice perspective, they consider structural reinforcements burdensome. Aragó 359 is an example where the overall load of the building increased after the rooftop expansion. Contrary to what architects would think, the project was still feasible because making the necessary repairs was fairly simple.

Architects need to first test the building before making any assumptions. Standardized building surveys could be established, by either private or public entities, to showcase that, in most cases, the buildings' existent structure can bear new loads if lightweight materials are used and unnecessary existent items are removed.

Figure 3.54 Picture of the central structural intervention on Aragó 359: the chained forged beam is seen at the bottom of the picture. Source: LCT Website (Aragó 359 y Roger de Llúria 41, 2015)

The fact that Aragó 359's overall new weight surpasses its previous weight and can still withstand more than 500 mt2 of new expansion, as proved by a structural safety test, is undoubtedly a remarkable feature. Aside from the chained forged beam done in the upper slab (Figure 3.54), the tests showed that no further reinforcement was needed. The key to this approach is to identify the required load that can be extracted so that the reinforcement cost does not make the project unfeasible in the long run. It is also important to note that not all buildings need or can receive further loads. Sometimes, buildings are at full structural capacity, and architects, in collaboration with civil engineers, need to value the costs and benefits of developing a project. (Dossier Enric Granados 69, 2015)

3.8 CASE STUDY 4: GIRONA 81

3.8.1 Project description

Figure 3.55 Frontal view Girona 81. May 31, 2018.

Seven blocks north-west from Letamendi 29, sits Girona 81. The building is in front of Carrer Girona, in between Aragó and Consell de Cento. It is within walking distance of Parc de la Ciudadella, Girona metro station, Passeig de Saint Joan, and Passeig de Gracia.

Figure 3.56 Girona 81 site plan. Source: Casa Ático (Dossier Girona 81, 2015)

LCT developed the building's renovation and vertical expansion. The typology of the existent property is a form of the typical 19th-century Barcelonan development. However, the one-floor expansion was developed along with Letamendi 29 in the late-2014 (Artés, Wadel, & Martí, 2017).

The original multifamily building had five floors in total, with a small store on the ground floor. Moreover, due to the plot's location in the block, the building's footprint is narrow on Girona Street's front but elongated in depth. Furthermore, each of the upper floors is a single unit, and the building had a vacant buildability of one additional floor. Thus, LCT incurred in the rehabilitation of the building in exchange for finishing up the extra buildable space.

Girona 81 has 97.66 m^2 of built-area plus 14.29m^2 of terrace space in the back. The units are a two bedroom, two bathroom, and open kitchen design. Something interesting about the architectural design is the courtyard entrance, where the elevator and the staircase land before entering the apartment. Similarly, to the Enric Granados case study, this project uses a palette of exterior materials that mitigate the contrast with the building below and, at the same time, accomplish a contemporary look. On one side, the front façade of the expansion is not aligned with the main line of the building, but it respects the axes from the openings below. On the other side, the rear façade backs up to leave room for an open terrace facing the inner courtyard of the block, which contrasts a lot with the rest of the building.

Apt Number	Area	Terrace	Bedrooms	Bathrooms
Ático	97,66 m^2	14,29 m^2 / 0 m^2	2	2

Figure 3.57 Letamendi 29's table of areas. Adapted by the author from Casa Ático Website (Dossier Girona 81, 2015)

3.8.1.1 Cost

According to a publication by LCT's retail branch, Casa Ático, Girona 81 was listed at € 507,600 ($ 774,154) or € 5,197 ($ 7,926) per square meter at its moment of commercialization in early 2015 (Casa Atico, 2018).

3.8.2 Architectural Strategies

Figure 3.58 Left: frontal façade Right: rear façade. Source: Casa Ático (Dossier Girona 81, 2015)

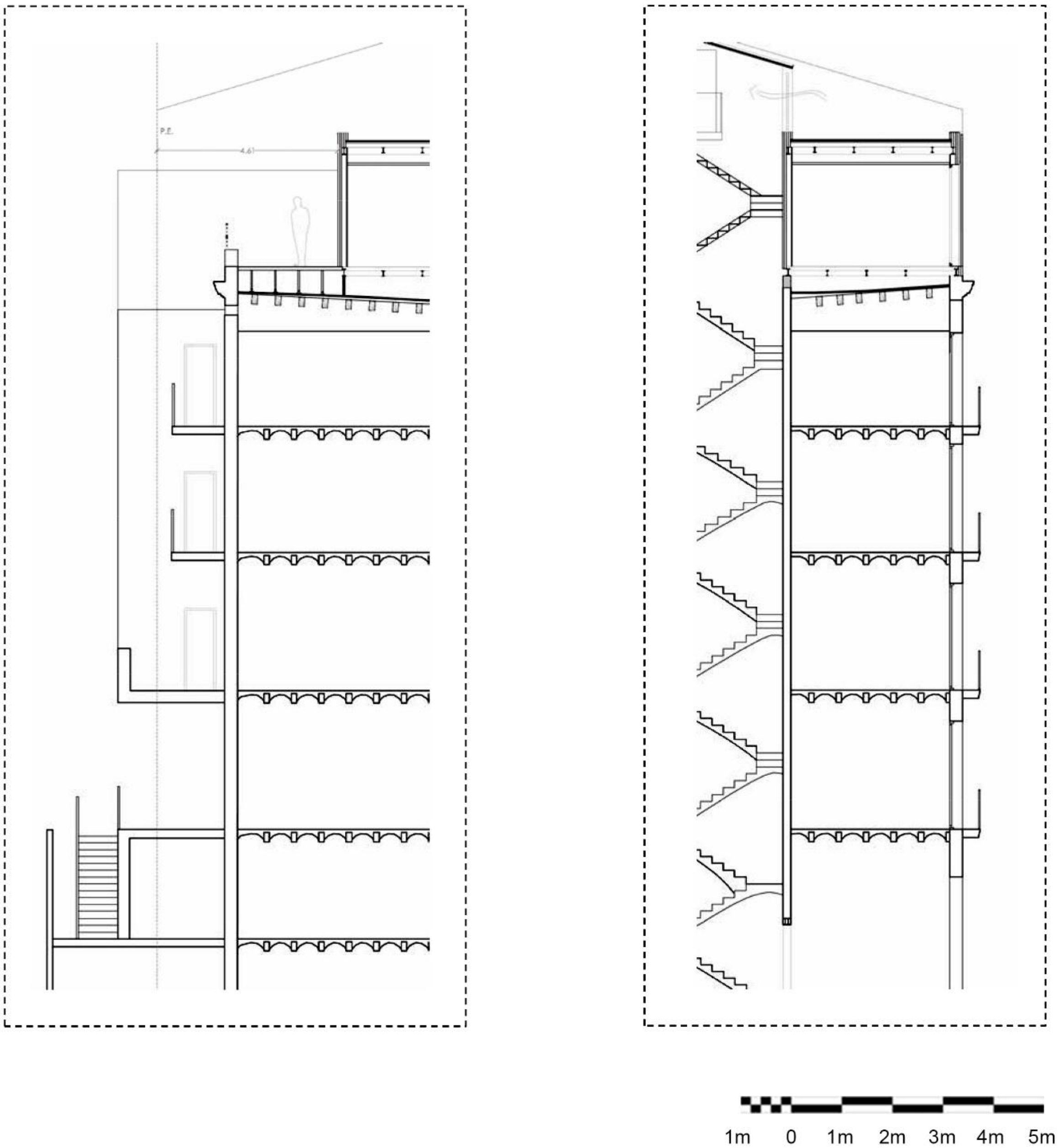


Figure 3.59 Left: Rear façade cross section. Right Frontal façade cross section. Source: Casa Ático (Dossier Girona 81, 2015)

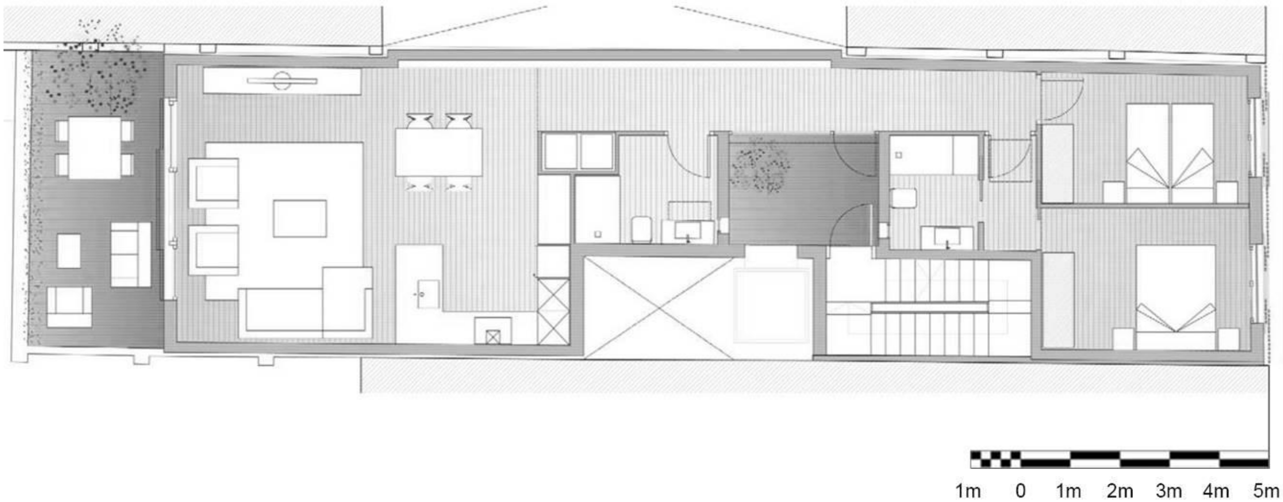


Figure 3.60 Floor plan Source: Casa Ático (Dossier Girona 81, 2015)

