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Urban sustainability as the result of a carefully integrated process: Case study of a new urban development on the Barcelona seafront

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Abstract – **An in-depth understanding of the basis of urban sustainability in urbanisation involves tackling a carefully integrated process. By means of a holistic guiding concept pushing the boundaries in the sustainable design of buildings, this article describes the development plan drawn up to reurbanise the seafront "Área de las térmicas del Besós" in Barcelona. This combines residential and tertiary uses, infrastructure and also free areas for museum use in a great industrial building home to a former power station. The current plan will add a kilometre of beach to be used and enjoyed by the citizens of Barcelona. It will also provide the municipality of Sant Adriá de Besòs with access to the sea.**

The plan's most original contribution lies in its aim to collaborate towards sustainable urban development. It sets out to do so by incorporating strategies not only on an urban scale, but also on an architectural scale and even introducing landscape and green elements into the design. This methodology will facilitate the generation of urban growth with a minimum environmental impact and with low carbon emissions.

Keywords; Barcelona seafront; sustainable urban development; carefully integrated process; the garden tower.

I. INTRODUCTION

With this century witnessing 15 of the 16 warmest years since 1880, climate change is irrefutable. A majority scientifically supported by the 195 countries to have signed a pact against climate change links the warming of the planet to human activity.
Due in particular to the greenhouse gases that are emitted when fossil fuels are burnt to generate energy, either to produce electricity or for transport

The accumulation of greenhouse gases in the atmosphere is also at record levels, with the Earth no longer cooling at the same rate as before. Countless scientific studies predict catastrophic effects if we fail to curb global warming. An upper limit has been set at 2 degrees Celsius, with a commitment made at the last climate summit in Paris to ensure that the increase in the average temperature by the end of this century does not exceed 2 degrees above pre-industrial levels, even lowering this limit to 1.5 degrees, if possible.
To achieve this target, emissions of greenhouse gases must be limited, while the signatories of the Paris agreement must reduce their CO_2 emissions to the agreed levels to be implemented as of 2020.
If the promises and the international commitment made by the 195 countries in December last year in Paris are to be taken seriously, we should be on the threshold of an energy revolution that will unquestionably affect Architecture and Urban Planning.
Taking into account that the construction sector in the EU (building + urbanisation) consumes 48% of the total energy and produces 46% of carbon emissions, it is clear that this objective directly affects how we plan new urban developments, and design and construct buildings. . 1

I. THE BESÓS POWER STATION AREA

The only zone of the Barcelona seafront that has not yet been urbanised is located on the left bank of the mouth of the River Besós. This seafront area of 28 ha, which includes

[1] Syntesis Report ARS, panel intergubernamental contra el cambio climático (IPCC), Fifth Assesment Syntesis Report, 2 de noviembre de 2014

almost one km of beach, is known locally as the “Área de las térmicas del Besós” (the Besós power station area).

The current image of this polygon of the Master Plan for the Metropolitan Area of Barcelona is dominated by a distinctive building with three 220 m chimneys. This was once a power station, but now forms part of the historical memory of Barcelona. “Fig. 1”

Until its closure in 2011, this building supplied an important percentage of the electricity consumed in Barcelona. It is now the last visible sign of what was once the great industrial area of the “Poblenou” area of the city and of what (towards the end of the 19th century) had been referred to as the Manchester of Catalonia.

The celebration of the 1992 Olympic Games and the 2004 Universal Forum of Cultures signified the dismantling of the old, and then obsolete, industrial metal-working and chemical plants and their transfer to other industrial areas. This also opened the door for property development along the Barcelona seafront. This urban renewal of the city’s seafront would probably have also reached the power station area if the process had not been interrupted by the bursting of Spain’s property bubble in 2008. This also heralded the onset of the present crisis in country’s construction sector

Figure 1 the existing Installation in 2004

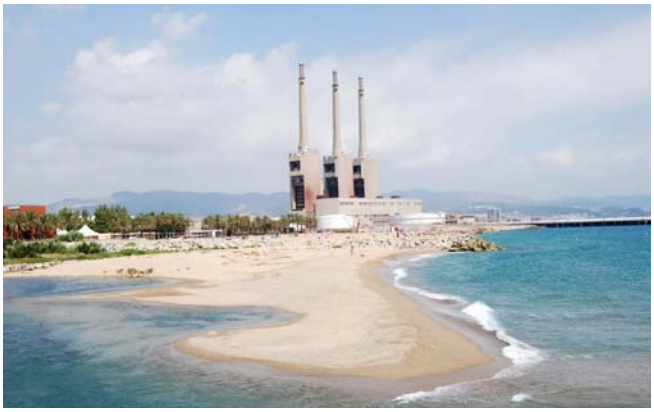


Figure 2 Present-day view of the former power station building and the area subject to the Plan

II. THE URBAN DEVELOPMENT OF SANT ADRIÁ DEL BESÒS

A. Origins and previous urban development policy.

Sant Adriá de Besòs is a municipality with a current population of 35,000 which lies within the metropolitan area of Barcelona. To be a little more precise, it is located in the delta of the River Besós, between the municipalities of Barcelona, Sta. Coloma de Gramanet and Badalona. “Fig. 2” This urban nucleus originated in the second half of the 19th century. It was the product of the industrialisation of an area across which a railway line - the first on the Iberian Peninsula - was constructed between Mataró and Barcelona in 1860. [1]

Figure 3. Location of the the Besós area inside metropolitan Barcelona

Throughout the later 19th century and during the first half of the 20th century, large-scale industry was attracted to the areas along this railway line. This blocked access to the sea from the city of Barcelona in this area. This lack of access continued until extensive urban remodelling was carried out in preparation for the 1992 Olympic Games.

As a result of the large-scale industrial development of the metropolitan area of Barcelona in the 1970s, the Besós delta was colonised by a wide range of different types of informal housing which provided accommodation for successive waves of migrants.

The first urban nucleus, which consisted of rather precarious, self-built housing, was formed by what were popularly known as the “barrio de la Bota” (Bota neighbourhood) and “el barrio de La Catalana” (the Catalan neighbourhood). These settlements mainly housed migrants who had arrived in Barcelona from the rest of Spain, looking for work in the city’s large industrial areas. This was also when the great Besós power station was constructed next to the sea in order to provide electrical energy for all of the industry in the surrounding area.

