Barcelona
Catalan Design
Conceptual Circuit
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Incorporated Energy
Low Environmental Impact
Sustainability
Zero Emission

Joan Sabaté

“The project puts forward development of a building standard that aims at closing off the natural material, water and energy cycles.”

Joan Sabaté, Architect and Director of the SaAS, has been in charge of the Ramon Llull University’s (URL) Construction Area for 14 years. He is the creator of buildings that are a benchmark in sustainable construction, as is the case of the Blood and Tissues Bank (Endesa Award 2009 and Sustainable Energy Europe Awards 2011) and the LIMA Model (Government of Catalonia Environmental Award 2009 and Acció 21 Award granted by the Town Hall of Barcelona).

Architecture and Sustainability in the Mediterranean. The Case of the Barceloneta District

LIMA, Low Impact Mediterranean Architecture, is an initiative that aims to demonstrate that reducing environmental impact of buildings in countries with warm climates is viable, both technically and economically. The project, which also improves the comfort and habitability of the building, can be applied to both new works, as well as to rehabilitation. A holistic view of the environmental impact that we are presenting not only includes energy consumption during the building's period of use, but incorporation of construction materials throughout the building's lifecycle, likewise covering the water cycle and aspects such as health and comfort. The Taller Barceloneta, which was commissioned by the Town Hall of Barcelona, is an example of the LIMA Model under real conditions.

Introduction

For thirty years now we have witnessed a transformation in environmentalism that is a result of the pacifist and conservationist movements of the fifties and sixties, leading to a real alternative to the traditional economic and technological model, which carries the name – on occasion excessively frivolously used – of *sustainable development*. This change has been possible thanks to two factors. In the first place, the effects of human activity on the planet and, in particular, on climate change, have been verified. And secondly, in the last few years analysis methods have been developed that allow us to make sustainability values more objective.

The creation in 1988 of the Intergovernmental Panel on Climate Change (IPCC) (www.ipcc.ch), under the sponsorship of the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP), has allowed us to evaluate the effects of human activity on global warming and its possible environmental, economic and social consequences, with hard scientific data. The four reports that have been presented in the last twenty years allow us to verify the man-induced effects on the planet's global warming and the risks that arise if the conditions of the current development model are not modified. One of the most crystal-clear conclusions is the need to reduce CO_2 emissions and other greenhouse effect gases (GEG), encompassed under the CO_{2eq}[1] index, down to the levels that existed prior to the industrial period.

1 In order to use a single denominator to measure the entire GEG, the term CO_{2eq} has been used, which adapts the potential of the effect of other gases (methane, nitrous oxide, hydrofluorocarbons (HFCs), etc.) to the potential of CO_2.

The study, which was commissioned by the British Government in the year 2006, was carried out by economist and academic Sir Nicholas Stern,[2] Vice-President for Economic Development and Economic Director of the World Bank between the years 2000 and 2003. It analyses the economic effects of climate change on the world's economy. The conclusion reached in this study was that a reduction of the foreseen adverse impacts of climate change is technically and economically viable, as long as strong and urgent action is taken. If these measures are not taken, an unprecedented economic crisis could arise, with continued drops of 5% in the global GDP, which could reach 20% of the GDP if a wider range of risks is considered. The same report also concludes that modification of the climate during the second half of this century depends in great measure on the actions that are undertaken in the next 10-20 years, and that the risks involved if we wait too long could lead to economic and social disruptions comparable to those of the "great wars and the economic depression of the first half of the 20th Century".

Given that the construction industry consumes a great amount of energy, an improvement in building efficiency is a key factor in order to reduce global emissions of CO_{2eq}. At this time it is estimated that 40% of the EU's total energy consumption is due to construction, with a tendency to increase in the coming years.[3] Likewise, the industry must incorporate a series of mitigation strategies that will allow maintaining the habitability of the buildings once the effects of climate change have taken place, in particular the generalised increase in temperatures, heat waves and the reduction in water resources.