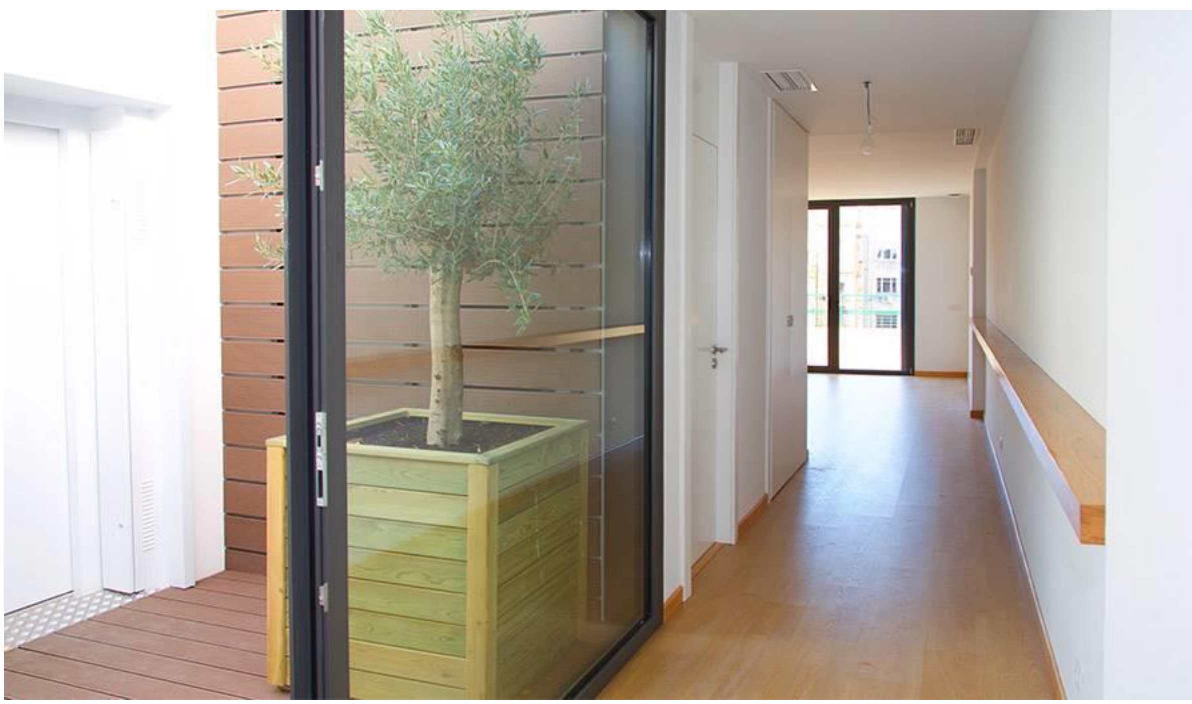


Figure 3.61 Interior courtyard used as main entrance of the unit. Source: LCT's website (Girona 81, en una Mañana, 2015)

Figure 3.62 Images of the finished interior and exterior areas at Girona 81. Source: LCT's website (Girona 81, en una Mañana, 2015)

3.8.3 Construction strategies

Girona 81 uses a three-dimensional structure of steel columns and beams divided into two longitudinal modules. The modules use a steel deck system with added concrete on its top layer. The sides of the modules also use LCT's standard insulated sandwich panel (described in the previous case study) where most of the MEP (Mechanical, electrical and plumbing) are embedded (Figure 3.43).

The project was prefabricated at Mothership, LCT's factory line. This allowed for precise detailing on dimensions and manufacturing, to decrease construction time, waste, and make the project low-weight. The two elongated modules were shipped to the site and installed on the rooftop in only one day time.

Figure 3.63 Images of installation of the three prefabricated modules at Girona 81. Adapted by the author from the video by Artes. (Girona 81, 2014)

3.8.4 Structural strategies

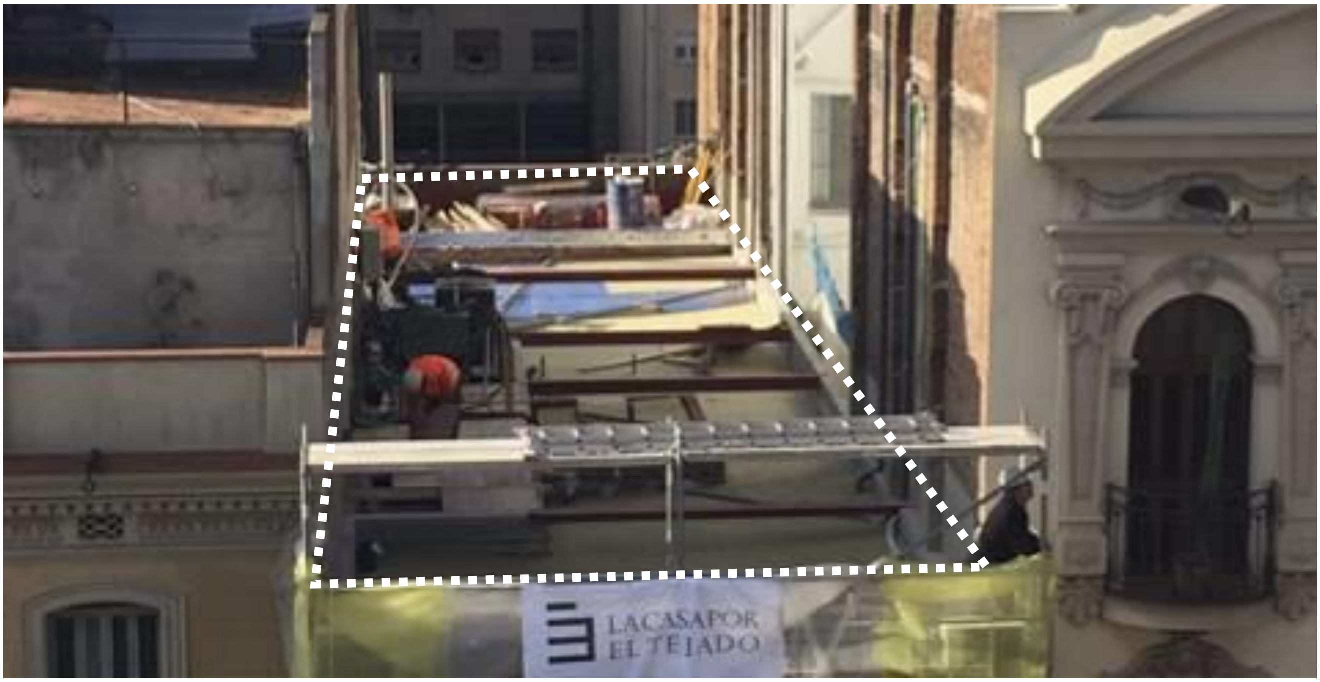


Figure 3.64 View of the rooftop preparation with the chained beam on top of the support walls and the transversal steel beams. In this case, the rooftop also received a waterproofing treatment to protect the existent penthouse from infiltrations while the new unit arrived. Source: LCT Website (Girona 81, en una Mañana, 2015)

3.8.4.1 When the new building's load are lowered

As it's been mentioned before, when developing rooftop expansions, a big concern is whether the building is going to be able to bear the new added weight. In this case study, the demolition of the unnecessary heavy elements on the roof and the lightweight expansion resulted in a reduction on the building's overall weight. Thus, making any structural reinforcements on the primary structure unnecessary.

Finding the right building to do the expansions is key because it is clear that not all buildings can be expanded. LCT puts its main focus on structures that share similar historical backgrounds and locations in order to make correlations on the building's state and ease the selection process of the next development. Girona 81 is an example of this because it was selected due to its proximity to the other projects developed by LCT.

In the process of structural analysis, LCT has the following practice (Artés, Wadel, & Martí, 2017):

1. An analysis on the loads of the existent building and the weight to be removed.
2. The required geotechnical studies, determining the values for permissible stress on the ground floor.
3. The analysis of the maximum permissible stress of the load-bearing walls and foundations.
4. A study on the construction loads to be added and their effects on the walls, foundation, and ground floor.
5. The design of the system of load transmission between the constructions added to the roof and the existent building.
6. Checking that the effect of the added construction on the walls, foundations, and ground do not exceed the maximum permissible values.

According to Artes *et al.*, the results of the test at Girona 81 showed a decrease in the overall weight of the building. This included the loads of the added expansion as well as the building below. As a consequence the stress on the ground, the bearing walls, and the foundations were reduced (Vertical Extension and Improving of Existing Buildings, 2017). This is because Girona used a system for replacement of load that removed most of the unnecessary parts of the building before doing any type of structural reinforcement. With this, the amount of weight removed exceeded the loads of the new modules used on the roof expansion.

3.8.5 Conclusion

Figure 3.65 Installation of the largest module at Girona 81. Adapted by the author from the video by Artes. (Girona 81, 2014)

Girona 81 is set apart from its neighbour case studies due to its small size and its lightweight construction. At just over 100m^2, the housing development provided a solution to a vacant space in one of the most desirable neighbourhoods in the region. Moreover, it became a possibility for the community to improve the mandatory municipal ITE reparations to keep the integrity of the building

Perhaps, the most notable factor in this case study is the capacity of the new construction materials to outperform in their lightweight and high speed of construction as compared to previous ones. Girona 81 is living proof of this because it accomplished a decrease in the overall weight of the building. Thus, reducing the stress on the structure, foundation, and ground floor. These set of results are grounded on advances in construction technology, materials, and processes. However, there is a need for more architects around the world to realize that they can also be used for alternative purposes, like finishing the existent stock of rooftop-lost-space in today's cities.

3.9 FINAL REMARKS

Who would buy air? At the heart of major cities, there is a tremendous amount of available land, but it is very different from what we picture. These plots of land have access to sunlight, natural ventilation, and rainwater too, but they sit a few stories above. Rooftops are a source of land cities currently have on hold, waiting to be developed.

Two important conclusions can be gathered from this chapter. First, buildings in Barcelona's Eixample have residual structural robustness, very much desired by this typology of expansion. However, most of them are over structured with the use of unnecessary heavy elements that could be replaced. Secondly, these buildings have a residual buildability that is used by LCT in their developments. The combination of these two is what creates a possibility for these projects to be developed given that there is no need to reinforce the structure extensively to keep the expansions within the allowed bylaws.

Perhaps, the hardest part is to coordinate the participating parties and factors for the project to succeed. These include the neighbours' opinion, the architects' design, the factory's specifications, all the authorities and heritage institutions, and finally, providing a decent return on the investment (ROI) to all parties. The rest of the processes are common in architecture practice; there is nothing new. Prefabrication processes are relatively conventional for 3D steel structures, insulation panels, and steel deck systems. The novelty comes in combining these to create an original logistic. The verticalization of the development process is what keeps the gears running smoothly and simultaneously, enabling LCT to create such expansions. For example, there might be times when there's legal setbacks due to some of the co-owners having an embargo or something similar. In which case, the developer needs to be able to solve this, while still being mindful of the rest of the development process.