This predominantly precarious housing situation and the informal nature of this settlement continued until the 1970s, when the La Mina neighbourhood (with 2,800 housing units) was constructed in order to rehouse the inhabitants of this marginal housing. [2]

B. Major events

The great urban transformation of the whole seafront of Barcelona occurred as a consequence of the city hosting the 1992 Olympic Games. As a consequence of this major international event, heavy industry was moved away from this area and the city regained access to the sea. As a result, the coastal strip acquired the new, urban residential and service functions that now form part of the great beach of Barcelona. “Fig. 3”

Figure 3. Current city map of Barcelona with the Besós area on right side

The 1980s saw the creation of the Besós Consortium, whose main function was to channel and generally clean up the River Besós and its immediate surroundings. This also included supplying some major environmental infrastructure, including an open-air treatment plant for waste waters from the Besós basin, in the area nearest the mouth of the river.

Coinciding with the celebration of the Universal Forum of Cultures, in 2004, “Fig.4” this waste water treatment plant was covered, a solid waste incinerator was constructed and a gas-powered and a local district heating (districlima) were built. This made it possible to take advantage of residual energy in order to provide hot and cold water for the whole neighbourhood of Poblenou.

Figure 4. Present-day view of the Forum of Cultures area

The use of new technologies to generate electricity based on less polluting sources rendered the old Besós power station obsolete, with it definitively closing in 2011.

At present, the building remains as the last visible sign of what was once the great industrial neighbourhood of Poblenou, “Fig. 5” and what had once been known as the “Manchester of Catalonia”. [3]

Figure 5. The area subject to the Plan in 1992

III. BASIS FOR THE URBAN PLANNING OF THE POWER STATION AREA

A. The metropolitan environment

The part of the Besós area known as “Barcelonès Nord” currently includes a continuous urban area with a population of 365,000. The vast majority of its inhabitants occupy high density housing distributed amongst with industrial estates that are subject to a process of urban transformation. [4]

Within this urban context, the Besós power station area is one of the elements earmarked for urban remodelling under the 1973 Master Plan for the Metropolitan Area “Fig. 6”.

Figure 6. Areas of urban transformation and consolidation along the Barcelona seafront and in the Besós area: new areas of centrality and major amenities

B. Biodiversity

As a consequence of its strategic position at the mouth of the River Besós, the study area is of great environmental value and needs to be both conserved and further exploited.

The river basin itself forms an ecological corridor between the sea and the coastal uplands and boasts a rich biodiversity.

Various public administrations have carried out projects to improve and restore the local environment and this has resulted in water of good quality and has helped to turn the banks of the river into a linear park “Fig.7”.

Figure 7. Biodiversity

C. Water Resources

The River Besós is the second most important river in Barcelona's metropolitan area. It has a water basin of some 1,000 km2 with a very irregular regime, which is typical of a Mediterranean climate.

In the past, the Besós delta aquifer served as a source of water for the city of Barcelona. However, in the 1970s and 1980s, it suffered a process of salinisation. This was the result of its overexploitation and the invasion of sea water, though it is now protected from such problems.

Part of the aquifer corresponds to the subsoil under the power station, which includes a large reserve of fresh water that prevents the invasion of sea water. Although this provides protection, the use of these waters that lie under the riverbed could also prove problematical as they have been polluted as a result of their recent industrial use "Fig. 8".

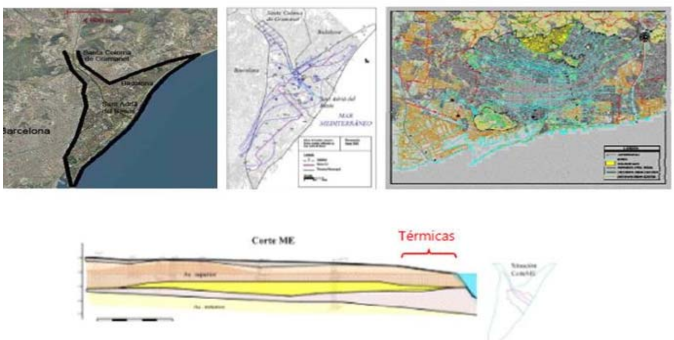


Figure 8. Water resources, (groundwater).

D. Energy resources

1) Energy from waste

The major industrial installations located on the right-hand bank of the River Besós and, more specifically, in the Forum area, are based on cogeneration.

They include a solid waste incineration plant, a waste water treatment plant and a gas power plant. All of these installations generate energy from waste in the form of electricity and heat. The Metrofang power plant makes it possible to recover 100% of the heat energy obtained from burning waste and the PVE incineration plant makes it possible to recover 30% of the energy in the form of electricity. This energy then feeds the district power station (districlima) and provides hot and cold water to the Poblenou neighbourhood. Given its proximity, it could also supply energy to the area of new urban development around the power stations.

2) Renewable forms of energy

The potential for generating energy based on renewable sources is very high:

- Photovoltaic solar energy
- Solar thermal energy
- Eolic (mini, onshore, offshore)

The proposed installations combine these different strategies to achieve the maximum energy rating of the CTE in the new buildings. This is achieved by using waste energy from the major treatment plants in the area and also by taking advantage of renewable forms of energy that could be used to cover 100% of the demand for energy "Fig. 9".

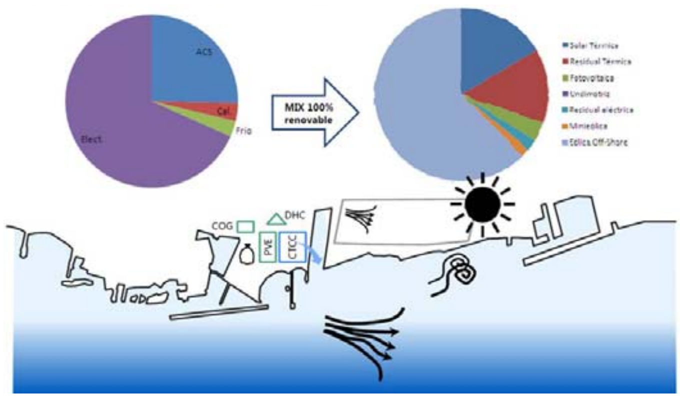


Figure 9. Energy mix

E. Threats: coastal areas facing climatic change

The UN report published on 2 November 2014, which contained a 5,000 page summary of research carried out by 800 scientists, confirmed the existence of climate change and that this is a phenomenon induced by human activity.[2]

Since the 1950s, when the scientific community began to spread the first warnings about climate change, global warming has become increasingly evident. The concentration of CO_2 in the atmosphere has now reached 400 ppm and it has

[2] Synthesis Report ARS, intergovernmental panel against climate change (IPCC), Fifth Assessment Synthesis Report, 2 November 2014

been shown that the average global temperatures rose by 0.85 ºC between 1880 and 2012. As a result, the planet's permanent arctic ice cap has been shrinking at a rate of between 3.5% and 4% per decade since 1973.

