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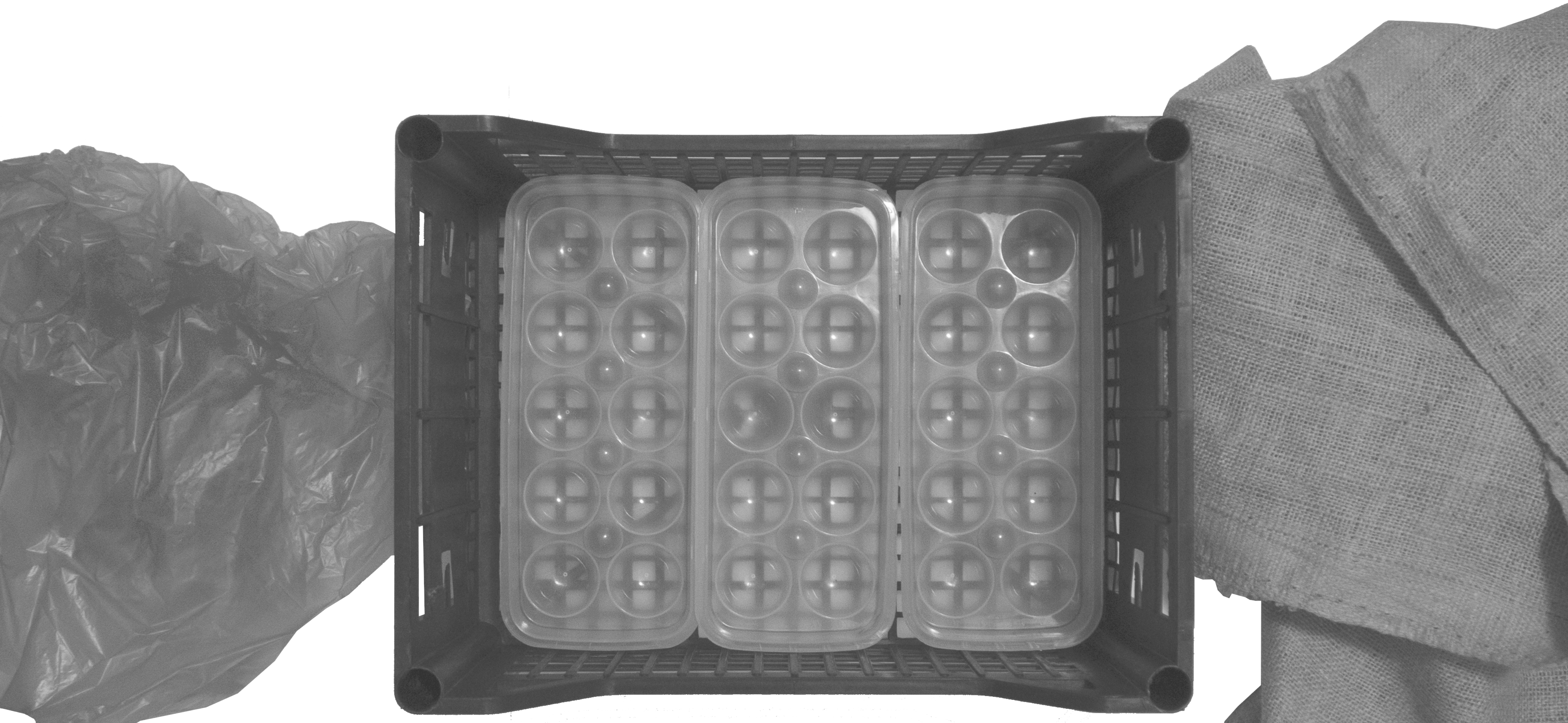
THE VIVIENDA AZUL-VERDE
a rainwater harvesting system for El Pozón, Cartagena de Indias



ARCHITECTURE MSc THESIS

Architecture Construction and City &
Architecture for Sustainability Design

Polytechnic University of Turin
Academic Year: 2019/2020

Si oyes correr el agua en las acequias,
su manso sueño pasar entre penumbras y musgos,
con el apagado sonido de algo
que tiende a demorarse en la sombra vegetal.
Si tienes suerte y preservas ese instante
con el temblor de los helechos que no cesa,
con el atónito limo que se debate
en el cauce inmutable y siempre en viaje.
Si tienes la paciencia del guijarro,
su voz callada, su gris acento sin aristas,
y aguardas hasta que la luz haga su entrada,
es bueno que sepas que allí van a llamarte
con un nombre nunca antes pronunciado.
Toda la ardua armonía del mundo
es probable que entonces te sea revelada,
pero sólo por esta vez.
¿Sabrás, acaso, descifrarla en el rumor del agua
que se evade sin remedio y para siempre?

Alvaro Mutis
Bogotà 25/8/1923 – Mexito City 22/10/2013

Abstract

The offer of social housing in South America and in particular in Colombia often does not meet the population real needs. Furthermore the consequences of climate change are affecting this reality, exacerbating even more the instability and insecurity of the informal settlements. For instance, the neighborhooud *El Pozón*, located in the colombian city of Cartagena de Indias, in addition to its social and economic problems, is characterized by a contradictory environmental situation. On the one hand it suffers the problem of floods due to its proximity to the C*iénaga de La Virgen* and to seasonal heavy rainfall and on the other hand the supply of drinking water is problematic and reaches unsustainable costs for a population who lives in marginal conditions. The project of the *Pontificia Universidad Javeriana de Bogotá*, in collaboration with the *Politecnico di Torino*, presented at the Solar Decathlon Latin America and Caribbean 2019 is aimed at improving the quality of life of the *El Pozón* inhabitants, proposing a new model of economic and sustainable house, self-sufficient from an energy point of view and achievable largely in self-construction. The participation in the design of the hidro-sanitary system of the *vivienda* presented itself as the starting point of the research, of which the theme of water is the main common thread. The prototype, that was built and tested for the duration of the contest, proposes an integrated water use strategy at the building scale, which combines different low-tech systems. At the same time, participation in the construction phase made it possible to conceive one of the main concepts that characterizes the neighborhood: the self-construction. The thesis work wants to present a possible methodology to conceive and realize a low-tech water technology: a blue-green roof module for the Solar Decathlon *vivienda Maquina Verde*. However the focus is placed not only the final product, but mainly on the process of inspections and interviews with the community that has strongly guided the final configuration of the module. The main purpose is to stimulate the inhabitants to address problems such as lack of sanitation, water quality and environmental improvement, through a scalable, sustainable and cost-effective solution.