"Construir Sobre lo Construido" is a common Spanish expression, typically referring to thoughts not things, which refers to the idea of building on top of what is already built. The set of case studies analyzed in the previous chapter portrays this in architectural terms, not only conceptually, but also physically. The alternative studied here capitalizes on the vacant buildable space that sits above buildings which have not met their maximum occupancy envelope. It is novel to some people but, in fact, it is a construction practice that has been used in Barcelona for over five decades. The innovation is their use of lightweight industrial modules, stacked using a Tetris-like system, in little time, to rehabilitate century-old buildings.

Moreover, although the four case studies had contrasting construction practices, they had correlating objectives. One objective was not only to provide buildable space where there was none available, but also to integrate a system that brings existent buildings up to date to today's standards. Another objective was to produce environmentally sustainable housing by producing units that outperform current environmental standards instead of only using the embedded energy from the existent buildings. A third correlating objective was to capitalize on prefabricated construction techniques and materials that lowered the overall weight of the units, creating a safe approach to structure feasibility.

With 6 months construction time, these projects are done reasonably faster at than those using traditional systems (concrete and brick construction) which take at least 18 months (Wadel, 2009). This also benefits existent neighbourhoods, given that the installation of the rooftop modules last no more than two days, thus, reducing disturbances to neighbors.

Drawing from the above, the key seems to be in three tactics. First, the use of a unique acquisition system where the co-owners trade their available buildable space in exchange for the building's update. Here, LCT gets to capitalize the otherwise useless rooftop and introduce new housing units into highly valued areas of the city. Second, the design of tailor-made and prefabricated expansions ensures that these projects fit all the heritage regulations and enables them to manufacture ultra-lightweight modules. The wooden or steel 3D structures with the floor, ceiling, and walls with excellent energy efficiency do not require LCT to make the overpriced and overcomplicated reinforcements to the structure, something that would be necessary on other conventional constructions. Third, the vast sunlight, rainwater, and wind exposure, enables them to create a cover on each building that makes the best use of these resources. What is remarkable is that these three tactics benefit all: the end user, the neighbours, and the city.

These four case studies support the position that buildings should not be understood as unfinished artifacts and that rooftop-lost-space (the remaining buildable space above buildings) can become a development platform for contemporary city growth. Still, it is unfortunate that LCT's projects remain catered only for those who can afford elevated prices, given that the average square meter (for sale) was $ 8,869.25, with some apartments, like Enric Granados 69, retailing for $ 1,130,730 in 2015. Perhaps, the technology that makes it feasible also needs a high sale-value that amortizes the overall cost of the process. This, in turn, increases the risk for the development of social problems, like gentrification in areas where vulnerable communities cannot afford the high cost of living. Gentrification is delicate in cities like Barcelona due to the already underlying problem of inflated prices, which are due to tourism and foreign investment.

Another problem comes from the lack of awareness within the building domain. In comparison to more popular typologies of lost-space, like renovated industrial buildings (see The SECS Pompei in Sao Paulo), or restored old infrastructures (see The Highline in New York), professionals in the field of architecture are not used to, or even aware of, this type of developments. As a consequence, the regulations on such type of expansions are unclear. With these vague boundaries, situations like the Porcioles Hats in 1960's Barcelona can destroy the landscape of the city with an uncontrolled expansion.

One of the possible causes for this was the lack of available technology and mentality. However, whatever the reasons might have been, rooftop-lost-space remains an undervalued space and, using the technologies available now, it could be a reliable alternative for 21st-century city development.

As we have seen through various authors, growth and adaptability is crucial to update through architectural time (Aravena, 2010; Artés, Wadel, & Martí, 2017; Brand, 1994; Bonnenfant, Georgieff, & Georgieff, 2008; Friedman, The grow home, 2001; García-Huidobro, Torriti,

& Tuga, 2010; Habraken, 2002; Schmidt & Austin, 2016). Significant advances have been materialized, primarily in small-scale proposals. Although these are remarkable successes, the current trends of urbanization and the lack of available land in cities is demanding a solution that can scale-up at the same speed as urbanization does. The argument for a need to enable the city to grow over time is clear, but how to do so is not. The previous chapter shed some light on an alternative solution which uses the already available buildable space with prefabricated and tailor-made 3D modules. Perhaps, the solution to the lack of land in urban settlements lies above our heads, not below our noses.

CHAPTER 4 - DESIGNING ON AIR

4.1 Introduction

This chapter presents a compendium of the reports' findings. The guidelines expressed in this section may be used by the audience to build the architectural and structural framework of rooftop expansions in urban areas. However, the intention here is not to create a set of rigid rules, but rather to provide a group of guidelines to be modified by the designer. Any intention of standardization would drive to undesired effects given that every city, neighbourhood, and building is unique and, thus, each has different needs. Additionally, the framework of these criteria is built upon architectural aspects, such as materials, construction processes, and structural design, among others. However, when needed, the guidelines expand to other matters outside that framework to complement it. As such, further research in aspects and disciplines outside architecture, such as civil engineering and urban planning, would be desirable given that this report is limited in its coverage of these.

Rooftop expansions are complex and diverse. The key is to balance all of its *gears*. Thus, this chapter is organized in a matter that allows the audience to differentiate each and associate them as necessary. A *gear* represents a part of the process needed in the development of rooftop expansions. They are divided into two groups. The first group includes the tools needed before designing and building a rooftop expansion. This covers recommendations on how to find rooftop lost space, how to choose a building, what essential parts the designer needs to review prior to intervention, and how to structure a sustainable economic model for the projects. The second group includes the tools needed to design and build the project. This addresses design recommendations, including its architecture, structure, utilities, circulation, materials, and construction.

Finally, it illustrates other opportunities these developments have regarding city's preservation and environmental sustainability. These criteria are meant to empower designers or developers to make rooftop expansions and finish building the extensive stock of micro-spaces available above.

4.2 Development tactics

4.2.1 How to find rooftop lost space?

The first step in rooftop expansions is to locate rooftop lost space in the city. The designer needs to begin by defining the permitted building height and Floor Area Ratio (FAR) of the chosen location. Then, the designer needs to compare the FAR and height desired with the current building FAR height. If the height is yet to be met and there is still available FAR, the property has designated rooftop lost space. Other bylaws, such as heritage preservation, materials chosen, and square floor index (FSI), are explored later in the process. The goal is to first map rooftop lost space for future use.

This process is extensive and manual. Given this, researchers argue that the authorities should enable this process by helping with the cross of information, which they have available with their access to the current building characteristics as well as to the existent bylaws. The use of GIS software could aid to quickly identify and make public the information for designers to make use of. It would be highly valuable to have all types of lost space categorized as such in every city so that designers can be aware of the building space available.

Given the massive nature of cities and the fact that not all rooftop lost space is suitable for rooftop expansions, it is essential to focus on a space that increases the chances of success by using the required tools. Thus, if the designer does not have the time or human capital, it is recommended to focus on a specific neighbourhood or area of the city to make expansions feasible.

4.2.2 How to choose the first neighbourhood?

A commonality between the case studies is their location at high value and centric neighbourhoods. This pattern might appear to be excluding and elitist, but there is a reason behind it. First, housing developed under rooftop expansions needs to be in a centric area where high market demand is, which tends to be in neighbourhoods that lack ground space. Additionally, outdoor spaces are close to non-existent in these centric neighbours.

Last but not least, the strongest argument is associated with the cost of construction these expansions have per built square meter. The technology, reparations, research, tests, and risks involved in the process increase the cost of production per square meter. Therefore, the unit price needs to amortize the cost of these. The only way to do this is to develop in areas where land is scarce and sale values are high. This pattern is a common practice not only to rooftop expansions, but among many other new techniques that decrease in price as they become more ubiquitous. In Barcelona, this neighbour is localized in the Quadrat d'Or and in Eixample.

Hence, the recommendation is to focus on neighbourhoods that share these base-characteristics: a significant lack of space, high sale value, and centric location, all useful for rooftop expansions.

4.2.3 How to find the genetic code of the buildings?

Identifying rooftop lost space is a great step, but the information is still too broad to be useful. So, once the neighbourhood and the buildings with remaining buildable space are identified, the recommendation is to use the "genetic code" breakdown. This technique is frequently used for neighbourhood scale analyses, but it is especially useful for rooftop expansions because it can quickly identify the right cluster of buildings to intervene. The authors that created the method argued that buildings share an embedded language that repeats itself across different structures in a given site, also known as its "genetic code" (Koolhaas, et al., 2000). The goal is to decompose urban complexity and highlight the features common to some buildings. This tactic is done through the categorization of buildings based on their components by designers.

The recommendation is to analyze the neighbourhood's generic code from its historical evolution. This includes age, material selection, construction techniques, typology of structure, and the detection of old and heavy features that can be replaced with lighter ones. The idea is to have a specific category that separates potential buildings to intervene from the large stock of rooftop lost spaces identified. The designer needs to select buildings through the identification of each building's condition and group together the ones that have potential for intervention. It is crucial to strive for constructions that have unnecessary bulky items to eliminate and that have well preserved structural components too.

4.2.4 How to structure an economic model?

One of the reasons why people do not build rooftop expansions is their high cost. The financial management of these projects is a recurrent issue. The economic structure begins with the selection of the neighbourhood. As mentioned in the previous section, the neighbourhood should be centric so that available land is scarce, but also of high sale-value so that it can easily amortize the technology used and its refurbishments. It is recommended to make a market analysis to define the cost of aerial rights. This will set a baseline for the designer to work with. It is also recommended to use a Proforma analysis to get an estimate of the sale values for new apartments, as well as the current sale value for an apartment in the building to intervene. By this point, the designer should be familiar with the property's bylaws. This includes the allowed FAR, FSI, building height, typology of housing, the maximum number of units (housing density), heritage conservation rules, permitted uses, car parking, and complications of the property.

In this stage, the main goal is to estimate a baseline cost for the aerial-rights to begin negotiations. According to the case studies, the best strategy is to do an inverse calculation. To do this, the designers need to evaluate the cost of construction, including the additional level, the refurbishments, onsite studies, a contingency fund, and the soft costs related to it. External costs such as the financial interests, taxes, and sales should also be considered. The sum of the previous items will be the total development cost. Then, the designers subtract the development cost from the estimated revenue of the project. The final value corresponds to the aerial-rights cost (**¡Error! No se encuentra el origen de la referencia.**).