This has been accompanied by a progressive acidification of the world's oceans (which has increased by 26% since the preindustrial era) and a rise in sea-level (20 cm, since 1901).

This synthesis report summarised what science knows about the global warming that has taken place to date.

It concluded that if emissions of the three main gases released as a result of the combustion of fossil fuels (carbon dioxide (CO2), methane (CH4) and nitrous oxide (NO2)) are not curtailed, the result will be ever more frequent incidences of extreme meteorological phenomena. An average increase in temperatures of 4.8 ºC is forecast for between now and 2100; this would be associated with an average increase in global sea levels of around 0.82 m with respect to current levels.

This will, without a doubt, have a great impact on coastal areas, with land currently inhabited by millions of people being submerged.

In the words of the co-president of IPCC Work Group III, Youba Sokona, "....What we need are appropriate policies and institutions ....The longer we wait before taking action, the greater will be the cost in terms of adapting to and mitigating climate change...".3

It is for this reason that the challenges are important: Port cities and those with waterfronts face numerous (urban, economic, environmental, etc.) challenges and their reconversion therefore also constitutes an interesting opportunity for their reorganisation and dynamisation.

From the discipline of urban planning, it is necessary to confront the risks to the natural environment associated with climate change. With this in mind, urban planning should seek to incorporate strategies for sustainability that will help to combat climate change through a transition towards a low carbon emission economy. [5]

This is both technically and economically viable and will be absolutely necessary if we wish to prevent the flooding of coastal areas as a result of rising sea levels.

IV. PLANNING GUIDELINES FOR THE NEW MASTER PLAN OF THIS AREA

In the 1976 Master Plan for the Metropolitan Area of Barcelona, the area on the right bank of the River Besós was qualified as one of transformation.

With the transfer of industrial activities and the definitive closure of the old power plant, a very large space has been left free of buildings. This land, which lies along the seafront, covers an area of 28.52 hectares. This is a unique asset that has no equal in the rest of the metropolitan area and is a location that offers centrality and new opportunities. It is well connected to existing transport infrastructure and is therefore easily accessible and well-connected to the major urban axes "Fig. 10".

Figure 10. Position of centrality and relations with the main civil axes

A. General guidelines:

In line with the objectives of the development plan, the City Council employed a holistic guiding concept and proposes the following actions:

To incorporate strategies for urban sustainability in order to reduce the environmental impact of the new urban development. This will help to minimise the consumption of energy, water and other resources, as well as to reduce waste and keep the emission of greenhouse gases to a minimum.

To increase density in the design for the new neighbourhood in line with the Mediterranean tradition. Considering Urban Density as a challenge and an Opportunity for Liveability will help to make the lives of the inhabitants more practically viable, more manageable and more urbane.

To introduce greening not only through green spaces but also by integrating vegetation into the heights of the buildings.

B Specific guidelines:

- To integrate the power station area into the municipality of Sant Adriá. This will permit better access to the sea, provide the area with a beach and also help to consolidate it within the urban structure of "Barcelonès Nord" (Northern Barcelona).
- To connect the area's communications infrastructure and civil axes with those of the rest of the coastal strip.
- To recover the waterfront and provide Sant Adriá del Besós with direct access to the sea and create a new beach area.

3 The fifth UN report on climate change, El PAIS, 3 November 2014

- To provide a mix of different uses: residential, commercial, hotel and tourism services, offices, educational and general activities. All of these will be related to the coastal area and should help to create employment.
- To reuse the old power station building for cultural and/or museum purposes.

C. Urban Planning Standards.

As detailed in Table 1

Total surface area of the new development: 280,526 m2

Density index: 1.60m2cap/m2floor

Maximum surface: 448,841.60 m2floor

TABLE I. DETAILED TABLE OF URBAN PLANNING STANDARDS

% Occupancy according uses		**Surface area**
85% Residential	76,5% Residential	343.363,82 m2
	8,5% Hotels	38.151,54 m2
15% Non Residential	60% Commercial	40.395,74 m2
	40% Offices	26.930,50 m2
100% TOTAL		448.841,60 m2

D. Environmental guidelines

Dividing environmental guidelines into individual modules such as energy, water, greenery and building material waste and linking them in a network has proven to be the correct approach.

1) Energy

Residual energy

- The use of residual energy from major water treatment plants (Metrofang) and from the electricity generated by cogeneration (Districlima)

Metrofang will allow the 100% recovery of residual heat and PVE incineration will permit the recovery of 30% of the electricity produced through cogeneration.

2) Protection of biodiversity

3) Water cycle

4) Waste treatment

5) Biodiversity

6) Protection against the sea level rise

Should protect against the sea level rise

VI. URBAN PROPOSAL

The urban proposal "Fig. 11" is based on previously formulated planning guidelines:

A. Access to the sea.

Future development will provide access to the sea for the municipality of Sant Adriá and connections with the neighbouring municipalities of Badalona and Barcelona that will overcome the current island effect.

The existing urban structure is supported by a road system that provides connections with various roads located on the other side of the railway line and with the road network of the neighbouring municipality of Badalona. Underground passing points are proposed to provide access for vehicles and pedestrians.

This will make it possible to overcome the historical barrier that the railway has presented since its construction in 1860. It will also provide access to the sea for the population of Sant Adriá. (This is therefore a plan that unites rather than separates).

B. Sustainable mobility:

The new development proposes the prolongation of the present tram line. This would cross the River Besós, running parallel to the current railway line, and would then continue on as far as Badalona, with various stops in Sant Adriá.

The pedestrian axis and bicycle lane would also be extended from the Forum of Cultures area. A footbridge would connect this area to the seaside promenade and the beaches of Sant Adria and thereby to the rest of Barcelona's seafront.

C. Mixture of uses

The proposed zoning would combine residential uses with hotels and other tourism-related functions, offices and shops.