An effort has been made in the past few years within the scope of the EU to reduce the environmental impact of buildings, which has translated into a reduction of the energy consumption of new buildings and, to a lesser extent, in energy rehabilitation. At any rate, this reduction has been limited to consumption during the expected lifetime of the buildings, without taking into consideration the energy that is needed to build and maintain these buildings, the so-called *embodied energy.*[4]

As an example, the National Emission Rights Assignment Plan 2008-2012 of the Spanish Government attributes 20% and 8%, respectively, of final energy consumption to the domestic and ancillary sectors, which represents slightly more than 30% of total emissions. Emissions generated by the manufacturing of materials such as steel, cement, ceramics and glass are dealt with separately in the same document, hence they are not included in those corresponding to the building sector.

The most developed countries are leading the way in the effort to reduce consumption. These countries are basically located in the northern hemisphere, in particular in northern and central Europe and, just recently, the United States. In this regard, to date Catalonia has unfortunately not made an effort that is proportional to its economic potential and capacity for innovation.

This circumstance would explain why efficiency improvement technologies for buildings have been focused on reducing consumption arising from heating and the production of sanitary hot water (SHW), on improvement of lighting systems and on the production of heat and electricity with renewable sources. On the other hand, it has not undertaken development of adequate technologies with the same intensity for countries with temperate and warm climates. Apart from the problems noted,

2 Stern, N. *The Stern Review: The Truth About the Climate Change*. London: HM Treasury, 2006.

3 "Directive 2002/91/ec of the European Parliament and of the Council of 16 December 2002 on the Energy Performance of Buildings." In: *Official Journal of the European Communities*. Legislation. No. 46, Part 1 (2003), p. 65-71. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:001:0065:0071:EN:PDF

4 Embodied energy is the energy coming from non-renewable resources that is required to generate a certain product. This includes extraction of raw material, transport, manufacturing process and its placing at works. Subsequent deconstruction, recycling or energy that can be obtained (or saved) by recycling have not been taken into account in the process due to the complexity involved in its calculation.

these countries must confront another series of specific matters, such as consumption generated by air-conditioning used in the summer or the reduction in the consumption of water in order to address the drop in the hydrological regime.

In the case of the Mediterranean area and other temperate areas of the planet, the IPCC[5] foresees a drop in rainfall that could reach 20% by the end of the century, with a notable increase in periods of extreme heat.

On the other hand, it is to be highlighted that improving new buildings in order to achieve a net reduction in CO_{2eq} emissions is not enough. The most important efforts will have to be made in energy rehabilitation of existing buildings. Decision 406/2009/CE of the European Parliament and Council establishes the intensity of CO_{2eq} emission reduction for the year 2020 with regards to 2005 for each country. In the case of Spain, the percentage stands at 10%. In order to achieve this reduction, the rate of annual rehabilitation will have to be increased by 2.5% (about 60,000 housing units on an annual basis in Catalonia),[6] with an average reduction in energy consumption for subsequent use (not only heating) following rehabilitation surpassing 45%.[7]

These rehabilitation policies must be conceived in such a way that they include the urban or natural context in which the building is found. The traditional Mediterranean city model, with an average-high density that favours relationships and limits displacements, incorporates a compact network of streets and squares that encourages social life. This recognised urban model is also a good model of efficiency, given that apart from including neighbourhood facilities and shops or public transport, it seeks to establish services that require a high number of users: urban heating and cooling networks, rainwater collection networks, second use water supply (domestic waste water, groundwater or water from purification plants) and waste treatment, among others. However, in order to use this potential it will be necessary to fight against excessive fragmentation in thermal production, water treatment or renewable energy production, which in good measure is a consequence of individualism, a feature that is also distinctively Mediterranean.

It will be necessary to develop a viable strategy for reducing the impact of buildings in all these dimensions in the coming years. This strategy will have to include the buildings' life cycle – specific problem for temperate countries. It must also include energy and environmental rehabilitation as a priority and the adoption of a high efficiency urban model. The commitment to closing-off the material, energy and water cycles and on the improvement of the health and comfort conditions of the buildings should make it possible to reverse this situation, hence transforming the problem of climate change and the drop in hydrological regime – categorically announced by the IPCC – into a lever for improving competitiveness of the Catalan economy and the country's progress.

LIMA, Low Impact Mediterranean Architecture

LIMA is an initiative that aims at influencing the search for sustainable buildings within our geographic, climate and cultural scope, apart from demonstrating that a drastic reduction of the impact of residential buildings in the Mediterranean area – and likewise in countries with similar temperate climates – is indeed viable.