It is recommended to negotiate the aerial-rights cost in building refurbishments, or as a hybrid instead of a fully monetary compensation. This is a great tactic because the building gets restored, accessibility is improved, and the property's valuation rises an estimate of 10 to 15% (Dirksen, 2015). At the same time, habitability improvements get equally split among all the property owners. It is a win-win situation which makes the development economically viable.

Enric Granados 69 economic structure				
Project area			189.25	m2
Onsite studies		$	6,415	
Total cost of construction (additional floors and required building refurbishments)		$	614,211	
Contingency fund	5%	$	30,711	
Soft cost (legal, project management...)	23%	$	171,979	
Financial interests	12%	$	73,705	
Taxes (Over revenue)	5%	$	100,473	
Sales (Over revenue)	3%	$	60,284	
Total development cost		$	1,057,777	
Development cost per m2		$	5,589	
Estimated revenue		$	2,009,456	
Revenue per m2		$	10,618	
Estimated profit	17.5%	$	351,655	
Aerial rights cost		$	600,024	

Figure 4.1 Breakdown of Enric Granados 69 economic-structure key elements. Data adapted from: (Casa Atico, 2015; Delgado, 2016)

4.2.5 How to launch the first project?

It is crucial to follow the previous recommendations in order because they drastically reduce risks for the development of the project.

Now that the rooftop lost space has been located, a genetic code has been identified, and the economic strategy has been established, it is time to launch the first development. The first attempt to build an expansion is the most challenging given that people might be skeptic towards these developments (Moran, 2015). The uncommon nature of this system raises questions regarding the structural capacity and construction processes. It is probable that the project will need to be financed by a developer or a client. This initial project should be considered as an investment opportunity. The first expansion not only provides invaluable information about the buildings' condition that are otherwise impossible to get, but, with its success, skeptic opinions are eliminated.

Building a pilot project illustrates rooftop feasibility. As a consequence, it allows the architectural and structural condition of the neighbourhood to improve with the help of new investors who can see the opportunity that rooftop expansions are. Moreover, the main reward of this initial project comes in the form of the information it provides for the *genetic code* of the area. Thus, it is essential that designers strive to survey the buildings as much as possible in this phase. For example, Letamendi 29 demonstrated the high value of this information because neighboring buildings had similar architectural and structural conditions, enabling the designer to predict the condition of the buildings in the area. Key onsite inspections are explored in the following section.

4.2.6 What to look for in the building's inspection?

Once the building's inhabitants have accepted the initial economic proposal, the designer needs to begin the preliminary inspection to verify the building's condition and the project's feasibility. It is recommended to inspect three components: structures, utilities, and architecture.

4.2.6.1 Structural inspection

As mentioned before, the key to make a structurally feasible rooftop expansion is to remove unnecessary weight before doing any major structural reinforcements. According to the case studies, "buildings can remove around 1000kg/m^2, while adding only 300kg/m^2 of new construction" (Moran, 2015).

Certainly, a rooftop expansion cannot run merely on this premise. Therefore, the recommendation is that all projects do the required inspections and test the structural capability of the building before signing any purchasing agreement. The structural inspection must address the structural capacity of the bearing walls, columns, foundations, and terrain. Additionally, it must include a visual inspection of its physical elements to review the continuity of the structure. Finally, it needs to identify unnecessary heavy elements that can be removed from the property in order to reduce weight.

4.2.6.2 Utilities inspection

The utilities are divided into five sections, sewage water, rain-water, water supply, electricity, and gas.

4.2.6.2.1 Sewage water

It is difficult to expand the sewage water system to the new apartments because it is often not well connected to the municipal pipeline or obstructed. However, depending on the capacity of the existent communal drain and the required needs of the new apartments, the current pipes might be reusable. LCT representatives mentioned that the most common scenario is to reuse the existent pipe.

If the communal pipe is in bad conditions, or if it cannot support the new water demand, the designer has two possibilities: either to replace altogether the communal sewage drain, or to install an independent drain for the rooftop expansion. The process can be complicated depending on how the pipe is located in the building. If it is at easy reach, like the ones from the case studies addressed, it is easier. However, in buildings where the pipes are protected from the weather, like in Montreal, it may become a complicated process. In such cases, and if the space for expansion is also highly limited, the designer needs to review the case to redefine its feasibility and cost.

4.2.6.2.2 Water supply

The primary problem with water supply is to maintain water pressure even with the height increase. The recommendation is to raise the water pressure with a new pump system to meet the new demands. Independent water supply pipes in all new apartments are highly encouraged. This recommendation is especially important in Montreal's old buildings, where the water supply is commonly unified, and it is difficult to distinguish the water consumption per property.

4.2.6.2.1 Rainwater

Rain water tends to stay within the same capacity because the roof's area remains the same despite the rooftop expansion.

4.2.6.2.1 Electricity

The electrical network is usually the easiest to manage given that the cables are easy to expand without producing major inconveniences. However, it is highly recommended to be aware of the building's voltage capacity to make sure that it does not collapse with the additional electric devices. In the majority of cases when the electrical capacity is increased, the capacity of the building's shared electrical box is also incremented. This will ensure that the new electrical demands are met. The phone, TV, and electric cables are all extended using a rectangular channel that connects the building power source with the new rooftop.

4.2.6.2.2 Gas

Gas utilities do not require tests or expansions given that appliances come with built-in systems for electricity. These include heat pumps, kitchen appliances, and water heaters.

4.2.6.3 Architectural inspection

Architectural inspection includes both the aesthetical and the functional parts of the building. It is important to pay special attention to communal spaces like hallways, stairs, and façades. Identifying the building's largest deficiencies will help in the outlining of the restorations needed and with the aerial rights negotiations. The architectural inspection should improve functionality over any other aspect. For example, the construction of an entrance ramp and an elevator can make the building more inclusive for the elderly population or for people that struggle with long flights of stairs. It is recommended to focus on lighting, window performance, the intercom system, the elevator, and the access ramp. After this phase, the designer can focus on aesthetic aspects such as the building's façade, the woodwork, and interior finishes. It is recommended to focus on the restoration of the façade, windows and doors, woodwork, and painting of communal areas.

Once the structural, utilities, and architectural inspections are done, and only if the project is still feasible after all the projected interventions, the designer ought to continue into the next phase: design and construction of the rooftop expansion. It is important to note that many buildings fail to pass these tests due to feasibility issues concerning any of the previously mentioned components. In this case, the suggestion is to store the data for later review and to move onto another building.

4.2.7 How to partner with key stakeholders?

Before diving into construction and design strategies, the designer needs to partner with strategic stakeholders. The research identified five key groups. Giving these partners a vision of what the city could become is crucial for their engagement. As it is expected, these five stakeholders will tend to push their individual interests forward. A useful strategy is to persuade potential partners by reframing our thoughts to appeal to theirs. This is because it is often hard to modify the stakeholder's beliefs, but reframing the architectural ideas is much easier and effective. In other words, instead of convincing the stake holders to adopt rooftop expansion goals, the designer needs to reframe the project's goals as personal benefits for each stakeholder (Grant, 2017).

4.2.7.1 Building owners

The first stakeholder are the building's owners. LCT's representative mentioned that they are the trickiest stakeholders to get on board. Building owners tend to have divided opinions regarding the building's management. Additionally, as mentioned before, co-owners tend to be skeptic towards these projects. It is recommended to focus on the potential benefits that the renovated property will have for all, such as improved accessibility, preservation of the building's appearance, an update to the utilities, lower cost of running the building per unit, and an overall increase in the valuation of the property. Besides, it is an opportunity for them to capitalize on a space that has no value unless the whole building is sold.

4.2.7.2 Manufacturing facility

The second stakeholder is the off-site manufacturing facility. It is highly recommended to partner with a manufacturing facility that can prefabricate high precision modules. The selected partner should be able to deliver on time because onsite and offsite work synchronization is crucial for the success of the projects. Moreover, they should pay close attention to detail since any mistake could lead to a module that does not fit on the designated roof. Preferably, the facility should be automated to reduce construction cost, time, and material waste.

4.2.7.3 Onsite workers

The third stakeholder corresponds to the team of onsite workers. They are a crucial group because they will make all the pre-construction work, the installation of the modules, and the post-construction finishes. Based on the case studies, workers tend to be unfamiliar to this type of prefabricated structures, especially when it comes to the rooftop installation. Thus, it is recommended to hire contractors with prefabricated structures expertise, or to train them before the development of the project. The execution of the rooftop expansion relies heavily in the know-how of this group of stakeholders.

4.2.7.4 Financial investors

The fourth suggested group are the financial investors. These institutions are an elemental part of the project because they provide the initial capital to run tests, refurbishments, and the subsequent acquisition of the aerial rights. The challenge is to offer an excellent return on their investment (ROI) that competes with the real estate development market. It is recommended to focus on the added benefits this type of development has over traditional systems. One of these advantages is time because these developments can be executed in 6 months or less, in comparison to the average 15 months that a conventional construction takes (Wadel, 2009). Besides this, its low-entry investment price plays an important role for financial institutions. A standard construction implies the high risk of purchasing the land and the building, but for rooftop expansions the cost is only for a small portion of the development. Therefore, rooftop extensions have a much lower-entry risk since the financial stake holders only need to fund a portion of the whole property acquisition.

4.2.7.5 Governmental authorities

The fifth stakeholder group is the authorities. The unique nature of this construction makes the need for a shared vision with the city's authorities essential. In Barcelona, authorities were highly supportive of these initiatives. Aside from the urban benefits of rooftop expansions, the designer has to highlight to the authorities the potential updates to be done to the buildings, including the improvement in their energy performance and the preservation of the historical landmarks.

The goal of the designers is to balance the stakeholders' interests in such a way that benefits all parties involved.

4.2.8 How to synchronize different construction sites?

Building on the top of a residence is challenging. Thus, a successful synchronization of construction phases is essential for rooftop expansions to succeed. Time and disturbance reduction is the main goal of this process. The construction system can be divided into three groups. Pre-installation work, offsite prefabrication, and post installation work. The first two happen simultaneously in the first three months, and the later occurs in the last three months.