D. Design strategies

- Plans include the construction of a maritime promenade between the new building and the beaches which will be provided with amenities such as bars, restaurants and small businesses associated with tourist activity.
- It will be necessary to take into account the threat of an increase in sea level as a result of climate change. The whole of the new sector will therefore need to be located at a height of at least 3 m above the current level of the beach in order to protect it from the battering of storm surges. These often come from the east and are caused by a phenomenon known as the "Llevantada", which occurs from time to time. Increasing the ground level will also make it possible

to build above the great collector that currently runs along the edge of the beach. The beaches will also be regenerated in order to increase their size.

- The position and of the new building, which will progressively increase in height, will allow all of its apartments to enjoy views of the sea, without any of them being left in the shade. Its orientation will also allow the whole building to receive the benefits of the sea breeze.
- The positions and shapes of the highest buildings at the end of the alignments will create a unique urban landscape.
- The area where the new building is concentrated will be structured with urban elements belonging to the Mediterranean urban tradition. The main street in the built up area will therefore take the form of a “rambla” or promenade. This will lead to a square, located in front of the new power station museum, which will look out towards the sea.
- The square will be located above an underground car park which will provide parking for vehicles coming from the rest of the metropolitan area.
- The main route for road traffic will cross at this level to connect with the Badalona walkway. The square will extend towards the sea on a pier raised upon stilts. This pier will be reminiscent of that of the former docks that were used for supplying fuel from boats. It will also incorporate recreational activities for tourists.
- The power station building will be recovered for museum and cultural uses.
- An educational amenity will be located on the neighbouring plot, next to the power station building. This will be destined for the construction of a vocational training centre.

VII. ENVIRONMENTAL OBJECTIVES

A. Protection of biodiversity

In order to protect and increase the biodiversity of the mouth of the River Besós, it is proposed to create an urban park next to the mouth of the River Besós which will then act as a zone of transition between the natural space of the river and the urban development in the new sector. The vegetation of the park will be introduced into the heart of the housing estate creating alternative routes to the roads.

An increase in marine biodiversity will also be promoted through the construction of artificial reefs along the coastal fringe located opposite the beach.

B. Energy

All of the new buildings constructed will have to comply with the NZEBs standard in order to minimise carbon emissions. To achieve this, they will be projected according to strategies that minimise energy consumption. The resulting energy demand will be fully covered by residual energy produced by the treatment plants in the area plus the active exploitation of renewable energy. Three types of strategies will be pursued to achieve this:

1) Passive systems

- Passive solar design
- Insulation
- Regulation of solar radiation
- Cooling by ventilation

2) Active systems

Energy efficient installations:

- Low energy building: The maximum level of efficient energy certification: level A of the CTE (Spain’s official energy regulation certification)
- Air renewal via a heat exchanger
- Geothermal energy

Heat and cold supplied by the district heating, (districlima) of Poblenou.

Active use of renewable energy:

- Solar thermal energy
- Solar photovoltaic energy
- Mini windmill energy plant.

C. Water cycle

- To establish strategies concerning the water cycle, it is necessary to take into account Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000. This directive founded a framework for community action in the field of water policy – the EC Water Framework Directive (EC WFD) – for the future protection of waters in the EU and accession countries. It represents a general European legal framework for the protection of all bodies of water (surface water and groundwater).
- With Barcelona’s Mediterranean climate, the management of water from precipitation is a major step towards a sustainable use of resources and a vital prerequisite. Managing water from precipitation, such as by means of water evaporation in ponds, waste water use and rainwater infiltration, must be examined and considered via a network approach.

- As the water from the groundwater reserves could be polluted, it cannot be used for domestic consumption. The strategies used will therefore focus on encouraging water saving and on the appropriate management of rain water.
- Minimising the consumption of water by buildings.
- Taking advantage of rain water and storing it in the park's lagoons.
- Reusing grey waters to irrigate the gardens and green areas.

D. *Introducing greening measures*

Greening concepts must be developed for building plots and buildings. Options for building greenings and façade and roof greenings should be examined in order to improve the urban climate.

Greening should usually be planned for flat, slightly sloping and visible roofs. Increasing the proportion of green space on properties enhances the quality of amenities for users, improving the microclimate and air circulation and reducing temperature extremes, forming an integral component of species protection.

In choosing plants, local conditions (light requirements, orientation), maintenance requirements (pruning, fertilisation, pest control/plant protection, removal of unwanted growth) and the use of suitable growing media and watering systems must all be considered.

E. *Waste treatment*

This will include:

The selective collection of 80% of the waste created

Reducing the misuse of the remaining water as much as possible

Reusing rubble from the demolition of previous buildings for the new ones

The management of unpolluted, fertile land obtained by earth movements in order to create spaces destined for public parks.

The management of land derived from earth movements in order to increase the height of the new urbanised area.

F. *Biodiversity*

The action undertaken will include:

The conservation of the biodiversity of the ecological corridor around the River Besós.

The conservation and improvement of biodiversity in the delta area with an increase in the number of tree-lined green areas and a concentration of such spaces in a park next to the mouth of the River Besós.

G. *Protection against the sea level rise*

To protect of the sea level rise, this new development will be built 3.5 m. above the level of the current beach.

Figure 11. Rendering of the proposal

VIII. CASE STUDY ON THE ARCHITECTURAL SCALE: THE GARDEN TOWER

Rapid global urbanisation is an incontrovertible reality. More than half of the world's population already lives in cities, with forecasts suggesting that by 2050 there will be over 600 cities with over one million inhabitants. To avoid consuming useful soil and destroying the natural environment as we have done in the past, the urban form has continuously evolved to adapt to these new requirements. High densities can only be accommodated by high-rise buildings. This should not be a problem, because, as demonstrated by the architecture of cities in recent decades, high densities can be designed and designed successfully.

In the era of sustainability and ecology, urban planning projects should incorporate "virtuous cycles" in “imitation of the natural world”. To ensure that all resources are used to their fullest potential before being disposed of, an in-depth understanding of sustainable strategies is crucial. This entails taking full advantage of passive design, efficient systems, renewable energy sources, landscape and greening and integrated controls for measuring and verifying performance.

On the architectural scale, the "garden tower" project (Fig 12) integrates vegetation in the higher levels of housing, and is not only aesthetic but also a functional and sustainable option. Greenery regulates water flow, improves water quality and air quality, reduces noise and relieves stress.