5 Bates, Z. W. [et al.]. *IPCC Technical papers 6 [climate changes that have been observed and planned in relationship with water]*. Geneva: IPCC Department, p. 27.

6 According to the Statistical Institute of Catalonia (IDESCAT), in 2007 there were 2,782,300 main housing units in Catalonia; not counting those corresponding to the 2005-2007 period, we can estimate 2,500,00 first residence housing units in the year 2005.

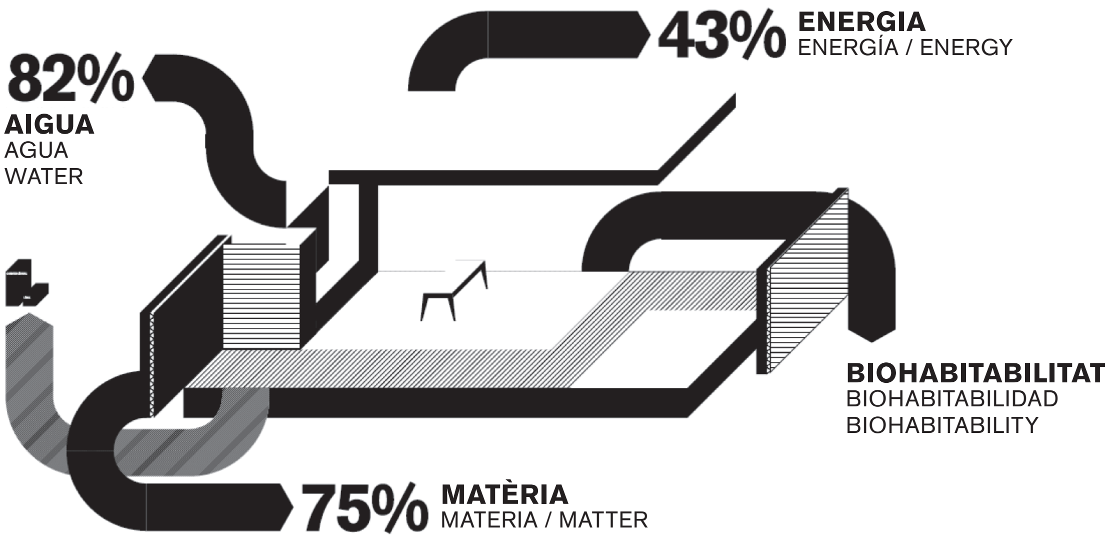
7 Rehabilitation that involves a reduction of 45% is viable but complex; 2.5% of the annual rehabilitation rate implies rehabilitating 22.5% of the housing units that existed in 2005 in the next nine years. With a reduction of 45%, it is possible to achieve a cutback in emissions of 10.10%.

The project, which is headed by SaAS, Sabaté Associats Arquitectura i Sostenibilitat (www.saas.cat), puts forward development of a building standard that aims at closing off the natural material, water and energy cycles, and it incorporates measures to improve the health and comfort of the users, grouped under the concept of *bio-habitability*. This system must be adequate for the construction and rehabilitation of housing units, be these private or under a public protection regime and, therefore, it includes schools and other facilities with similar characteristics.

The first prototype was presented at Construmat 2009 under the slogan "This is not a house… this is a tool for transforming the future." This experimental model was subsequently transferred to the Ramon Llull University Campus, where it is currently in a verification phase. The process is divided into two phases. In the first, which will be developed up until

▲ Taller Barceloneta

◄ Assembly of structure with plywood wood structural panels



▲ The LIMA project is based on four important areas: Material, energy, water and the health and comfort of users

the end of December of 2011, operation of the model under established conditions will be evaluated with the simulated presence of two users. Thermal and water steam loads equivalent to this occupation have been arranged, including sensitive and latent heat let off by the users, sensitive heat from illumination and appliances, and water steam from the shower. This monitoring allows us to obtain data, under calculation conditions, on real consumption of the module during the winter and summer and verify the precision of these simulation tools.

During a second phase, which is to take place under real conditions, other aspects will also be considered, such as operation of the geothermal climate control systems (Provencal wells), the complete water cycle and various verifications pertaining to the health and comfort of the living quarters.

The LIMA project is based on four important areas: Material, energy, water and the health and comfort of users. The objectives in these areas are focused on defining indicators and standards that can be technically and economically achieved and also on obtaining reliable cost-benefit ratios corresponding to each improvement action. LIMA leaves no footprint.