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Introduction

The thesis proposed, focused on the contemporary problem of the effects of climate change, is the result of the combination of two different but complementary educational experiences of the master's degree courses in "Architecture for Sustainable Project" and "Architecture Construction and City".
The main attention of this work considers seriously a new approach to the changes that we will have to face. The new conceptions of the architectural process more respectful of the surrounding environment do not consider only the achievement of goals established by sustainability, but develop a further approach more attentive to the long term and to the changes that will affect that environment over time. As is well known, most of these changes are induced by the effects of the global warming in progress and incorrect urbanization. The large population areas affected by these events are already arming themselves with urban plans for greening and depaving, proposing appropriate solutions aimed at achieving resilience. Instead, our question tried to take a more attentive path to those marginal situations, where neighborhoods arise spontaneously and are places of a population abandoned to itself that almost seems to be self-regulated: informal neighborhoods. Our work concerned one case study in particular, the informal neighborhood *El Pozón* in *Cartagena de Indias*, Colombia. In this place near the southern bank of the *Ciénaga de La Virgen*, a multiplicity of houses, mostly self-constructed, rise spontaneously and without any building regulations. The uncontrolled - and in some cases inexperienced - building design generates different problems regarding basic living conditions. In addition, in the past, the district due to its proximity to the mangroves lagoon has been subject to flooding, which has flooded most of the houses in the north. The Pontifical Javeriana University of Bogota, in collaboration with the Polytechnic University of Turin and Oxford Brookes University try to provide an appropriate response to a more resilient and sustainable development of the neighborhood, through the project *Maquina Verde - El Arca* by PEI team. Being very interested in the proposed sustainability and resilience of the project, we participated in the design and construction crew with the particular assignment of determining the hydraulic design of the prototype housing module proposed for the Solar Decathlon in Cali 2019, focusing on the issue of sustainability regarding the saving, recovery and reuse of water resources. This work has brought us to confront ourselves with experts in the field and local companies, implementing our knowledge about plumbing systems and collection of houses. At the same time, we acquired information about the water needs of the occupants and forecast consumption and planned the savings of individual equipments. Following the realization of the prototype of the *Vivienda Maquina Verde* at the *Cali* competition, the several inspections of the destination site in *Cartagena de Indias* provided us with ideas for developing a further theme to be integrated into the house's plumbing system. The attention that we have developed in the analysis process aims at the respectful achievement of a modular prototype of

a green system for the collection and cleaning of rainwater. Following a market research of modules that serve this function, and the analysis of the elements and materials that compose them, we have chosen to design a green module in self-construction that aims at the reuse of waste materials, giving it a new life. The technical part of the research provides to demonstrate the performance of water management strategies used on private spaces, trying to apply them also to the green public spaces through a connected network system, from the microscale of the *Vivienda Social* to the Masterplan. The work determines a possible solution, leaving open the future possibility of a project that, by including these tchnologies, can provide a large scale impact that aims to reduce the environmental pollution that affects the *Ciénaga de La Virgen* and that can counteract the floods that could return as a result of climate change. The main idea of this thesis work is to design in a sustainable and resilient way for the disaster before it happens.

The main scope and the specific objectives

The main purpose of the thesis is to identify a possible methodology that can stimulate informal settlements inhabitants to address problems such as lack of sanitation and water scarcity through a scalable, sustainable and cost-effective solution.

Once resilient design in the context of climate change is established as the general field of investigation, the first objective is to identify what are the main effects of on the constructed landscape and what are the means adopted so far to tackle them. Although this theme is presented in a general way, it is later limited to the context of the project, whose peculiar characteristics exemplify many realities of contemporary living. The second objective is to examine the context of the neighborhood *El Pozón*, *Cartagena de Indias*, taking into account how the case study belongs to a very different reality from the one in which we are used to planning. From this need comes a third objective: to have a direct experience of the neighborhood in order to fully understand its social and economic context, through inspections and guided interviews. Direct experience is fundamental in this thesis work; in fact the participation in the construction of the prototype of the Solar Decathlon *Vivienda*, identified as the reference study, plays a key role in the identification of a technological solution to the environmental difficulties of the neighborhood. The last objective is to design the chosen technology: a green-roof vegetated module, focusing mainly on its composition in terms of stratigraphy and materials. Particular attention is paid to the methodology of representation of the technological solution: the attempt is to give the drawings a mainly illustrative character, so that they can represent an executive guide to the realization of the module. The aim is to give the project a character of feasibility in a context where the practice of individual self-construction drives most of the development and expansion processes.

Chapter zero: A resilient approach to the climate change

Anthropological, environmental and theoretical contest: the anthropocene era

In the last 11,700 years, humans have lived in a geological epoch called the Holocene, characterized by relatively stable temperate conditions. An era, which the journalist Alex Blasdel calls "the California of planetary history" in an article[1] for The Guardian. Recently, human beings have started to modify the Earth so drastically that, according to many scientists, a new era is emerging. "After the shortest of the geological holidays, we seem to be entering a more unstable period" Alex Blasdel continues in his article. This period is called Anthropocene. At the beginning of the new millennium, the Nobel Prize for Chemistry[2] Paul Jozef Crutzen made public the term anthropocene referring to the current geological era during a scientific conference in Cuernavaca, Mexico.

Image: The sand mine Enterprise a North Stradbroke Island, Australia. Photographer: Dave Hunt / AAP. From www.theguardian.com/environment/2019/may/30/anthropocene-epoch-have-we-entered-a-new-phase-of-planetary-history

A few months later, the American biologist and ecologist Eugene Filmore Stoermer - who coined this term in the early 1980s as a combination of "*anthropos-*" which from the Greek means "human" and "*-cene*", a suffix used for geological eras and which from the Greek means "recent". Together with Crutzen he wrote an article in an IGBP[3] newsletter. This article was written to concretely identify a more recent phase in the Earth's history in which the human actions are producing significant perturbations in the Earth's climatic conditions. The concept gained a general scientific consensus immediately. "The proliferation of this concept can mainly be traced back to the fact that, under the guide of scientific neutrality, it conveys a message of almost unparalleled moral-political urgency", said the German philosopher Peter Sloterdijk. (Davison, 2019) Some scientists proposed to consider the beginning of this new era 5000 years ago, when the nomadic human became sedentary and increased the levels of methane in the atmosphere due to agriculture.

[1] Found in The Guardian's article "The Anthropocene epoch: have we entered a new phase of planetary history?" of Nicola Davison, 30th May 2019;
[2] Crutzen won the Nobel Prize for Chemistry in 1995, together with the Americans Mario Molina and F. Sherwood Rowland, for studies on atmospheric chemistry, in particular on the formation and decomposition of ozone. From www.nobelprize.org/prizes/chemistry/1995/crutzen/biographical/;
[3] The International Geosphere–Biosphere Programme; The article appeared on page 17 IGBP's Global Change newsletter 41, May 2000.