Figure 12 The garden tower.

Figure 13 Relationship with nearby buildings

"The garden tower" project develops the residential towers drawn up in the Plan. It occupies an area of 25x25 metres, is 30 floors high, and features a total of 56 duplex apartments with a garden. The north-south axis orientation is located on the diagonal, so the building has facades oriented southeast/northeast and southwest/northwest.

It represents an evocative reinterpretation of the "garden city movement" of the early 20th century. A house with a garden in a suburban development can generate the same kind of comfort and happiness as a garden apartment in a high-rise building in the city centre, consuming far fewer resources.

A. Integrated System design

The challenge is how to minimise the consumption of natural resources. Difficult to execute in conventional buildings, highly efficient building system designs are even more complex for high-rise buildings.

B. Energy requirements

Reducing CO2 emissions will satisfy the standards for Nearly Net Zero energy buildings (NZEBs) as outlined in the EU's Energy Performance of Buildings Directive (2010/31/EU).

NZEBs can be roughly defined as buildings with a very high level of energy efficiency, whose very low energy requirements should be met by energy from renewable sources. For this purpose, the following strategies are integrated into the design:

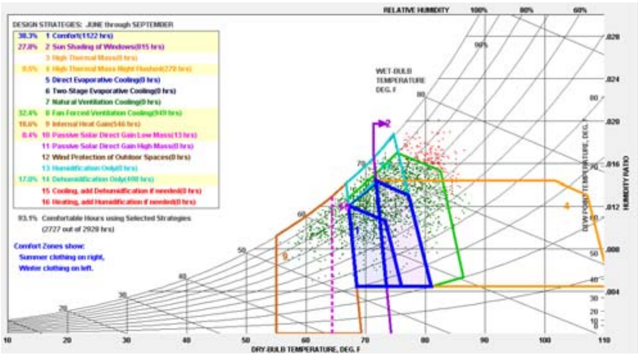
C. Passive design strategies

In the Mediterranean climate, external factors such as outdoor air temperature, air movement, relative humidity and solar radiation greatly influence a building's inside comfort levels. Design strategies based on climate analysis are summarised in the psychometric abacus. (Figure 14)

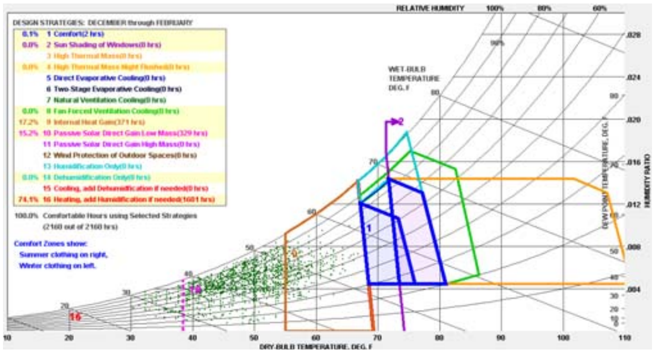
There are several analyses that influence the design of a building's envelope.

1. Solar radiation

The selection of an appropriate shading system and the glazing performance are imperative in order to balance solar loads and daylight availability. In terms of the use of on-site renewables, urban high-rise buildings allow for the allocation of photovoltaics (PV) on vertical façade surfaces, building integrated photovoltaics (BIPVs) to generate electricity or solar hot water systems. The orientation and solar radiation values should be carefully considered in order to calculate the payback period.



Summer



Winter

Figure 14 Design strategies based on climate analysis

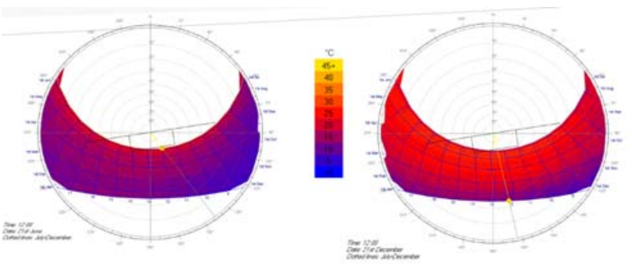


Figure 15 Solar chart, 12:00 on 21 June (left) and 21 December (right).