Material

Life cycle analysis (LCA) of the material is a technique to assess the various environmental impacts that material can give rise to and the search for alternatives to reduce the same. An important part of energy consumption during the standard lifetime[8] of a building is dedicated to manufacturing the materials that make up the same, transport of the material and its installation at the work site. This is a very short period of time, which may last between one and two years, yet it is intense in terms of consumption. This embodied energy[9] is responsible for 30-40% of the buildings CO_{2eq} emissions during its entire expected useful lifetime.

LIMA's proposal is to substitute materials that require more energy for their manufacturing or

8 Considering 50 to 60 years for the purpose of calculation.

9 Energy consumed in raw material extraction and transformation processes, transport to the worksite, the construction process, maintenance carried out during its period of use and subsequent dismantling and assessment of waste once the expected lifetime has reached its end is denominated *embodied or gray energy*.

that have greater impact on the environment with renewable materials obtained from the biosphere or with recycled material. One of the conclusions pertaining to the consideration of embodied energy is the interest in rehabilitation in view of the increase of new buildings, as the first option directly eliminates part of the need for new energy due to manufacturing of the materials.

The two buildings that are based on the LIMA model, the experimental prototype and Taller Barceloneta, have been basically constructed with material of plant origin. Sixty percent of the material is renewable, of plant origin (wood or bamboo) and 20% is obtained from recycling (compost, soil, gravel, metal, etc.) in such a way that only the remaining 20% corresponds to first-use material (basically the installations).

By substituting materials such as concrete, steel and aluminium – manufacturing of which exacts high energetic levels – with materials of plant origin, we can reduce both impact and emissions. It is not so much that plant origin materials require less energy in order to be produced and transformed, but that they are in fact lighter materials (hence a reduction in transport, infrastructures and foundations) and, what's even more important, they act as carbon sinks, given that they seize CO_{2eq} from their natural cycle. In this sense it is important to take into account that vegetation absorbs CO_2 during its growth period, it is neutral in its adult stage and once it has died off it returns the carbon it has absorbed into the environment in the shape of CO_2 or methane. Thus, if plant material is used and it is neither burned nor rotted, the cycle is broken and the carbon that has been previously extracted from the air is captured.

Energy

The second important phase of energy consumption corresponds to the period of use. This is energy consumption that is metered by the electricity and gas meters[10] and consumption generated by climate control (heating and air-conditioning), production of hot water, illumination and appliances or other equipment. From among all these consumptions in traditional buildings, the most important is HVAC systems. What's more, this is the area that is most highly linked with the building's construction systems.

In order to reduce the energy demand resulting from climate control, first of all we have to ensure a thermal cover (insulation, thermal inertia, solar contributions and protections) and then improve the efficiency of the installations (climate control systems, appliances and illumination) and use control mechanisms that will allow management of use in a rational way.

In order to minimise energy consumption during the building's period of use, LIMA proposes an increase in insulation and solar protection, in-

▼ "Quarter house" module in the Barceloneta District

10 Energy measured by computers "on-site" is known as *final energy*.

corporation of thermal inertia in the cover (preferably with plant origin covers), control of ventilation according to occupation and use of heat recovery systems, incorporation of control and management systems, and use of low-energy lighting and bi-thermal class A+ and A++ appliances.

As far as thermal production is concerned (heat-cooling), we consider that it is best to opt for the efficiency of centralised systems – both for the building, as well as the block or district –, production of distributed electricity (with cogeneration systems that allow recovery of residual heat) and use of renewable energies (solar, thermal, photovoltaic, wind, biomass, etc.).

The LIMA prototype, which is based at the Ramon Llull University, has a demand of 2.26 kWh/m^2·l per year for heating and 9.16 kWh/m^2·l per year for cooling,[11] with which a reduction of 97.4% in CO_{2eq}. emissions is achieved in comparison with a traditional housing building.[12]

Water

One of the results of climate change in the Mediterranean will be the reduction of rainfall. In order to reduce the demand for water, low consumption taps and appliances will have to be adopted. Likewise, the sanitary quality of the water must be adapted to each specific use, reusing the same in the urban context or for the building itself, and we must take advantage of local sources such as rainwater or groundwater.