A popular theory suggested that the Industrial Revolution was the beginning, when the levels of coal and methane in mass production began to pollute the atmosphere more. Others thought that the beginning should be 1945, after the tests of the first nuclear bomb and after the bombardments of Hiroshima and Nagasaki, because of the radioactive particles present in the ground later, particles present all over the world. This could be considered a significant event of modification made by man to the original conformation of the earth. In 2016, the Anthropocene Working Group agreed that the Anthropocene is different from the Holocene[4], and began in the year 1950 when the Great Acceleration, a dramatic increase in human activity affecting the planet, took off. Although the term is widely used by scientists and thinkers, it has not yet been formally recognised by IUGS[5] (International Union of Geological Sciences). Whatever its beginning or its formal placement in the chronology of the Earth's epochs, the most interesting is the birth of a consciousness that concerns the socioecological relationship with the context in which we human beings live. This relationship shows a strong influence of the human being on his surroundings that is so important that it can change the qualitative aspect of the planet. For this reason it is logical to talk about a system. The very idea of the anthropocene takes into consideration the idea of the earth as a system of connected forces and flows that feed back on each other through unstable relationships due to their complexity. Humans are part of a species caught in the grip of a collective challenge that Unrich Beck called "the risk society"(Beck, 1992). This contemporary trial to which human beings are subject requires a deep comprehension of events that seem in some cases not to reflect the nature of the process taking place over the longest period of time. Reality does not follow a linearity, it does not appear constant because the system is open, more complex and adaptive. The uncertainties cover most of the arguments, more than anything else. Working within a system without realizing that the subject is constantly changing by adapting to its surroundings increases this risk of collapse of the whole system. "The Anthropocene is not only a period of man-made disruption. It is also a moment of blinking self-awareness, in which the human species is becoming conscious of itself as a planetary force. We're not only driving global warming and ecological destruction; we know that we are" (Blasdel, 2017). A member of the object-oriented philosophy movement[6], Timothy Morton reports the human species' reckoning. His ideas may seem a bit bizarre, but the philosopher wants humanity to renounce some of its habits or beliefs, to shake off the fantasy of man- aging and controlling the planet and to stop considering itself above other beings.

"Part of what makes Morton popular are his attacks on settled ways of thinking. His most frequently cited book, Ecology Without Nature, says we need to scrap the whole concept of "nature". [...] He believes all beings are interdependent and hypothesizes that everything in the universe has a kind of consciousness [...] He says that we are already rules by a primitive artificial intelligence: industrial capitalism. At the same time, he believes that there are some "weird experiential chemicals" in consumerism that will help humanity prevent a full-blown ecological crisis",

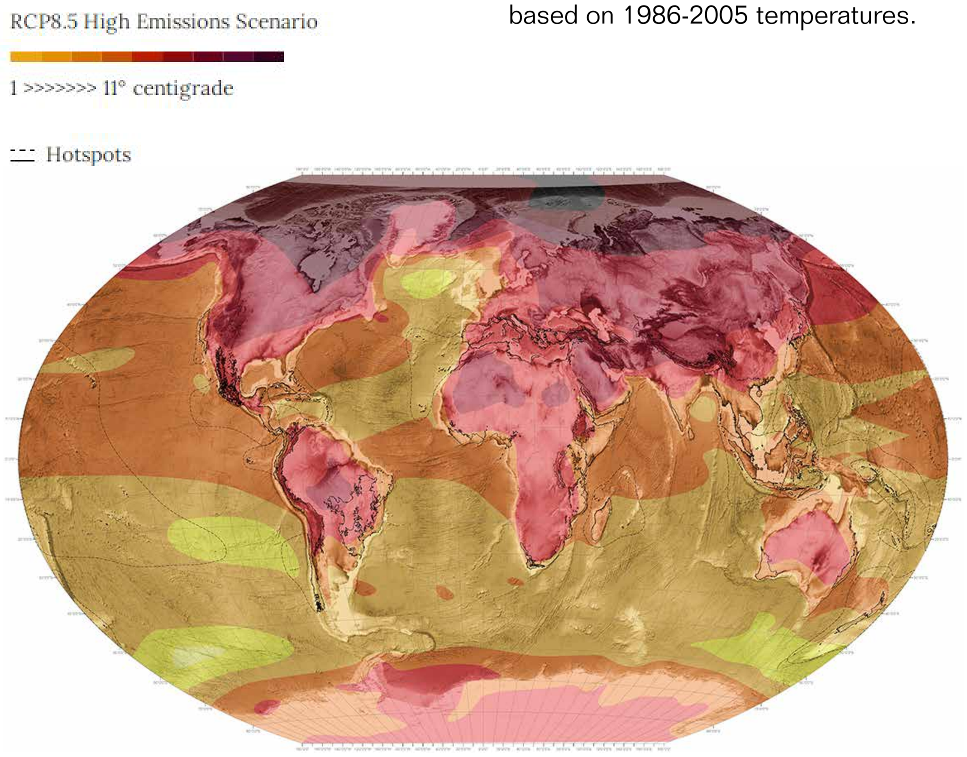
explains Blasdel in an article that sees him interviewing the "prophet of the anthropocene". One of Morton's most powerful intuitions shows the sentence to live with awareness at all times of what is happening. "We live in a world with a moral calculus that didn't exist before. [...] Tragically, it is only by despoiling the planet that we have realised just how much a part of it we are." (Blasdel, 2017).

In the beginning what seemed to be a technical discussion that required a geological investigation for the definition of a new era has now become a real confrontation with reality and an analysis of some elementary ways of understanding the world, the beyond. The Anthropocene has become a complex concept as any other world historical paradigm. Considering once again the ideas of the philosopher Timothy Morton, the concept of ecologism is desgnaturation of its anthropocentric value considering man within the same system of nature. in this way, it is freed from its metaphysical "elsewhere" value to be preserved, becoming one with humanity. Morton uses hyperobjects as conceptual tools to read the world, an entity that possesses space and time. "A hyperobject could be a black hole. A hyperobject could be the oil center in the Lago Agrio area of Ecuador or the Everglades reserve in Florida. A hyperobject could be the biosphere or the solar system. A hyperobject could be the sum total of all the nuclear material on Earth." (Morton, 2013)

[4] For more information visit www.britannica.com/science/Holocene-Epoch;
[5] International organization that decides the chronology of the Earth's epochs through the study of stratigraphy;
[6] A school of thought influenced by Heidegger of the 21st century that rejects the privi- lege of human existence over the existence of non-human objects;

According to Morton, global warming is the most important hyper-object. It is everywhere, it has features that change with the passage of time, interacting closely with human beings and their activities, defining the objects or problems present. Its peculiarity resides in its existence on space-time dimensions too large, therefore extremely hard to perceive directly.

Global average temperature change 2081-2100, based on 1986-2005 temperatures.