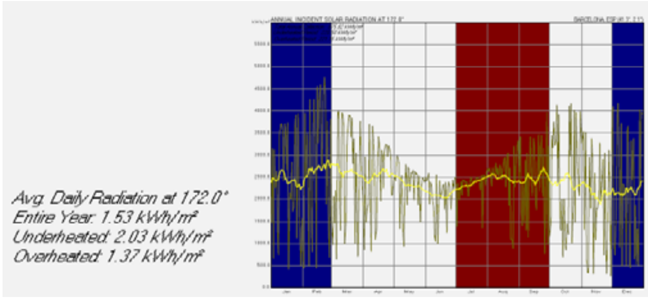


Figure 16 Average daily radiation at 172.0º

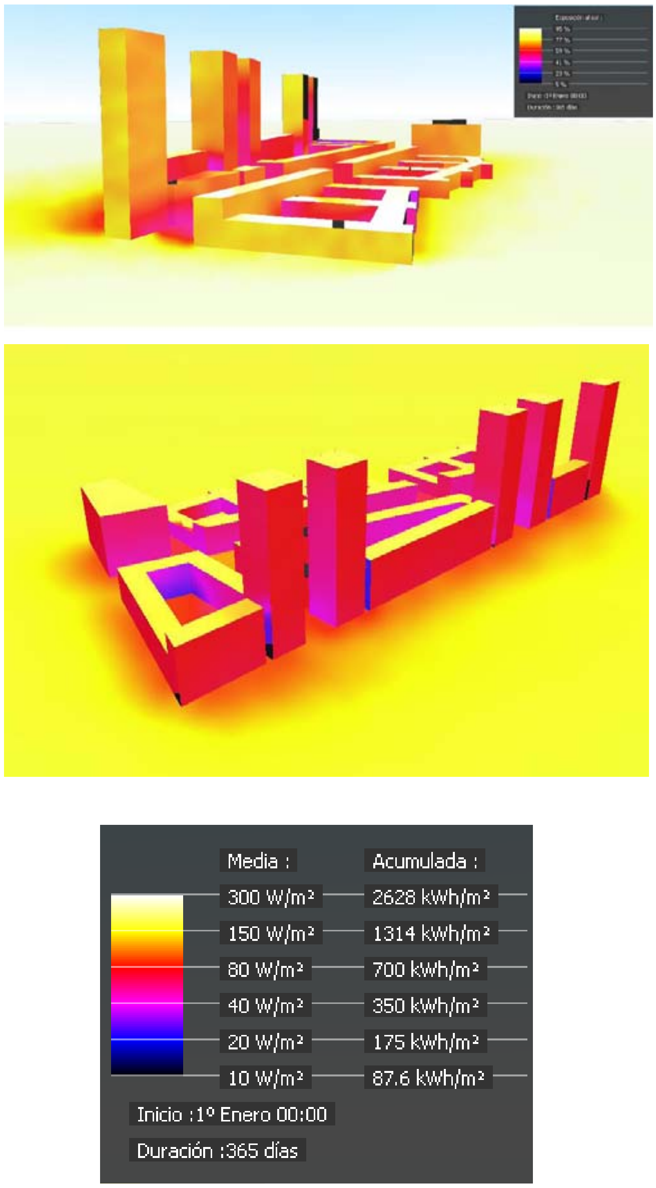


Figure 17 Overall solar radiation registered on all exposed facades over the course of a year

2. Facade Technology

Facade optimisation can balance all climatic factors. Adequate massing can also reduce the overall energy demand by at least 10%.

The optimum glazing ratio in Barcelona's Mediterranean climate is approximately 40% to 50%, depending on the facade's exposure to the external environment and the direct daylight availability.

This building is designed with a double-layer system. The second skin featuring motorised slats constitutes an appropriate sun shading system to balance loads and daylight availability. Its position alters in an automated manner with sensors that control mechanisms in order to balance:

- The regulation of solar radiation over the course of the year
- The protection of solar loads in the summer and solar gains in the winter
- Daylight availability
- Evaporative cooling from ventilation generated by sea breezes
- The protection against the wind and against the "Llevantada" storms typical at the end of the summer.

Figure 18 Building Envelope

Figure 19 Detail of the louvers

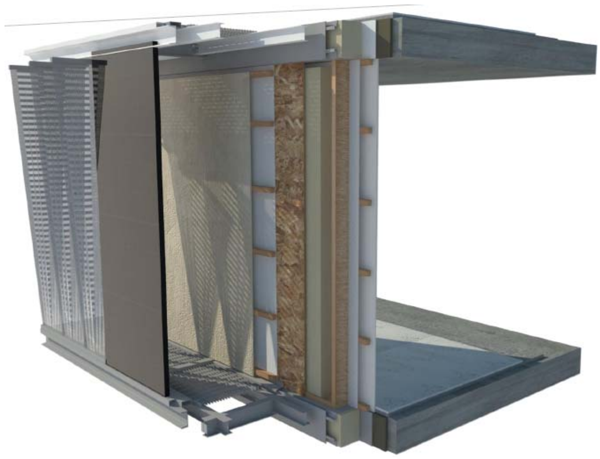


Figure 20 Double layers of the facade system

D. Sky Gardens

The greening of buildings offers a range of advantages, which may be divided into private benefits for owners and residents, as well as those which extend to the wider world.

Benefits include enhanced overall visual quality, improved insulation and rainfall retention, which usually result in a reduced rainwater fee.

These advantages normally become apparent in the annual bill for the building's ancillary costs.

Advantages for the wider world include the reduction of urban heat islands, reduced rainwater runoff and a decrease in the burden on the sewage system. The positive effects on "urban nature" are another important factor. Green roofs provide habitats for specialised types of plants and animals. This potential to "increase urban biodiversity" is vital, but cannot be expressed in monetary terms. (16).

A "greener" city is regarded positively by most inhabitants, but the financial value of this effect is difficult to estimate. For a relatively small additional sum, however, greenings result in a wide range of benefits.

The higher construction costs involved in creating greening systems can be directly added to the rent at a rate of a quarter of the roof garden's surface. A sky terrace or roof garden significantly increases the value of the property beside it.

Regarding the classification, we can distinguish between extensive green roofs and intensive green roofs. Extensive roofs usually manage with about 0.1 m of substratum, extending over a large area on buildings. The choice of plants is limited to "low maintenance" vegetation that can survive dry periods. The site conditions can provide extreme habitats for a series of specialised plants which would not stand much of a chance at ground level.

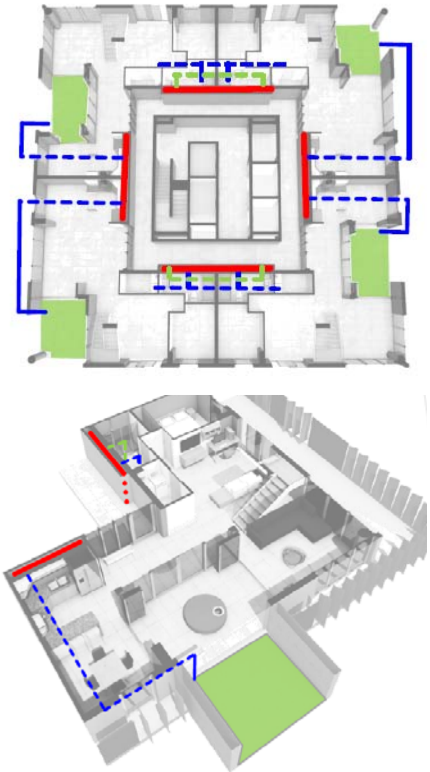


Figure 21 Distribution of terraced gardens linked to flats.

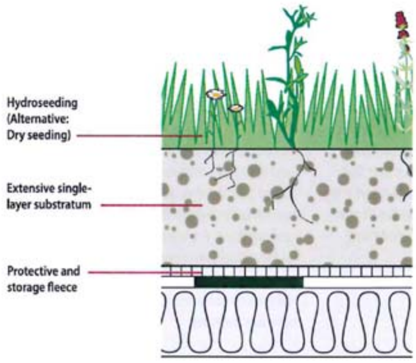


Figure 22 Extensive single-layer greening.

Intensive gardens are created on special areas of buildings, such as terraces with plantings typical of gardens with growing media from 0.5 to 1 m thick. This type of garden requires a substrate of soil of 0.5m or more. All kind of plants found in ground-level gardens are used.

1. Structural requirements

This type of gardens have an average value ranging from 200 to 300 kg/m2, although these values have no upper limit for intensive roof gardens. It depends on the species planted and also the rainwater stored in the growing media, which serves as a major factor in the weight of green roofs.