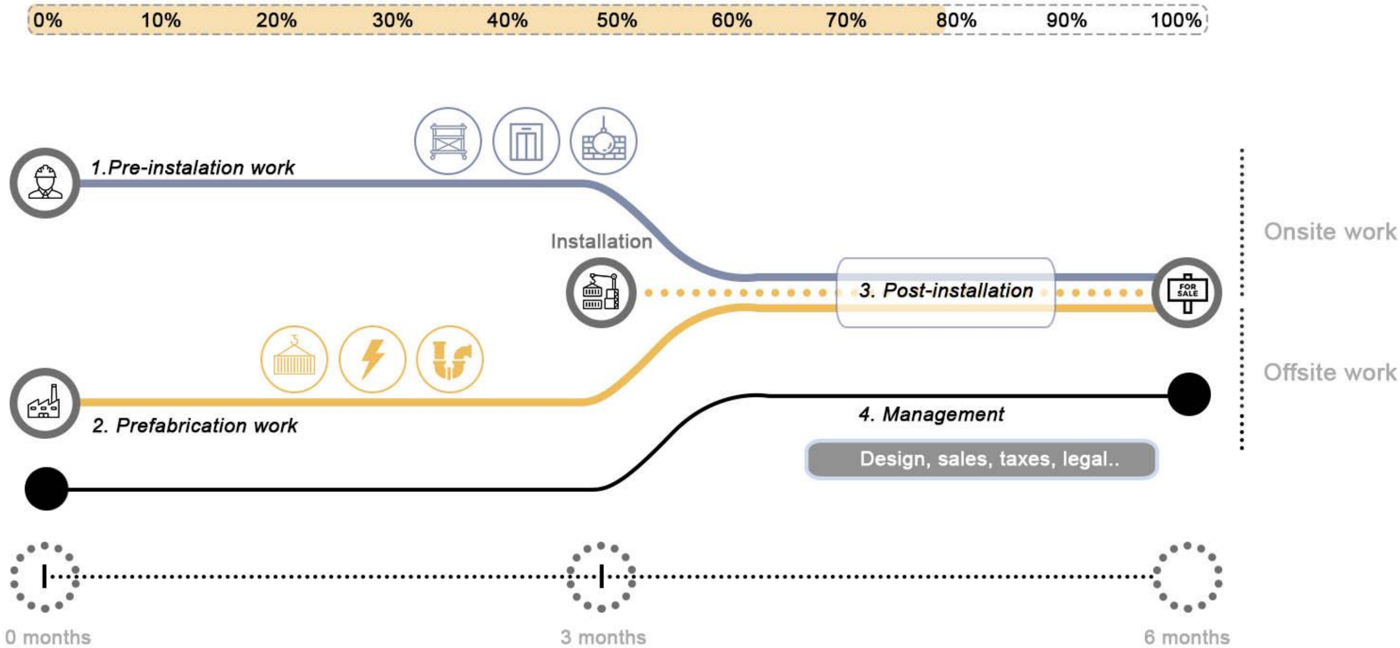


Figure 4.2 The recommended system of simultaneous construction phases.

4.2.8.1 Pre-installation work

Figure 4.3 Rooftop at the pre-installation phase, Girona 81. Source (Artés, Girona 81, 2014)

a. Rooftop preparation:
   i. Utilities expansion.
   ii. Structure reparations.
   iii. Stairs expansion.
   iv. Demolition of any heavy-structures on the roof.
   v. Construction of a chained beam and its transversal steel joists.
   vi. If required, a waterproof layer is applied.
b. Demolition of unnecessary and heavy structures within the apartments below.
c. Construction of elevator's pillars, footings, and pit.
d. Construction of temporary structure to cover stairs and elevator void.
e. Construction of an entrance ramp (preferably connected to the elevator).
f. Installation of a new intercom system.
g. Begin façade restoration.

4.2.8.2 Prefabrication work

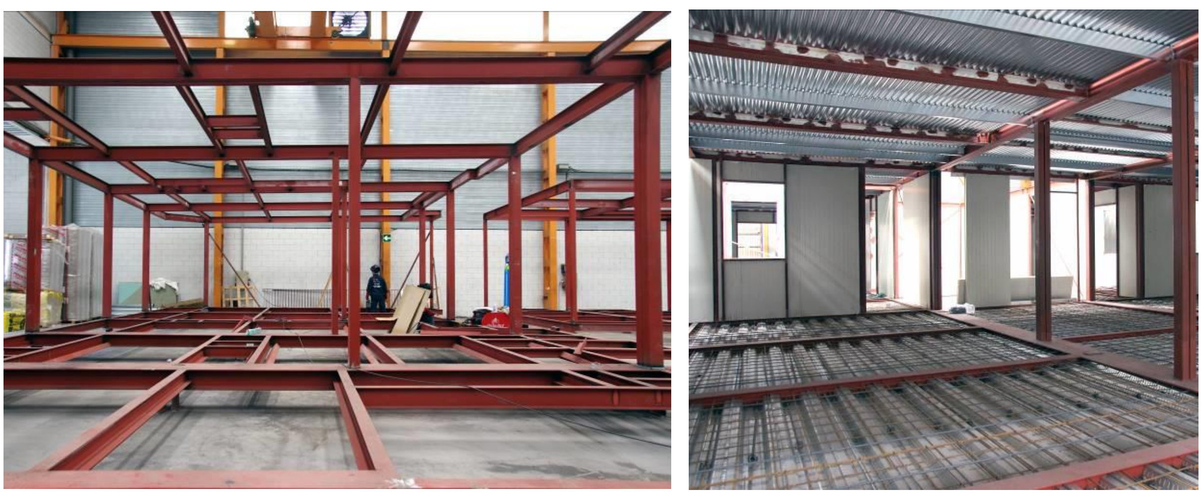


Figure 4.4 Left: Picture of new modules at Gava, LCT's prefabrication facility. Right: Picture of modules with the exterior panels and steel deck already in place, same location. June 6, 2018

a. Construction of the main structural frame. Either steel 3D pillars with steel deck or mass timber panels.
b. Installation of enclosures and interior subdivision for the steel structure.

c. Installation of fixed furniture including kitchen counters, cooking appliances, lights, windows, and bathroom apparatus.
d. Embedded utilities designed to be attached easily to the building below.

Figure 4.5 After three months, the prefabrication phase is done. All the modules need to be shipped to the designated location to go into to the post-installation work. Source: Dirksen (Popout prefab flats assembled and stacked on Barcelona roofs, 2015)

4.2.8.3 Post-installation work

Figure 4.6 Left: Interior of the modules during the post-installation phase at Rambla Catalunya 70. June 6, 2018.

a. Installation of floors' finish.
b. Painting of the modules’ walls and ceilings.
c. Connection of utilities.
d. Sealing of the modules' joints.

e. Finish façade restoration.
f. Painting of the communal areas.
g. Cleaning and testing.

4.3 Design recommendations

The following design recommendations are done to assist designers and developers in conceiving the modules for construction. The intention of these is to cover the architectural and structural aspects, given these are the main focus of this research.

4.3.1 Architectural design

Due to the controversies regarding rooftop expansions, special attention should be paid to their design. When it is not done correctly, it can lead to disastrous results, like the 1960's Porciolismo in Barcelona which destroyed the city's townscape. The architectural design of rooftop expansions has to preserve the building at all costs. Certainly, there is no clear agreement how much change is enough but keeping certain design features has worked to keep the authorities and the citizens content.

Based on the research, the following architectural features were identified:

4.3.1.1 Façade design

The main recommendation is to keep continuity from the main design features on the façade below onto the rooftop expansion by recreating them on the façade. This process should include the materials'-pallet and its functionality across the building. The first case study addressed in this report, Enric Granados 69, is a great example of material selection, and façade functionality, as well as designing with continuity.

The main goal here is to understand the existent language of the building and build upon that. Whereas some buildings could be classified as having an unfinished top (Figure 4.8), others have a finished one (Figure 4.7).

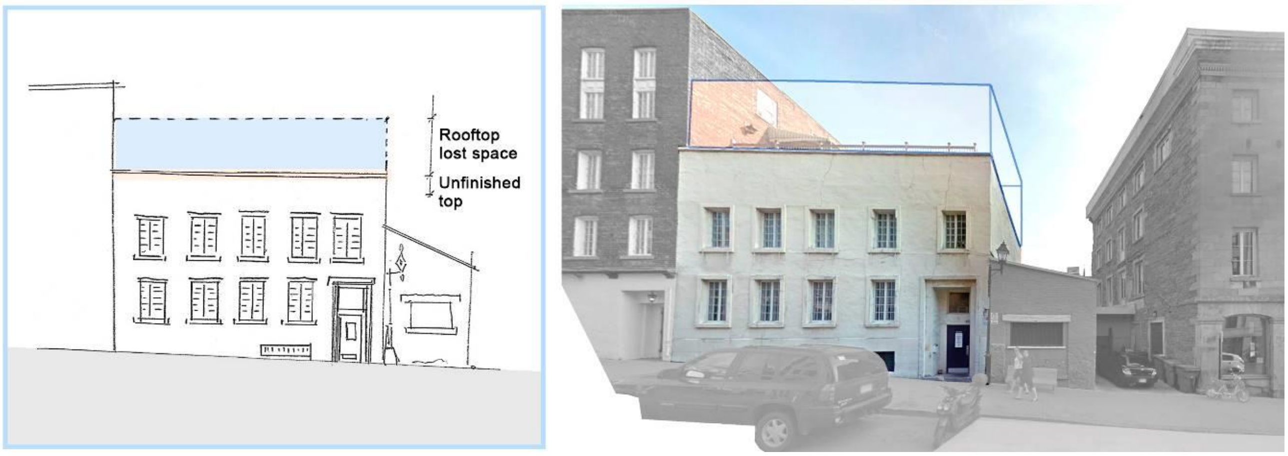


Figure 4.8 Scenario 1: Rooftop lost space above 411 rue st. Claude, Montreal. This figure shows the lack of a hierarchical element that finishes the top of the building. Image Source: Google Street View