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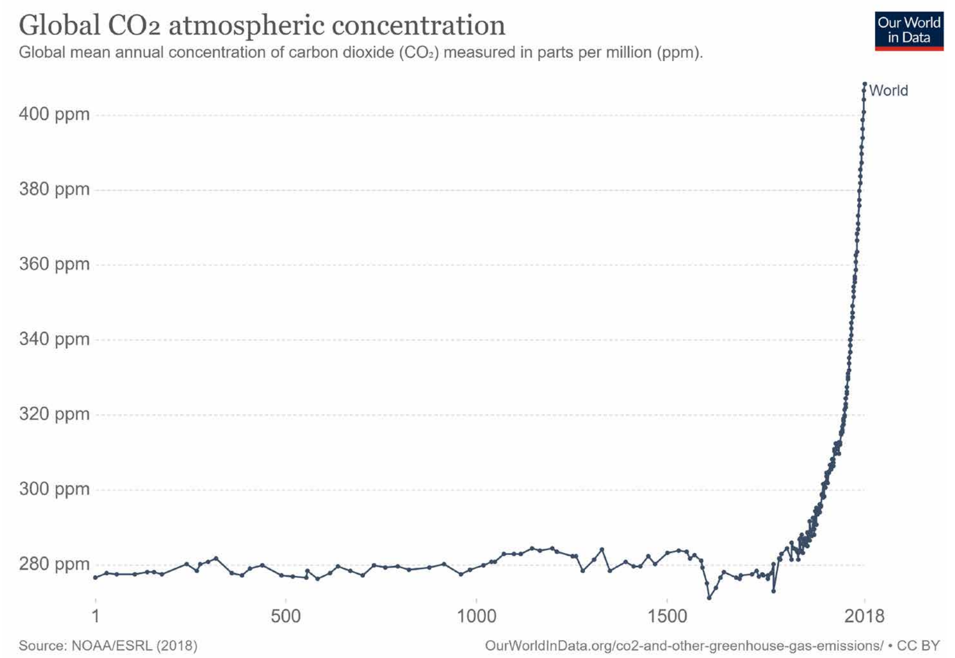


Overview of the main artificial and natural causes of climate change

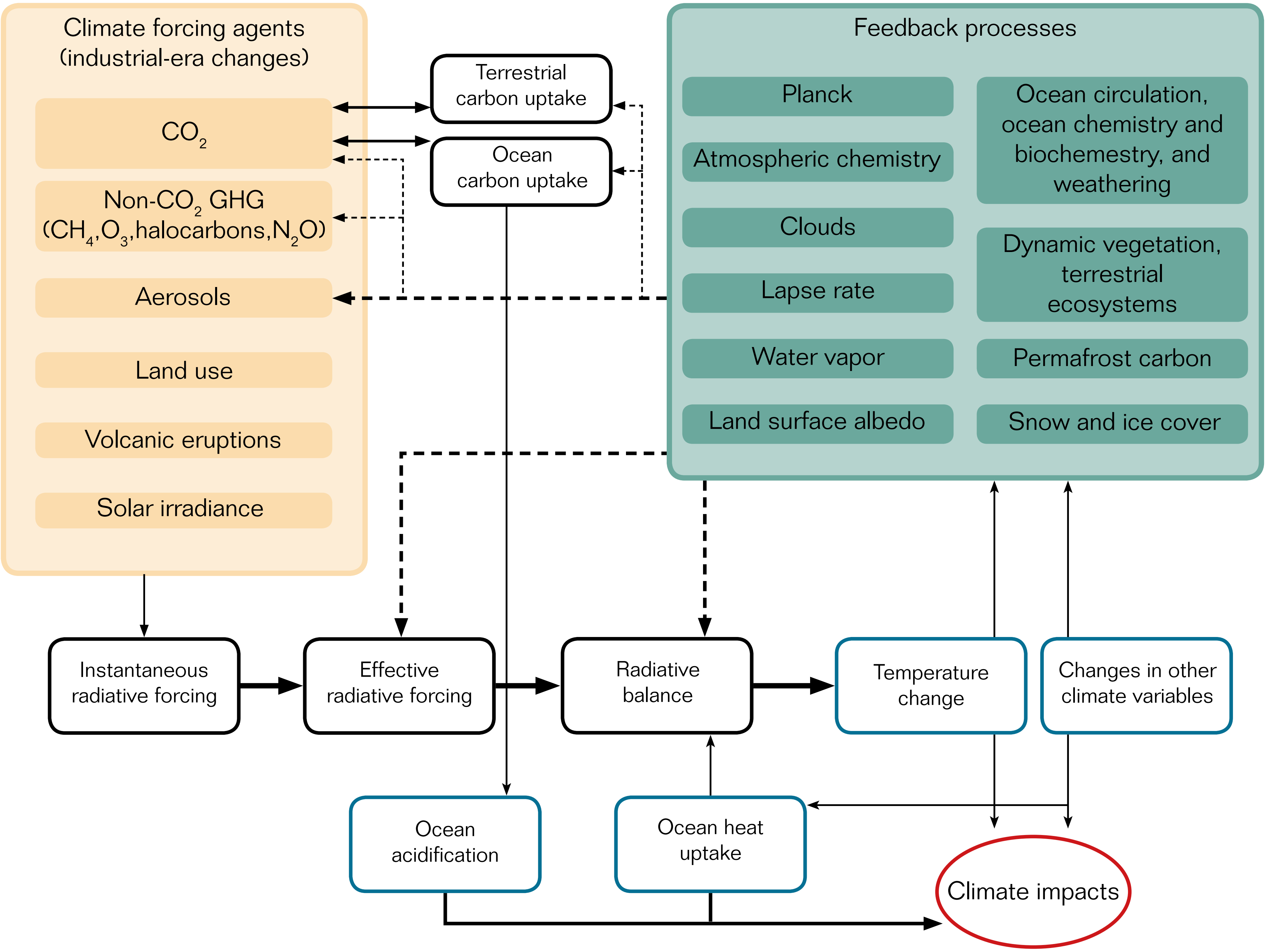
"Climate change could be identified as the emblem of the anthropocene condition." (M. Garcìa Garcìa, 2017) Climate change and global warming are often used as synonyms, but they describe two different major themes. Similarly, weather and climate are events that are constantly confused, although they are characterized by different spatial and temporal scales. Global warming is the long-term warming of the Earth's climate system observed since the pre-industrial period (between 1850 and 1900) caused by production activities, mainly the burning of fossil fuels, intensive livestock farming and deforestation that increase the levels of greenhouse gases trapping heat in the Earth's atmosphere. Climate change refers to both artificial warming (produced by human activities) and natural warming. In addition, climate change also considers the effects on the planet. It is commonly measured as an average increase in the Earth's global surface temperature, but it also includes the different effects that this seemingly slight change in temperature brings to the Earth's system. Earth orbiting satellites and technological advances have allowed an estimate of the variation in the averages of meteorological models that after careful analysis describe the local, regional and global climates of the Earth. These man-made temperature increases are commonly indicated as global warming. In addition to these anthropogenic alterations in the earth's composition, there are also natural events that promote their increase. For example, the internal variability of cyclical oceanic models such as *El Niño*, *La Niña* and the Pacific Decadal Oscillation or external forcers such as volcanic activity and variations in the Sun's energy production due to slight shifts in Earth's orbit. The climate change is understood as a change in the statistical properties of the climate system that is analysed over periods of decades, usually at least 30 years. These statistical properties include averages, variability and extremes. So it is possible to say that global warming is one of the effects that best describes climate change, but it is not the only one. As explained above, the climate system is a complex system where its constituent parts establish interconnections with each other. A disturbance in the balance of the system can trigger changes that amplify or dampen the initial disturbance. There are close connections between temperature, water vapour, the extension of the polar ice sheets and concentrations of greenhouse gases (in particular CO_2) in the atmosphere.