2. Temperatures/wind conditions

Facades are very exposed to wind in high-rise buildings, especially over large areas and according to the direction of the prevailing wind. The wind can also cause drying and mechanical damage. Facades or parts of buildings that get very hot or reflect strong sunlight in summer may also be unsuitable for greening.

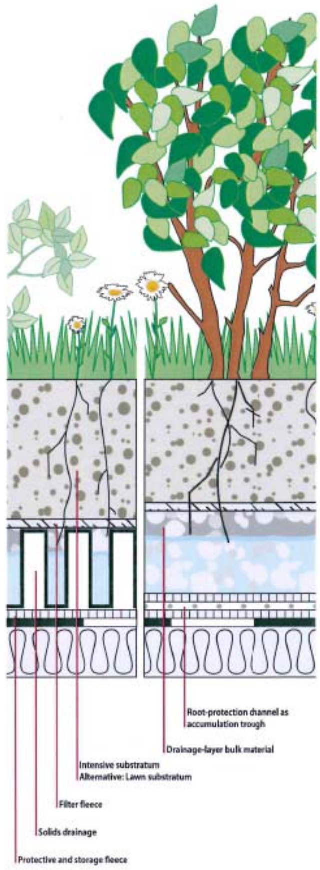


Figure 23 Intensive layer greening, depending on the depth of the growing media.

In terms of the necessary requirements, it would appear that the construction of roof gardens is an exception that is not viable for all buildings.

In a conventional high-rise building, only the cover may be used to make a green roof. This represents a small percentage of the total area, although such areas in these buildings normally feature common areas and facilities.

In order therefore to incorporate gardens at a height, each flat contains an enclosed or partially enclosed sky garden terrace with spaces suitable for a variety of everyday and leisure activities. Enclosures are set back from the slab edge under deep overhangs in order to create open double spaces linked to the living room for a variety of densely planted gardens, which provide a loose definition for informal activities. In this vertical threshold, the integration of plants defines and customises each flat and creates a range of relationships with the city at large.

In addition to the visible surfaces of the gardens incorporated into the terrace of each flat with watering systems, visual perception can be significantly improved from the inside and outside, with the microclimate tempered in the summer.

Figure 24 View of the sky garden from the inside

Figure 25 Outside view of the sky garden

E . Water management system

The management of water from precipitation is a major step towards a sustainable use of resources, particularly in Barcelona where rainfall is highly irregular. The discontinuity characterising such rainfall, whereby months of drought alternate with heavy rainfall accumulated in a few days, requires a consideration of rainwater management.

In addition to retaining water where it falls in so far as is possible, the garden tower uses a separate system, distinguishing between clean water and grey water used to irrigate the sky garden terraces.

F. Active strategies

1. Ventilation system

Heat Recovery Ventilation (HVR) is used in order to reduce the energy used for cooling or heating air from outside. In warm climates such as Barcelona's, HVR works well, with efficiency rates from 50 to 80 % providing up to approximately 5 to 10 % of energy savings .

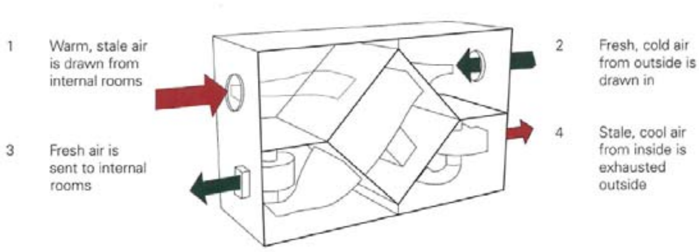


Figure 26. Outdoor air system

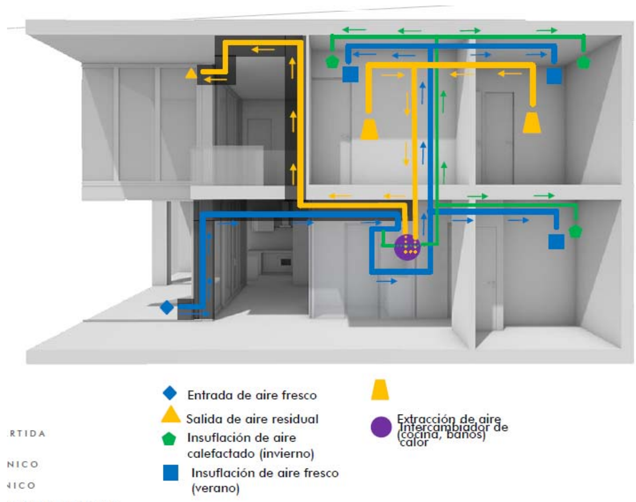


Figure 27 Energy recovery ventilation diagram

2. Air conditioning system

In the garden tower flats with low-occupancy areas where ventilation requirements are also low, VAV hydronic systems with fan coils are used to condition fresh air. Efficiency levels are higher because energy can be transferred more effectively through water than through air.

Support is also provided for ground source heat pump systems which exchange heat with the existing underground water, because of the higher Coefficient of Performance (COP).

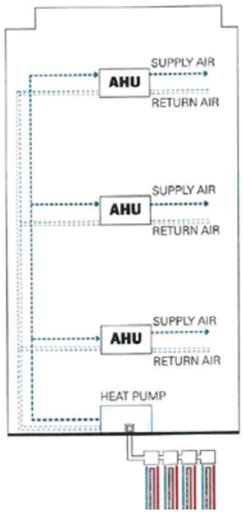


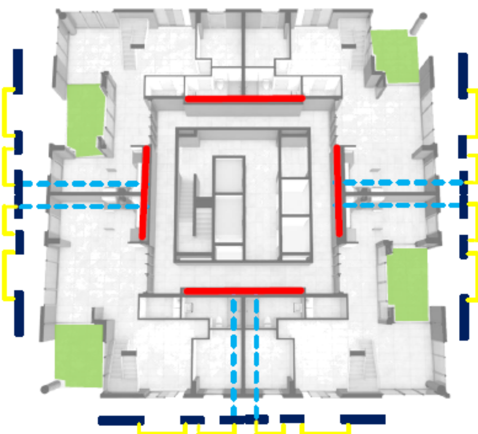
Figure 28 Ground source heat pump

3. Use on-site Renewables

In order to push building performance to its highest efficient limits in line with the "EU's Energy Performance of Buildings Directive (2010/31/EU)".