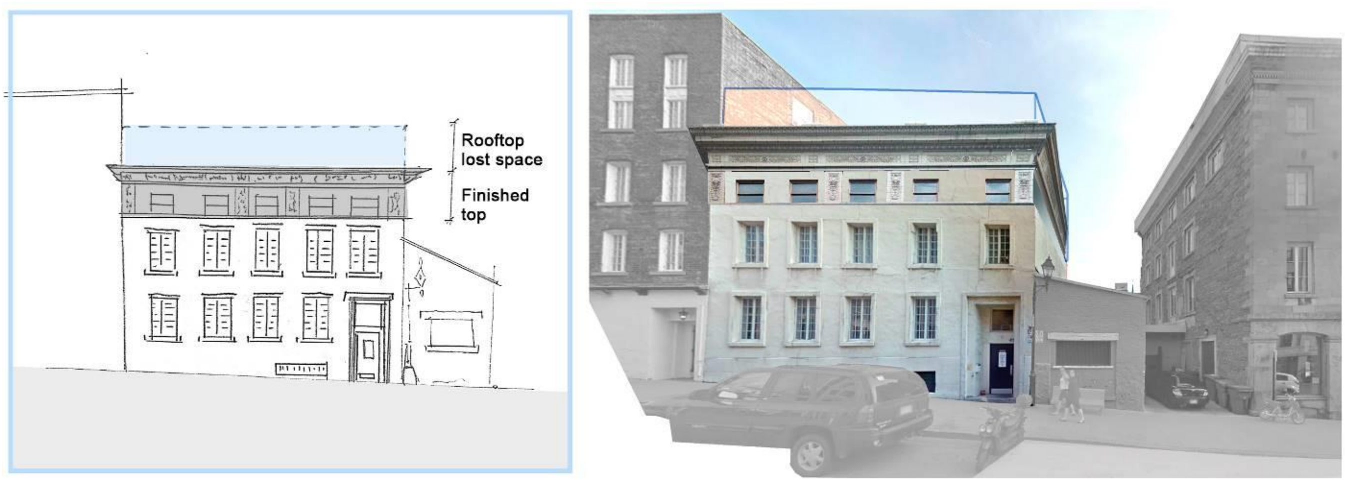


Figure 4.7 Scenario 2: Photomontage of 411 rue st. Claude, Montreal with an imaginary cornice that top´s the design of the building.

In the first case, it is recommended to design the expansion as a piece that follows continuity but ends the building. This could include a greater level of detail that tops off the vertical lines of the building. For the second scenario, it is recommended to design with a low level of decoration that respects the façade design and roofline. Flamboyant designs are not recommended because they would contrast with the building below and the rooftop would not be integrated into the townscape. Instead, it is better to design with self-imposed setbacks that preserve the building's architecture, or to use a material palette that blends with its surroundings.

4.3.1.2 The apartment layout

Due to constructive and functional constraints, it is recommended to design based on the apartment's layout below. Particular attention should be given to bathrooms, laundry, and kitchen spaces, because these three require many network connections. These spaces should be close to the main sources of water, gas, and electricity. This tactic is not only more effective during the installation of the modules, but also produces less disturbances to the neighbors below. Furthermore, designers need to remember that the apartment layout is directly linked to transportation and material constraints. Thus, the dimensions of the modules should be divided in a way that is easy to construct and transport. For example, in Quebec, the maximum allowed length and width for a truck with a paired trailer is 23m, and 2.6m respectively. The height is constrained to 4.5m for road transports, but in cities this is compromised by the clearance height of viaducts and bridges. Thus, the designer needs to check the route clearances described on the Ministry of Transport Website, as well as the ones not described, like trees and corners before continuing (Patrice, 2018).

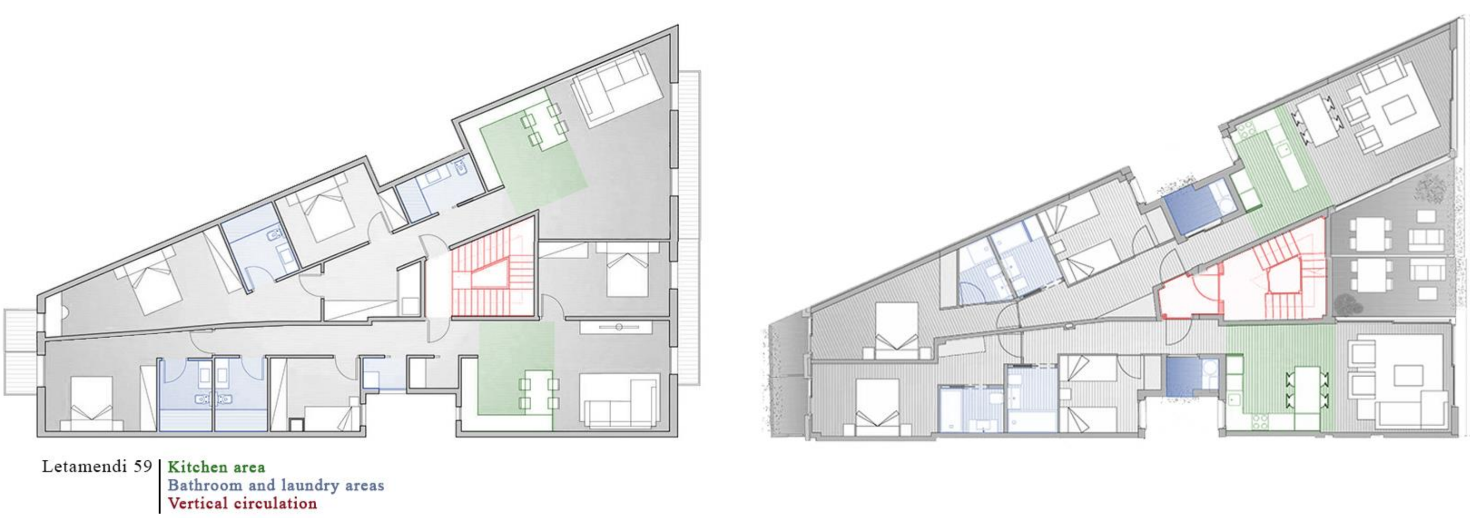


Figure 4.9 Left: Existent apartment layout. Right: Proposed layout for Letamendi 29's rooftop expansion. Note the similarities in the location of kitchen, bathroom, laundry, and vertical circulation areas. Adapted from Casa Ático (Dossier Letamendi 29, 2015)

Designers need to remember that architectural design has a direct influence on structural and utilities' demands. Thus, it should be done in balance with the buildings' constraints. In some cases, it is better to compromise available FAR and make the project safe for construction.

4.3.1.3 Patios

A notable pattern across the designs is the use of new patios for the rooftop apartments. This is an important recommendation not only because it reduces the built area in case it is required by the FAR, but also because it provides considerably more natural light and ventilation, thus improving the apartment's passive performance.

Figure 4.10 Left Interior courtyard at Enric Granados 69. Right: Interior courtyard and main entrance at Girona 81. Source: Casa Ático (Dossier Enric Granados 69, 2015; Dossier Girona 81, 2015)

4.3.1.4 Lateral gaps

It is very rare to find rooftops with perfect rectangular dimensions to fit the module. Usually, roofs have irregular shapes which contrast with the modules' square dimensions, especially the old ones. It is recommended to leave margins where the property meets the neighbouring building of 5 to 10 cm. This tactic will allow enough manoeuvring for the modules to fit in well despite plot irregularities. The remaining gap needs to be covered with a molded metal sheet to protect from water infiltration and humidity. However, building dimensions should be precise from the get-go, thus, this recommendation should only be used as a plan b.

4.3.2 Materials' selection

Materials used in rooftop expansions need to be lightweight and adequate for the prefabrication process. The two key materials that outperform the rest are steel and wood. The first was the most prominent, used in 75% of the case studies analyzed. 3D steel structures with a steel deck system, and dry walls made from aluminum pillars, gypsum board, and a sandwich panel, are the most common materials used (Figure 4.11). One of the most significant advantages of the sandwich panel system is the price when compared to Mass Timber Panels (MTP). Steel pillars, steel decks, and drywall systems are also more commonly available in material-stock, as well as in the workforce's expertise.

On the other side, wood is an emerging construction material that is important for the future of rooftop expansions. Timber is prefabricated in the form of MTP to be easily transported and installed. The two benefits of wood construction are its light-weight and its environmental sustainability. It is excellent for decreasing the construction's carbon foot-print. The use of either of these two recommended materials depends on the requirements of the building as well as upon their availability in the area. It is also possible to make combinations of three materials. For example, a new project developed by LCT has a standard 3D steel structure and drywall system envelope, but its floor is made out of structural wood instead of steel deck and forged cement (Figure 4.12). The reason for this case is a required decrease in the loads of the building.

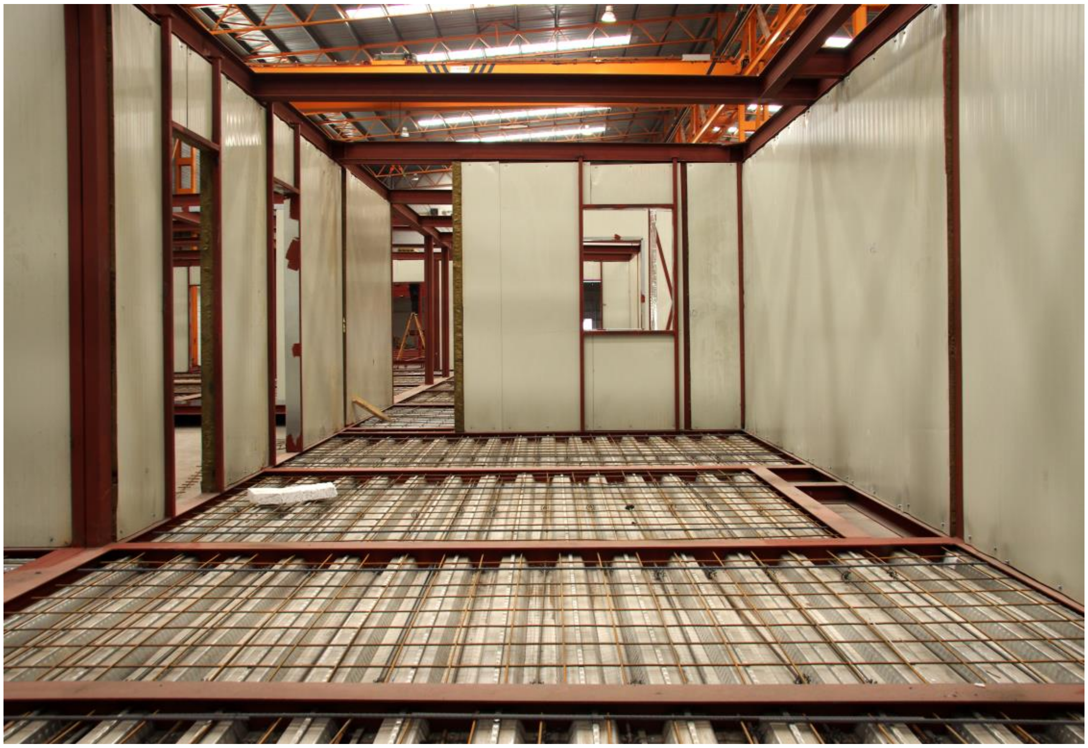


Figure 4.11 Standard module. Uses a 3D steel structure with steel deck and forget cement for flooring and roof. The envelope is built using a drywall system that consists of a sandwich panel and gypsum board. Gava factory June 6, 2018.