When one of these is altered, the others react by increasing or decreasing the original disturbance, on different time scales. The feedback resulting from the alterations is faster if events involving the atmosphere are taken into account, while those involving the deep oceans or ice caps are slower, resulting in long-term responses. There is a general consensus among scientists that global warming is attributed to the increase in the greenhouse effect of the Earth's atmosphere. The greenhouse effect is the chemical-physical process that allows the earth to distribute energy as heat. Energy particles in the form of radiation are partly absorbed, partly transmitted and partly re-emitted. The particles can be re-emitted into space or can be trapped under the atmosphere, warming the planet. Therefore, the green-enhouse effect is the radiant heat of the earth. Some gases in the atmosphere prevent heat from dissipating. The gases that contribute to the greenhouse effect are:

- Water vapour - the greenhouse gas with the highest percentage in the composition of the atmosphere, increases at higher atmospheric temperatures, also increasing the possibility of precipitation;
- Carbon dioxide (CO^2) - constitutes a smaller percentage and is released through natural processes such as breathing and volcanic eruptions or through human activities involving the use of fossil fuels. In addition, other human activities such as deforestation and land use changes prevent the disposal of much of the CO^2. Humans have increased the atmospheric concentration of CO^2 by more than a third since the beginning of the Industrial Revolution;
- Methane (CH^4) - A hydrocarbon gas produced both by natural sources and human activities. This gas is present in the decomposition of waste in landfills, in agriculture and in particular rice cultivation, in the digestion of ruminants in intensive livestock farming and in the management of manure associated with domestic livestock. On a molecular basis, methane is a much more active greenhouse gas than carbon dioxide, but fortunately it is also much less present in the atmosphere;
- Nitrous oxide (N^2O) - produced by soil cultivation practices, in particular the use of organic and commercial fertilisers, the combustion of fossil fuels, the production of nitric acid and the combustion of biomass;
- Chlorofluorocarbons (CFCs) - Synthetic compounds of industrial origin regulated in the production and release into the atmosphere by an international agreement for their ability to contribute to the destruction of the ozone layer;

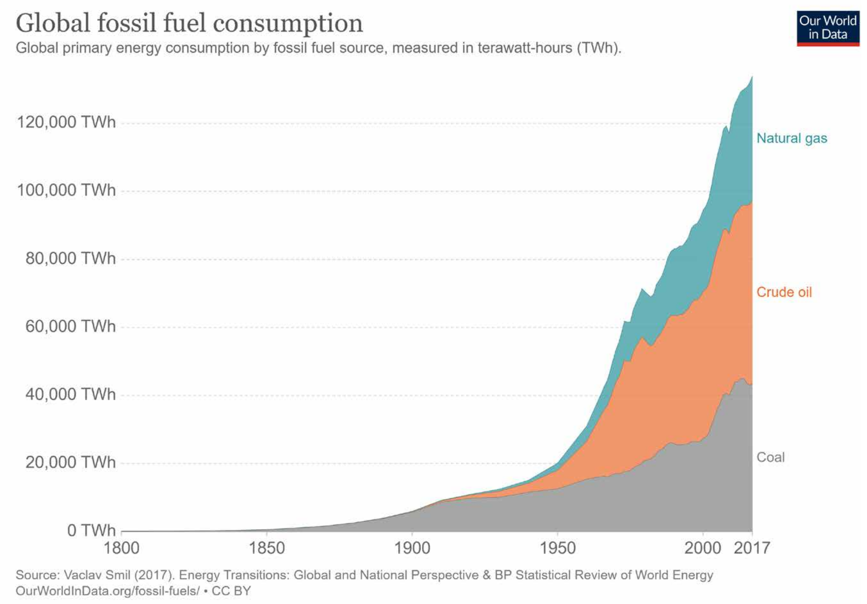
Carbon dioxide is responsible for 63% of man-made global warming. Its concentration in the atmosphere is 40% higher than the levels recorded at the beginning of the industrial era. CO^2 levels are measured in ppm (parts per million). The concentration has risen from an initial average of 270-285 ppm to over 400 ppm of CO^2 in the last period.The other greenhouse gases are emitted into the atmosphere in smaller quantities but have a greater "greenhouse capacity" than CO^2, this means they are more capable of absorbing warm than carbon dioxide. For example, a molecule of Methane has a greenhouse capacity like 23 molecules of CO^2 and is responsible for 19% of anthropogenic global warming. In the United States "Almost all of the methane in the atmosphere can be traced back to livestock farming," says Bard College's professor of Environmental Physics Gidon Eshel in the climate change documentary Before the Flood. On the other hand, fluorinated gases produce a very strong warming effect, up to 23 000 times than CO_2. Thankfully these are released in smaller quantities and are being phased down by EU regulation. The International Group on Climate Change, composed of 1.300 independent scientific experts from around the world regulated by the United Nations, has stated that human activities have increased CO_2 concentrations over the last 50 years, so greenhouse gases are considered to be more than 95% likely to be the major causes of global warming. All this through industrial activities, which have so far allowed the development of contemporary civilization.

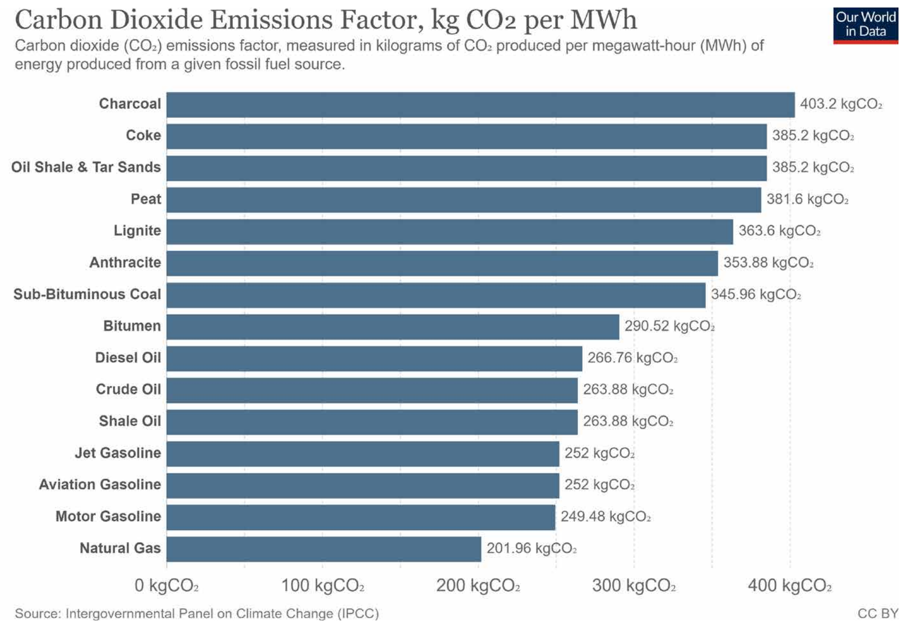
Simplified Conceptual Framework of the Climate System