With the LIMA prototype, drinking water consumption is reduced by 50% by using low consumption taps and appliances, rainwater recovery for irrigation and washing machine use, grey water from the shower for toilet flushing and biological treatment of waste water. Part of this process could be developed for urban use.

Bio-habitability

The LIMA project not only reduces the negative effect of buildings on the environment, but also improves the health and comfort of users. It controls the comfort conditions of the spaces (temperature, noise, light, air quality, etc.); improving the health conditions generated by biological agents (micro-organisms, spores, fungus, etc.), chemical agents (volatile organic compounds, carbon monoxide, carbon dioxide, etc.) and physical agents (hygrometry, electrostatic, etc.); intensities of electrical and electromagnetic fields and natural and artificial radioactivity.

The Taller Barceloneta

The LIMA module which has been installed in the Barceloneta district, covers the Barcelona Town Hall's need for a space for management of the Districts Plan and it likewise promotes participation of the neighbours in its establishment process.

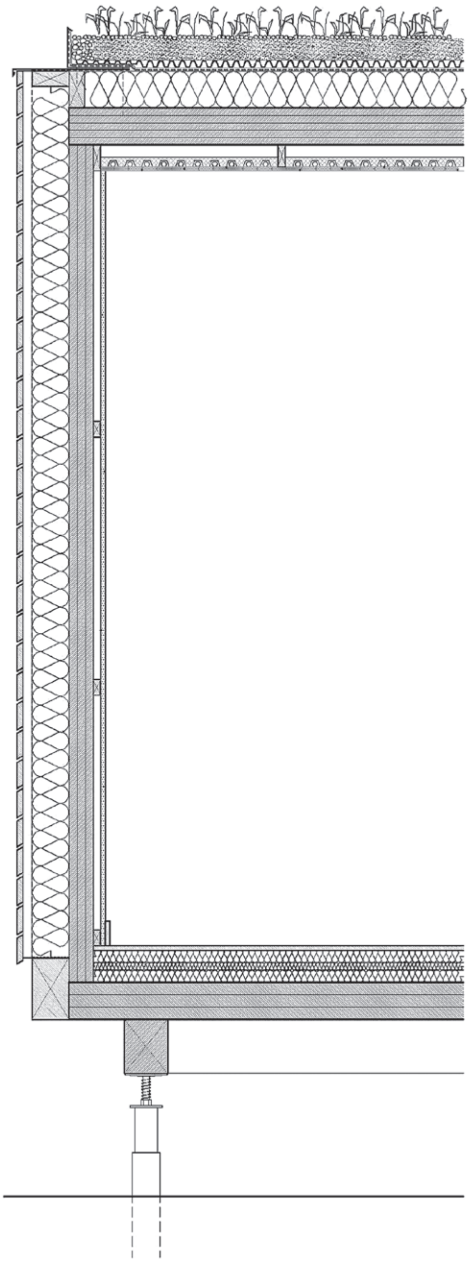
The architectural proposal is based on the specific geometry of the district's housing units, 8.40 × 4.20 m "quarter house" module, which is multiplied by four, forming a longitudinal rectangle measuring 16.80 × 8.40 m. Two of these modules are taken up by closed spaces, meeting rooms and service rooms, while the other two are designated for working spaces and neighbourhood attention services. A fifth model corresponds to the exterior space, thus extending the public area, and it is defined by a wooden platform and a pergola that that can be used in the summer or winter.

One of the most serious problems encountered in the Barceloneta district is the lack of space in the housing units. This district, designed according to military instructions, was built in rows of two-storey buildings, measuring 8.40 m × 8.40 m, in open blocks, with streets on both sides and without interior patios. This way the inhabitants of the neighbourhood were unable to elude military controls.

Growth of the population and a lack of available space in the city, which was still militarised since the Siege of Barcelona defeat on 11 September, 1714, forced consecutive splitting of the current

11 Calculation made with THERMPLAN, by Doppelintegral GmbH, experts associated to the Centre of Applied Research – Sustainable Energy Technology (zafh.net) of the University of Stuttgart, Germany.

12 That is, a benchmark building, with the same geometry, orientation and interior loads as LIMA, which complies with the minimum efficiency rates defined in the Technical Building Code (TBC).