The garden tower's extremely high level of energy efficiency also drastically reduces energy consumption. The low energy requirements should be partially met by renewable sources.

Photovoltaic panels are planned for the facades oriented southeast and northwest.



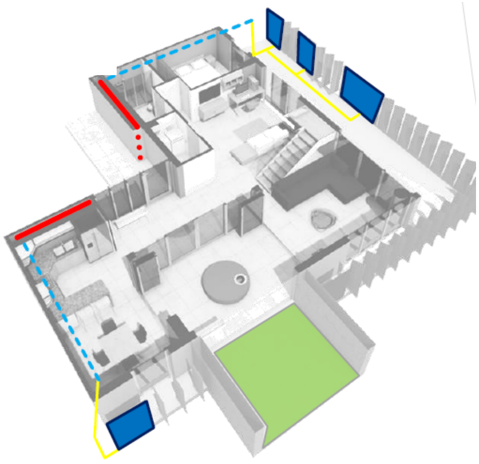


Figure 29 integration of photovoltaic panels on the facade

G. Building management system

To increase the building's energy efficiency, management systems in each flat regulate:

- The facade blinds, which serve as external shading systems.
- Automated slats are planned for each of the building facades.
- The slats modify their position according to radiation levels by means of a sensor that measures the solar radiation
- System Security and alarm
- Control and regulation of ventilation using a CO2 level sensor.
- Regulation system of the air conditioning temperature by thermostat.
- Regulation system for lighting and light levels
- System for measuring and monitoring power consumption.
- System for managing all the services proposed

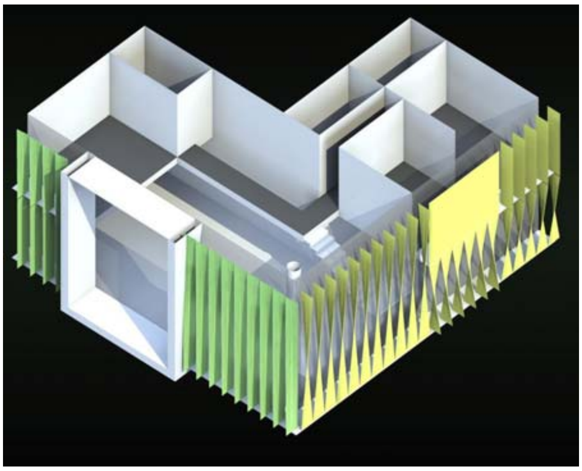


Figure 30 Automated slats

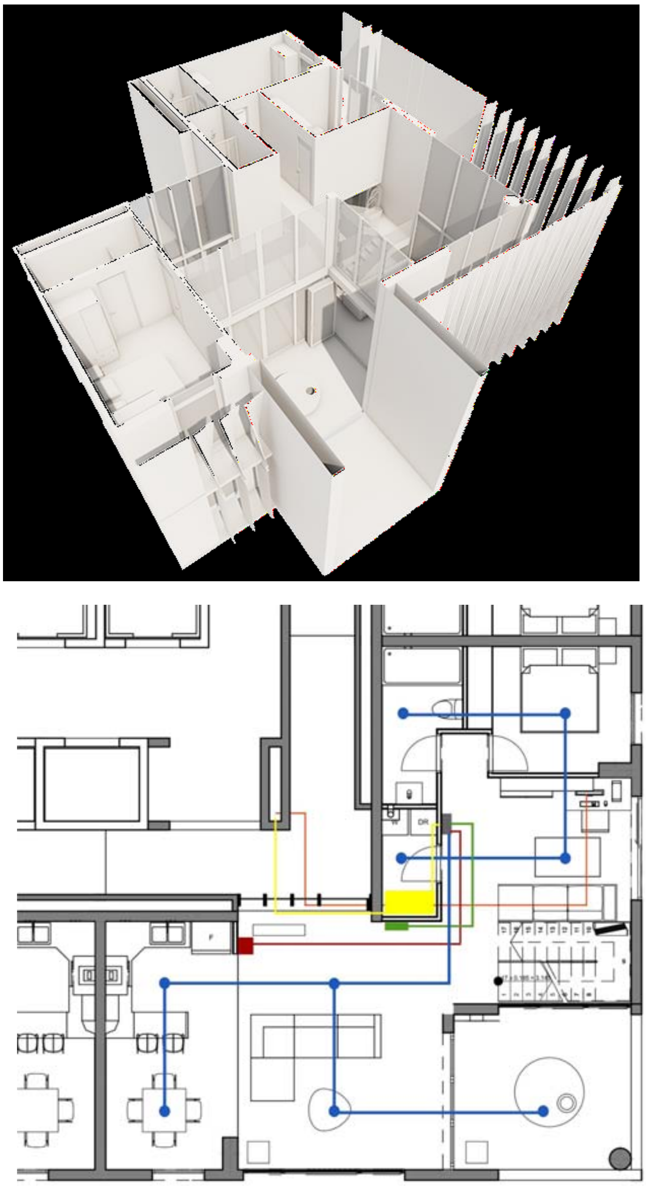


Figure 31 Building management system

IX. DISCUSSION AND CONCLUSIONS

In the era of climate change, it is necessary to incorporate strategies that favour urban sustainability if we are to move towards the goal of limiting global warming (which implies preventing an increase in the average temperature of the planet) to a maximum of 2°C by the year 2050.

This important challenge for governments and civil society can only be tackled by reducing carbon emissions and the environmental impact of urban development.

Once the main problems associated with urban growth and the planning of new urban developments have been identified - as shown in this article with reference to the example of the Besos power station area - it is necessary to base the new development on a catalogue of simple and understandable strategies that increase its global sustainability. We have done this in the belief that we can achieve overall results that will improve local processes and allow us to obtain similar results, but with lower levels of energy consumption and improved land use. In this way, it will be possible to reduce the production of waste and pollution and to achieve the final goal of creating a lively and liveable city.

In the not too distant future, the progressive implementation of the Energy Performance of Buildings Directive in the building sector will lead to a transition to the design of new buildings in which energy concepts constitute a fundamental premise. The garden tower project serves as a clear example of the use of a methodology featuring integrated system design, with this new way of thinking representing a major challenge for architects as it radically shifts the way we design buildings.

In our example we also found that applying sustainable strategies was not an obstacle to design, but instead offered an opportunity for creativity.

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