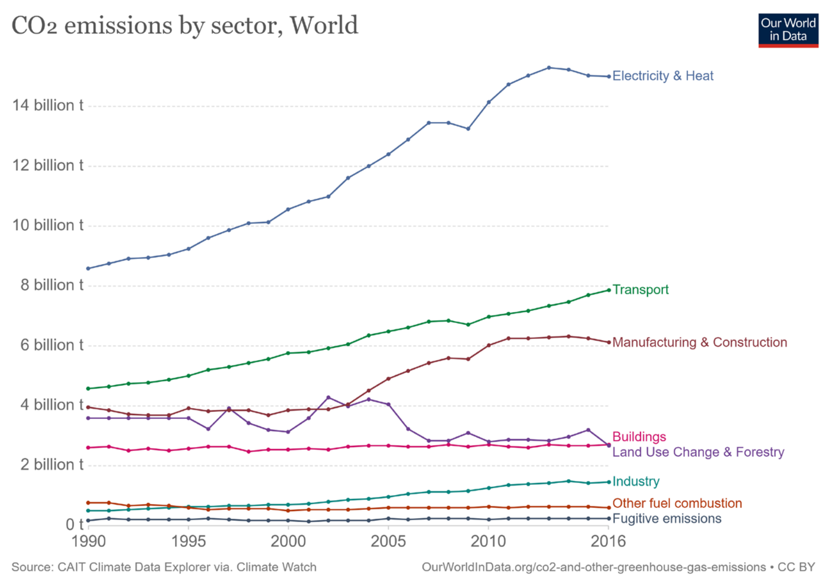


Simplified conceptual modeling framework for the climate system as implemented in many climate models. Modeling components include forcing agents, feedback processes, carbon uptake processes, and radiative forcing and balance. The lines indicate physical interconnections (solid lines) and feedback pathways (dashed lines). Principal changes (blue boxes) lead to climate impacts (red box) and feedbacks. (Figure source: adapted from Knutti and Rugenstein 2015). (Knutti, R., et al., 2015)

“Fossil fuels (coal, oil, gas) play a dominant role in global energy systems. Fossil energy has been a key driver of the industrial revolution and the technological, social, economic and developmental advances that followed. Energy has played a strongly positive role in global change”. (Ritchie, 2017) The production and consumption of fossil fuels began with coal. Its first uses were discovered in China around 4000 BC. However, large-scale combustion is related to the early period of the Industrial Revolution. The first graph shows the global consumption of fossil fuels. Coal was the first and only source of fossil energy until 1860 when the consumption of crude oil began. The use of natural gas occurred a few decades later. Fossil fuels are the main source of global energy production. These non-renewable resources are transformed into carbon dioxide according to different equivalences. Usually coal produces more CO_2 per unit of energy, oil produces about a third more than coal, while natural gas can produce about half of coal emissions. Therefore, the coal is the most polluting of fossil fuels. “The 20th century saw a great diversification of fossil energy consumption, with coal declining from 96 percent of total production in 1900 to less than 30 percent in 2000. Today crude oil is the largest source of energy, accounting for about 39% of fossil energy, followed by coal and natural gas at 33% and 28% respectively”. (Ritchie, 2017) The global greenhouse gas emissions are broken down by production sectors. These data are based on values reported by the United Nations from the EDGAR database. Considering directly proportional the consumption of fossil fuels with the production of carbon dioxide, it is clear that the sectors with the highest CO_2 emissions are present in energy production such as energy, manufacturing and construction industries. These emissions include public heat and electricity generation and have increased from around 9 billion tonnes of CO_2 in 1990 to more than 14 billion tonnes of CO_2 in the last period. In second place by emissions are those caused by transport: national aviation, road transport, rail transport, national shipping, other transport. These emissions have shown a growth of about 5 billion tonnes of CO_2 since 1990. Following the Paris Accords[7] of 2015, the 195 participating countries have defined a legally binding action plan with measures to be taken by each state to combat climate change. To bring the planet back to good conditions, governments have agreed to keep the average global temperature increase well below 2°C compared to pre-industrial levels, in order to avoid irreversible consequences for the planet, but above all for humanity (an attempt is made to aim for a limit of 1.5°C). In addition, global emissions should reach the maximum level as soon as possible, recognising that devel- oping countries will need more time to achieve this objective. Finally, industrial production should seek to reduce the emissions curve through more technologically advanced scientific solutions using renewable energy. The world is in the midst of climate change, 1.1°C warmer than the beginning of the Industrial Revolution. The scientists consider irreversible a situation where this temperature rises above 2°C.

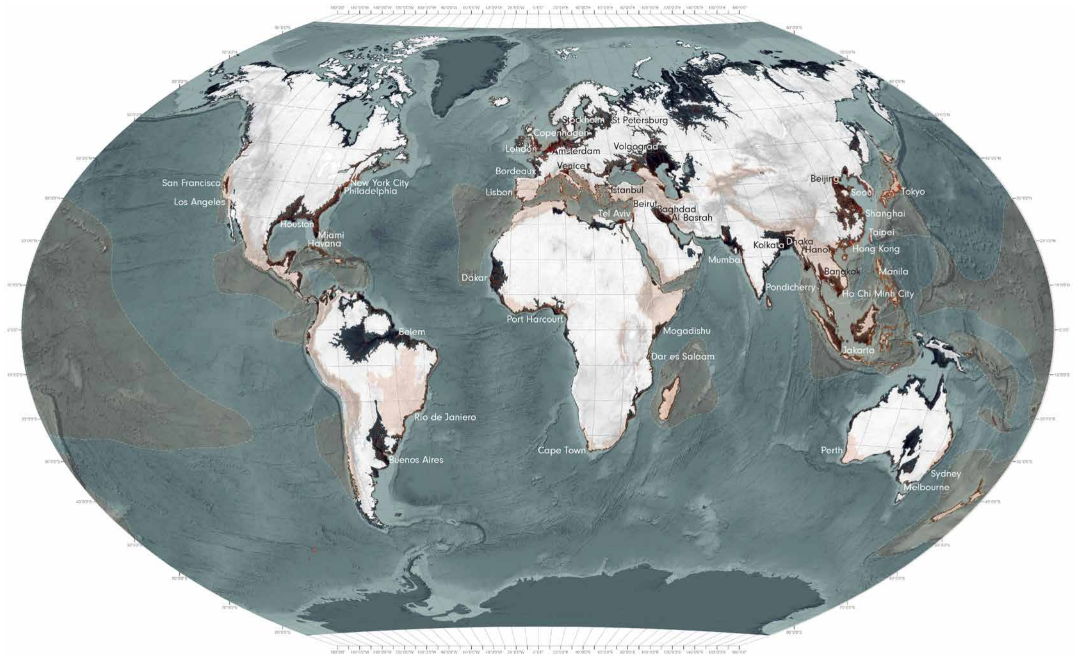






SEA LEVEL RISE

This map shows the land which would be flooded if the ice caps melt in entirety, in which case the sea level would rise by 80.32 m. In this scenario, vast new coastlines and inland seas will be created and 50 of the world's major cities would become architectural reefs. Even if sea level rises only 0.74 meters by 2100 as is conservatively predicted some 115 million people will likely be displaced and 420,000 km² of land will be lost to the encroaching seas.