◄ Cross-section of the wooden prefabricated module of the LIMA prototype

ROOF
-Substrate for extensive roofs, 70mm
-Polyester felt and PP
-Drainage and water storage, PE
-Filtering layer, PP fibres
-Waterproof sheet, EPDM
-Polyester felt and PP
-Wood fibre insulation, 120mm
-Vapour barrier,
-Structural plywood panel, 125mm
-Plasterboard, timber substructure (50 x 50), 15m

JOINERY
-Larch wood joinery i=6/15/3+3 glass laminates
-Exterior blinds, adjustable and foldable aluminium slats

FACADE
-Wood boards on timber substructure (30 x 50) 19mm
-Ventilated air chamber, 30mm
-Semi-permeable panel
-Wood fibre insulation, 120mm
-Plywood structural panel, 108mm
-Ventilated air chamber, 30mm
-Plasterboard panel, timber substructure (30 x 50) 15mm

WROUGHT IRONWORK
-Bamboo wood flooring, 15mm
-Wood fibre insulation, 30mm
-Polyester felt and PP
-Ballast, 60mm
-Polyester felt and PP
-Structural plywood panel, 125mm
-Cellulose insulation, 40mm
-Ventilated air chamber, 10mm
-Plasterboard panel, timber substructure (50 x 50), 15m

LOWER ROOF
-Floating bamboo wood flooring, 15mm
-Wood fibre insulation, 100mm
-Plywood panel, 125mm

buildings. First of all two housing units were built in each building, one per floor; later on each one of the resulting housing units was again divided into two. Hence, from a first area of 141.12 m^2, an average housing unit measuring 70.56 m^2 was finally reduced to a "fourth of a housing unit", measuring 35.28 m^2.

It is precisely these minimum "quarter house" modules that have now been recreated, with the idea based on visualising the size of the space in which most of the district's neighbours actually live. The workshop's floor is used to reproduce, in plaster, the floors and layout of the housing units that are to be refurbished so that each one of the affected neighbours can cross through the spaces of their own homes.

This "quarter house" idea has been reinforced both in the configuration of the floor, as well as in the façades, the same with three compositions: In the shape of flat, blocked (blind) or pane-glassed plans, or with three vertical openings, which bring to mind the balconies of the original housing units.

One of the operations foreseen in the planning, which has given rise to much controversy, is the possibility of increasing the height of some of the existing buildings, in particular those that still survive with the original two stories. In a district with average heights of about six stories, buildings with only two stories tend to be hidden away among the other buildings. An increase in their height could slightly increase development potential and might contribute to financing of the rehabilitation of the whole.

Following in the same line, the proposal of the Taller Barceloneta was to use prefabricated wooden module systems in order to increase the height, obtaining a higher level of comfort than with the traditional model, and with more reduced façade thicknesses. In this scenario, reduction was of paramount importance. Going from 30 cm to 20 cm thickness is equivalent to increasing the useful area by 0.84 m^2, almost 3% of the 30 m^2 of useful area of the "quarter house" units.

The construction systems used were the same as the LIMA prototype model. The idea is based on big spruce plywood panels, floor-to-ceiling height and with a length equivalent to the entire module between windows, up to 8.40 m. These five-layer, 64 mm-thick panels, are reinforced on the exterior – to avoid any warping – with a span of vertical 120 mm slats, between which wood fibre insulation is placed. The roof is also in accordance to the same plan, with 110 mm panels, supported by the perimeter walls and on an intermediate crossbeam that defines the "quarter house" module. It features exterior wood fibre insulation, EPDM (ethylene propylene diene monomer) waterproof sheet and extensive plant cover. The whole is placed on a floating concrete screed, supported on extruded polyester insulation.

Laminated larch wood carpentry with double glazed 6/12/3+3 pane, low emission sheet and argon-filled cavity. All the window frames have great thermal conditions, with $U < 0.3$ W/m^2 K thermal transmission and the glass and frame included in the carpentry $U < 1.7$ W/m^2 K.

The exterior façade finishing, in like manner to the LIMA prototype, is handled with a rear-ventilated sheet made of horizontal larch wood panels. This sheet includes sliding shutters with the same finishing, which allows the building to be closed-up, just like a box, when the centre is not in operation. This type of closing is not traditional in the neighbourhood and is motivated by the desire to ensure that the plant origin and provisional nature of the Taller Barceloneta is clearly evident.