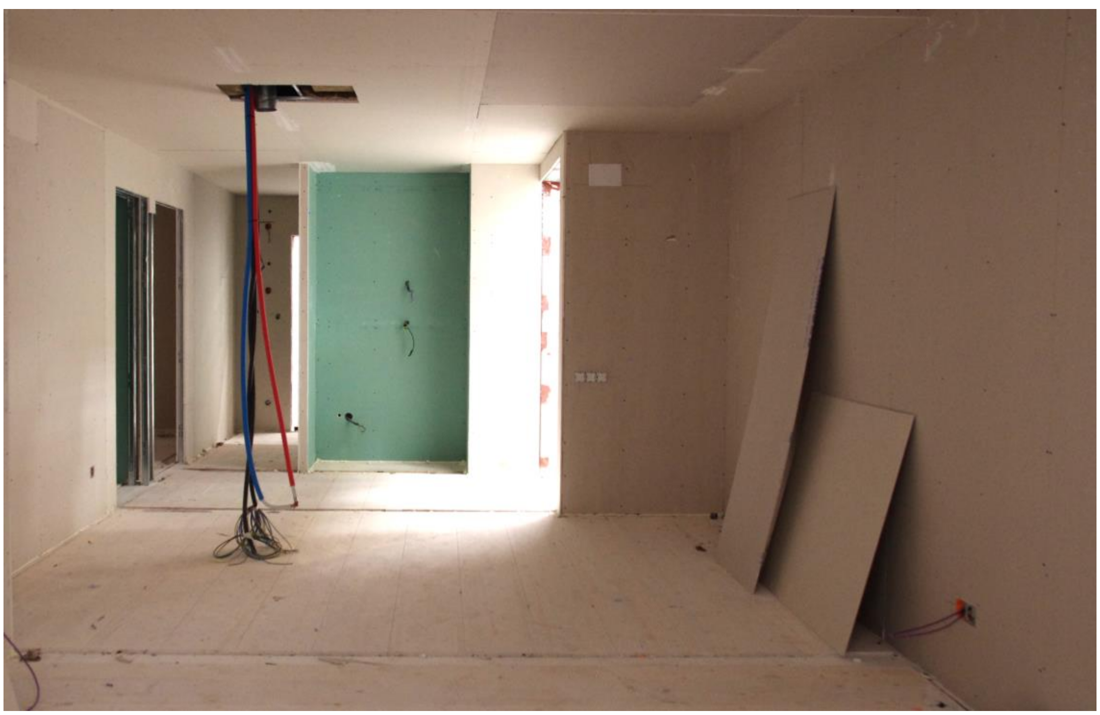


Figure 4.12 The module on the picture uses the same system from the previous one but, instead of the steel deck and forget cement, it uses structural wood. Gava factory, June 5, 2018.

Figure 4.13 This picture clearly illustrates the combination of different modules in a single project. The group of modules on the bottom uses the system expressed in Figure 4.11 and the ones on the top use the one described in 4.12. Gava factory June, 6 2018

The following diagrams summarize different material combinations for the same module.

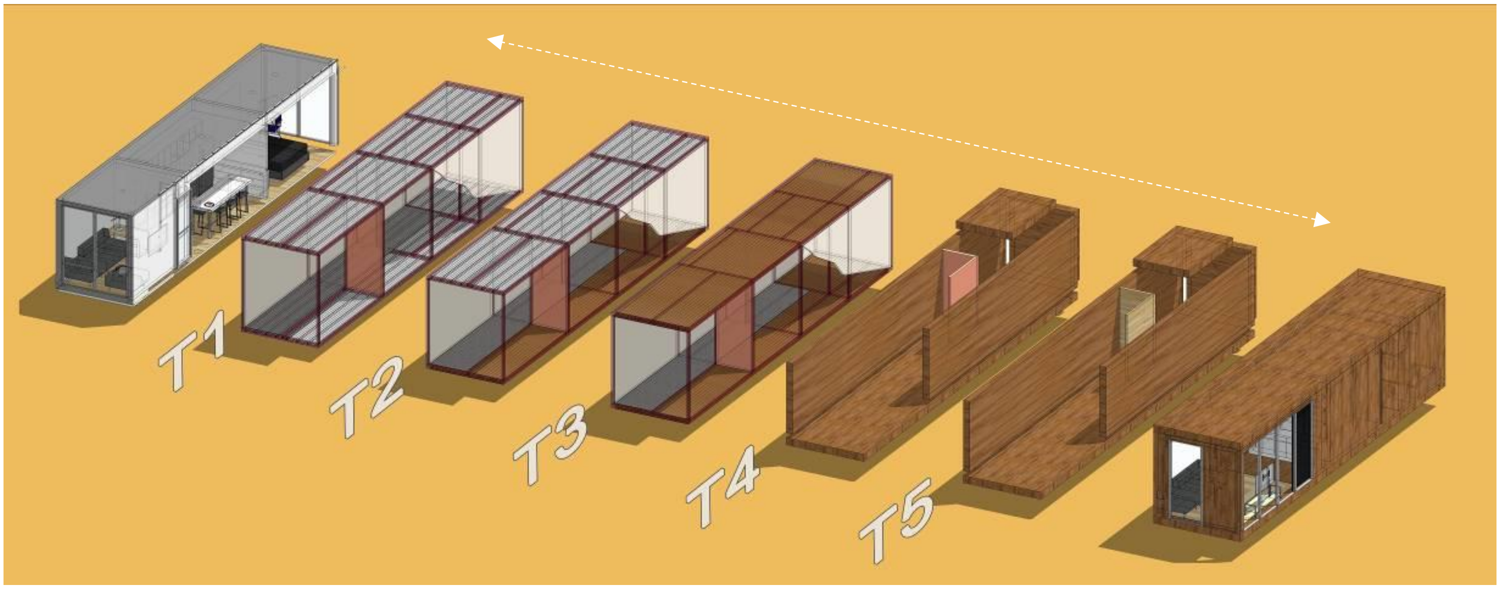


Figure 4.14 Combination of construction materials. The modules on the left start with a steel and drywall system, which raise towards the right with mass timber panels and wood interior divisions. The first and last module illustrate designs using both of these materials.

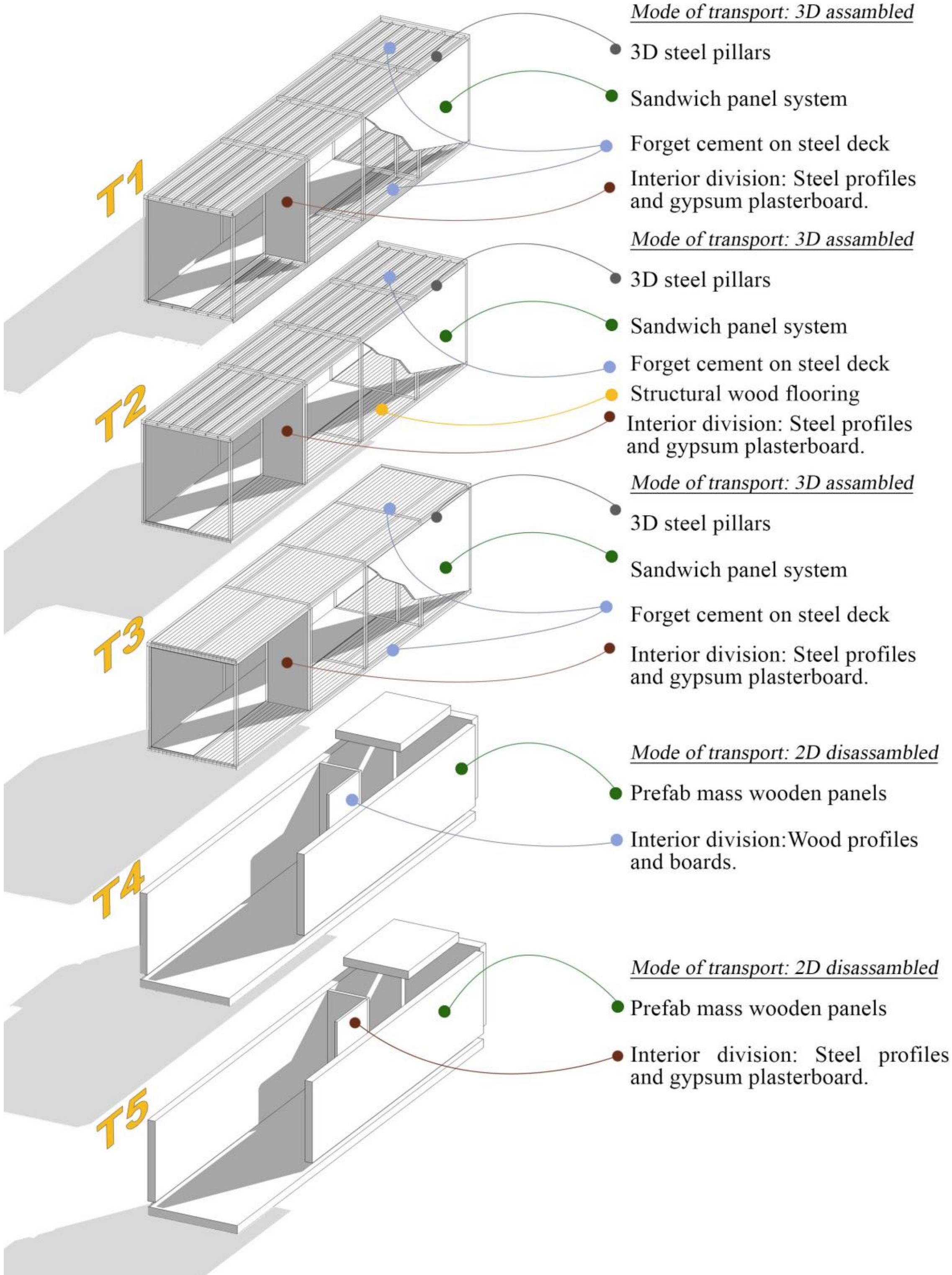


Figure 4.15 Description of material in each typology.