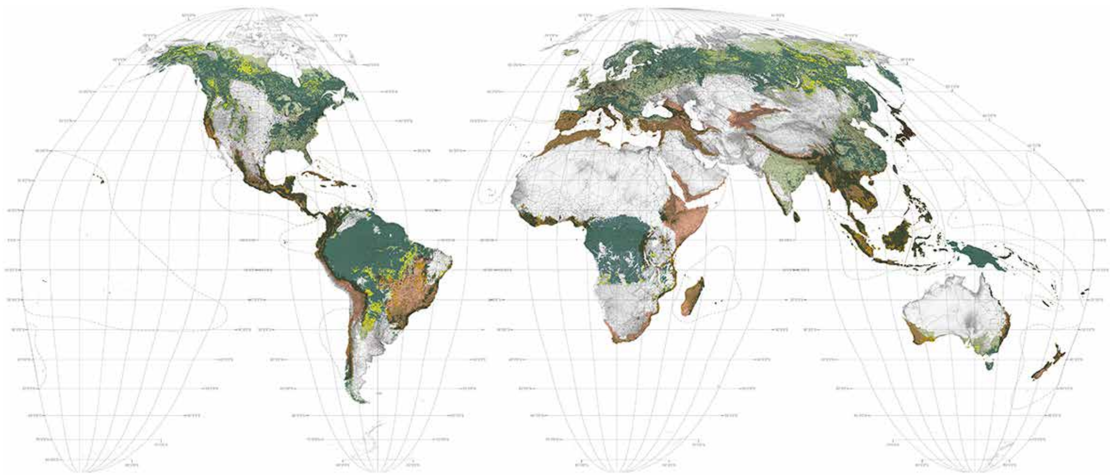
80.32 meter rise (all ice caps melted) Antarctica, Greenland, other ice caps, ice fi elds & valley glaciers

Inundated Urban Areas 50 large cities displaced

Hotspots

DEFORESTATION

It is primarily the result of logging and land clearance for agriculture and infrastructure but it also occurs as a direct result of urban sprawl. As documented in this atlas there are 383 cities in the hotspots whose 2030 growth forecasts indicate immanent conflict with high value biodiversity. The most defo-restation between 1990 and 2015 has occurred in Brazil, Indonesia, Myanmar, Nigeria and Tanzania. The greatest forest increases have taken place in China, Australia, Chile, USA, and the Philippines.



2012 Forest Cover (40,000,000 km²)

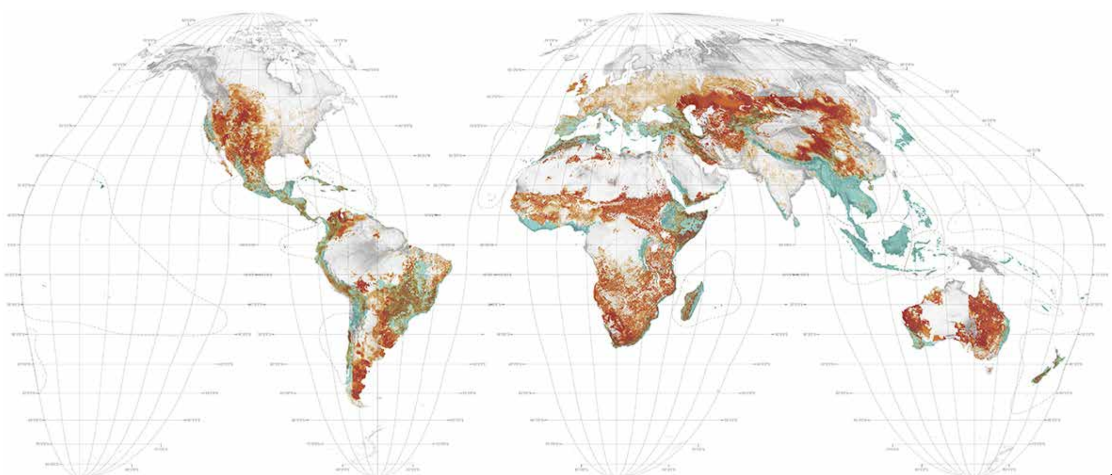
2000-2012 Forest Loss (2,300,000 km²)

Forest Biomes (former geographic extent of the world's forests)

Hotspots

MEAT MAP

Humanity extracts a third of its protein from livestock. To produce the necessary feed crops and graze the animals requires 3.38 billion hectares, a total of 38% of the earth's ice-free land, the largest single land use on the planet. Second to humans; chickens, pigs, goats, sheep and cattle are the dominant and most destructive forms of life on earth. The global livestock industry is active in 23 of the world's hotspots and it is little wonder that 306 of the world's 867 ecoregions report livestock as a significant threat. The livestock industry employs over 1.3 billion people, most of them poor.



Pasturelands (2000)

1 >>>>>> 100% grazing landuse

Hotspots

The images and informations are from atlas-for-the-end-of-the-world.com/world_maps_main.html#world_map_target

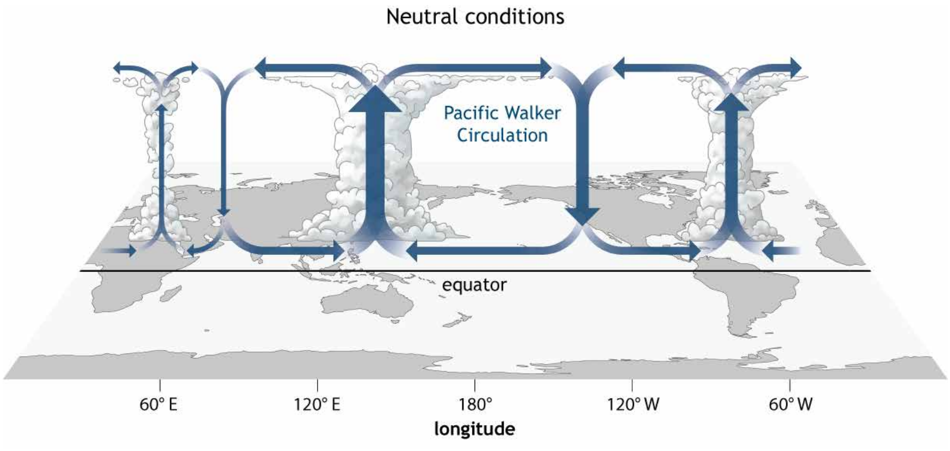
With current trends, global temperatures could rise from 3.4 to 3.9°C in this century, causing destructive climate effects on a large scale. In general, there is a huge category of consequences. Global warming will produce an increase in temperatures that will cause the melting of the polar ice caps and glaciers. According to a study published in the journal Geophysical Research Letters conducted by the University of Alaska's Permafrost laboratory, the melting of permafrost is 70 years earlier than predicted. Heat peaks in 2003 and 2016 triggered this mechanism by accelerating melting at a rate between 150% and 240% faster than 40 years ago. The combination of these phenomena raises sea levels, causing flooding and erosion along the low coastal regions. In addition, the change in annual rainfall distribution and the resulting hydrogeological risk will favour flooding. In correspondence with intense precipitation seasons will be longer periods of drought and increased fire risk. At the same time there will be an increase in frequency and intensity of extreme weather phenomena such as hurricanes, tidal waves and earthquakes. The different distribution of snow or other natural habitats will lead to the extension of some species and the expansion of the range of distribution of certain diseases transmitted by water or disease vectors, such as insects, will be accentuated. Finally, there will also be a variation in agricultural productivity and nutritional quality/capacity. While global warming has a matrix with mostly artificial causes, other effects of climate change that spill over to the planet are of natural origin and therefore unavoidable.