Finally, it is important to note the emergence of new materials that could influence the future of construction and rooftop expansions such as large-scale additive 3D printing (Figure 4.16). So far, the most advanced 3D printers can pour several layers of cement until a wall is built. The system allows to build in almost any shape, which is essential for these tailor-made projects. At the same time, with such a precise system, material and energy waste is almost non-existent. However, the weight and the small space available are still an inconvenience that limits the use of this technology.

Figure 4.16 Left: Layering of the cement walls using a 3D printer by New Story. Right: Same house finished. Source: Rob Reuland, Designboom website, "3D-print a home in 24 hours, a game changer for global homelessness" March 18, 2018

4.3.3 Structural design

More often than not, architects start to design and then accommodate the structure to support the design. Although this may be a common practice in architecture, it should not happen in rooftop expansions. For rooftop expansions, architectural design needs to begin by determining the loads available to then design based on those. At the same time, the structure below and the transportation of prefabricated modules should be considered. These two parameters are crucial given that the junction of the modules has to be supported by its structural components.

A common misconception is that old buildings cannot support any additions on top of them unless extensive structural work is done. Although it is the case for some buildings, others can support it by replacing unnecessary heavy loads for lighter ones. Construction technology advances have brought forward new materials and equipment that reduce the need for old, non-structural, and redundant elements. So, the recommendation is that designers and developers remove all the unnecessary loads like non-structural brick and stone divisions, brick storerooms, concrete rooftop water tanks, storage units, and stair exits. As a result the building will reduce the stress on the structure and therefore less structural reinforcement. As it is explained in the following fragment by Moran, if the building relives enough load, the project will not need major structural reinforcements and, thus, becomes feasible.

> Often there is no need for reinforcement, but each situation is different and must be tested. 'You can either do it or you can't,' affirmed Artés. 'And if it's not feasible, we move onto the next one' (Moran, 2015)

Based on the case studies, two structural works stood up consistently from the rest: footing reinforcements and repairs on the continuity of the structural elements. Other than these two, if more reinforcements are needed, it is recommended to discontinue the project and find another site. The reason for this is that when excessive structural reinforcement is necessary, the project becomes unfeasible and it is financially better to redevelop the whole property. As a consequence, the designer loses the benefits of repurposing the rooftop. The structural recommendation is to make sure that the structure has continuity and is not altered, nor any part damaged. It is crucial to pay close attention to the continuity of columns or bearing-walls, especially when they have been exchanged for a new beam. Similarly, designers need to test the state of footings and the ground load capacity.

The key is to begin by eliminating all the unnecessary heavy elements and use structural reinforcement only as a last resource. This tactic has proven to be more affordable and more accessible than the traditional way of rooftop expansions. An example of this is Girona 81, whose overall building weight decreased even after adding a new floor on top. Another case is Aragó 359, where the 400 m^2 project increased the overall building weight, but the structural design property was capable of bearing the loads without reinforcements other than the two mentioned above.

4.3.4 Further opportunities

4.3.4.1 City preservation

One of the significant challenges cities face is the deterioration of their townscape. The problem is that inhabitants cannot afford its necessary repairs. As a consequence, it induces the progressive decay of buildings and dangerous living conditions for its inhabitants. One solution is rooftop expansions. When designers acquire the aerial rights, they can pay through monetary compensation or in species, through building refurbishments. According to the research, the latter is a better deal for the developer, the property owners, and for the city. It is a micro-scale urban renewal that amortizes the cost of modernizing the city, one renovation at a time.

The challenge designers' face is to convince the building owners to choose the long-term benefits of building refurbishments over the short-term benefits of a typical monetary compensation. Building refurbishments are a necessary and strategic tool for designers who pursue rooftop expansions. It is an opportunity that benefits all.

4.3.4.2 Environmental sustainability

The strategic location gives rooftop expansions remarkable opportunities for sustainable development. Solar, water, and wind energy collection, which is freely available, is the most important opportunity provided by these projects. Rooftop expansions could become a way to update old buildings to the current environmental sustainability measures. Similar to the city's preservation, sustainability efforts can be amortized and implemented within the cost of the new units. New units should be designed for a high environmentally friendly performance. The goal is to include passive design strategies that make use of their strategic location and capture as much energy as possible.

Moreover, the sole notion of repurposing an existing building to create more habitable space is highly sustainable. The carbon footprint needed to build a new structure, circulation, and utilities is avoided by building on top of existent buildings. Some scholars argue that improving the environmental performance of a building has a greater positive effect than building a new one, not only for the aforementioned reasons, but also because the already built surrounding amenities' will be used by more people (Sturgis, 2017).

Lastly, it is understood that a small expansion in itself cannot make a city fully sustainable. However, providing tax breaks to encourage buildings to use these available rooftops with environmentally sustainable projects is a way towards environmental progress.

4.4 FINAL REMARKS

4.4.1 Research question

How effective is the use of rooftop expansions in addressing the needs for housing supply in low and mid-rise buildings in centric neighbourhoods?

As stated before, the key to address this need resides in selecting the right typology of lost space for each neighbourhood. Thus, defining whether rooftop expansions are an effective system or not is highly dependent on the amount of developable land, the integrity of buildings, and the housing market price of each neighbourhood. That being said, this research showes how the urban, economic, and environmental benefits of repurposing these spaces outperform standard methods that address the available space above low-rise and mid-rise housing buildings.

First, the benefits of amortizing the cost of updating the city without sacrificing the buildings' integrity are clear. These gains include the creation of habitable space where there is a lack of it. As a consequence, it not only allows people to live in centric-neighbourhoods, but also reduces the use of transportation and the horizontal expansion of the city. Additionally, the economic benefits of this technique remain equivalent to the standard real estate practices, but its high speed and low-cost entry price open a new market previously unexploited. These benefits are significant to new investors that are looking for a cheaper real estate investment and a faster return on it. Lastly, the environmental benefits of building in unused spaces by repurposing rooftops returns an excellent profit to the city. Rooftop expansions amortize the value of renovating buildings and allows to take advantage of the natural resources freely available, thus, improving the city's energy performance.

Notwithstanding, gentrification and the elevated prices of acquiring rooftop expansions are still big challenges that need to be solved. Furthermore, the bylaws of what is appropriate for a rooftop expansion remain vague. Addressing this issue should be a priority for authorities so that roof expansions do not become a risk to the city's heritage, as it happened in 1960's Barcelona. Given the aforementioned advantages and disadvantages of rooftop expansions, it is quite possible that other fields like civil engineering and urban planning will venture beyond the architectural principles of these projects and debate over its effectiveness to meet Montreal's housing needs in urban-centric neighbourhoods. It is clear that rooftop expansions are not a cure-all to urbanization and that they also pose different concerns, but it is also true that they are an underrepresented alternative that awaits to be adopted along other categories of lost space in the 21st century-city.

4.4.2 Sub-question

What strategies can be considered in the design of a rooftop expansion of low-rise and mid-rise housing that do not meet the maximum FAR?

The primary finding of this investigation is that the design and construction principles necessary to make rooftop expansions are relatively simple. However, the innovation comes in the synchronization of the critical tactics involved in the process. The last chapter of this report outlined and explained all of these to develop rooftop expansions successfully. Specific features, like promoting a holistic building update, exchanging loads instead of structural reinforcements, using of low-weight prefabrication materials, recreating façade designs, creating an apartment layout that copies the building below, and the use of simultaneous construction operations have proved to work efficiently. To conclude, it is important to stress that the ideas presented here are not meant to be a fixed manual because that would imply that every building is identical. Instead, these guidelines should be adopted as a toolbox that designers can adjust to the different conditions each development has.

4.4.3 Final conclusion

It is clear that there is an opportunity to find space where there seems to be none left. The broad notion of lost-space and flexible architecture is directly linked to the current needs of space within urban centres. It may seem challenging to develop these projects but this paper has deconstructed the building process and outlined the resources needed to start conquering rooftops. Certainly, rooftop expansions are not understood as a panacea that will solve every issue regarding the increasing urbanization trend. Instead, it is seen as part of the broader initiative of lost-space as a development platform for the 21st-century city, where designers take into account the stock of underused micro spaces and develop habitable spaces from these.

The previous century sought a great expansion towards the occupation of cities' ground floors. Now that this resource is almost extinct, designers need to find new ways to meet the cities' current necessities and conditions. The key is to define the typology of lost space that is best suited for a given neighbourhood. For example, some areas might be prompt to a large stock of abandoned warehouses, but in other areas, where buildings and land are occupied, rooftop expansions might be the paramount resource.

LCT's case study played a vital role in illustrating the architectural and urban outcomes that rooftop expansions have in consolidated cities like Barcelona. Additionally, the research presented evidence that building on top of buildings is not a new practice. In fact, it has been done for centuries in either informal or formal settings. However, when done in inappropriate ways that destroy the townscape of the city, it is dangerous or economically unfeasible.

It is important to note that not all rooftops are considered rooftop lost space. They must have available FAR and building height, and their structural integrity needs to be able to withstand the expansion without needing major structural reinforcements. The first challenge towards conquering roofscapes is to spot the ones suitable for this technique. Then, it is to establish a network of processes that enables the development of them. Finally, it is to design and construct using light-weight materials, prefabrication, simultaneous construction, and building refurbishments. Finding and intervening in this type of lost space is crucial since it will empower new players to fill these gaps across urban landscapes, as well advancing the practice to new ways of developing housing in dense urban areas.

Finally, the livability of cities depends on all the simultaneous ways cities get built every day. The old paradigm of densifying city centers by demolishing large areas of cities are being challenged due to their adverse effects. One alternative is the use of rooftops to meet the need for housing. The importance of rooftop lost space should be reconsidered by designers when developing housing in areas where land is scarce and urbanization is pushing the city to its limits. The idea here is to finish building the city that we already have.

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