On the basis of the problems addressed in this thesis, phenomena that can be traced back to the effects of an anthropic imbalance of the system have been taken into account, which, accompanying the natural effects, amplify the disastrous results. These phenomena are focused on those events that see as protagonists the water resource of the planet and the changes related to it. As mentioned above, the rise in sea level from year to year has a dual origin: the volume of water added by the melting of glaciers and the expansion of the oceans caused by higher water temperatures. Specifically, according to data collected by NASA since 1993, the average ocean surface area is increasing by about 3.3 mm per year, gaining 2.2 mm of mass per year. This phenomenon is mainly due to the mass loss of the Greenland and Antarctic polar caps of 280 Gt/year and 147Gt/year respectively since 2002. "Arctic sea ice is decreasing at a rate of 12.85% per decade, compared to the average of 1981-2010." (Data source: satellite observations. Credit: NASA Scientific Visualization Study). The increase in the mass of water bodies on the planet produces more intense floods. The evaporation of the largest quantities of water on earth is poured into the rainfall. A study conducted by researchers at the National Center for Atmospheric Research states that the variability of precipitation will continue to increase on the planet as the temperature increases; an increase of 2% for each degree of temperature is expected. In addition, these studies show that periods of drought will be more intense and floods will have more force in the same areas where the climate warms up. "When it is dry, it will be drier. When it is wet, it will be wetter - in the same place," said NCAR scientist Angeline Pendergrass.

In addition to the consequences of man's action that modify the balance of water on the planet, there is a natural event with a greater incidence called El Niño. This is a periodic climatic phenomenon that occurs in the Pacific Ocean and consists of an abnormal warming of oceanic waters[8]. As a result of the vastness of the Pacific basin - which covers one third of the planet - these changes in wind and humidity have consequences for the entire planet. The periodicity of El Niño follows a trend ranging from 2 to 7 years, and lasts around 5 months. In general, this event has seen peaks between November and January, showing the accumulation in the previous months and effects that spread throughout the world in the following months. It alternates irregularly with neutral conditions called La Niña. El Niño occurs when there is an increase of 0.5°C on the central surface of the Pacific Ocean. Although this event is not caused by human-induced climate change, it has often produced some of the highest temperatures recorded as a result of the high amount of heat rising from the Pacific Ocean into the atmosphere. "The major events in *El Niño* - such as 1972-73, 1982-83, 1997-98 and 2015-16 - have caused some of the major floods, droughts, forest fires and coral bleaching events of the last half century. (Carlowicz, Schollaert, 2017) The effects of climate change combined with natural events such as El Niño produce numerous disasters related to weather

[7] COP 21 - annual conferences of the parties, body of the United Nations Framework Convention on Climate Change (United Nations framework convention on climate change, Unfccc), for more information visit unfccc.int/process/bodies/supreme-bodies/conference-of-the-parties-cop;

[8] The characteristic warmth of El Niño is evident in the map of November 2015 on the following page. From NASA Earth Observatory; From earthobservatory.nasa.gov/features/ElNino?fbclid=IwAR3j9fXxLsxOkZh-SAgcispBn_UA8EHjmhuIXkqCcjScyYwXVbcBZTW4GaA;



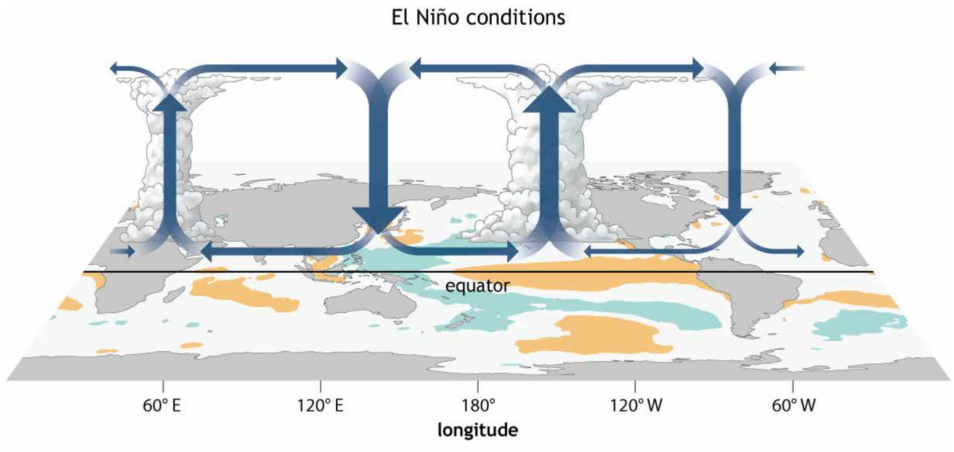
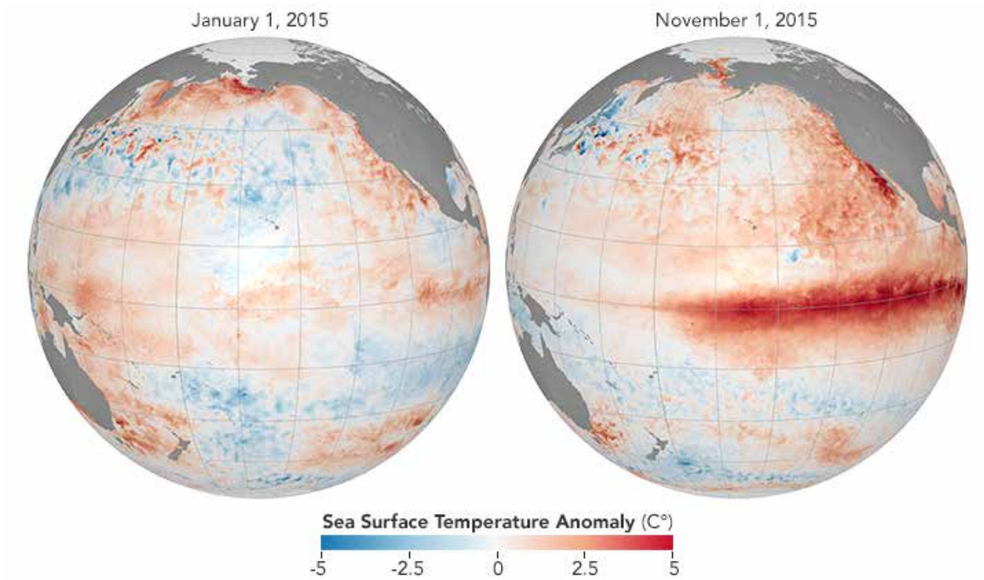


Illustrazione di NOAA / Climate.gov



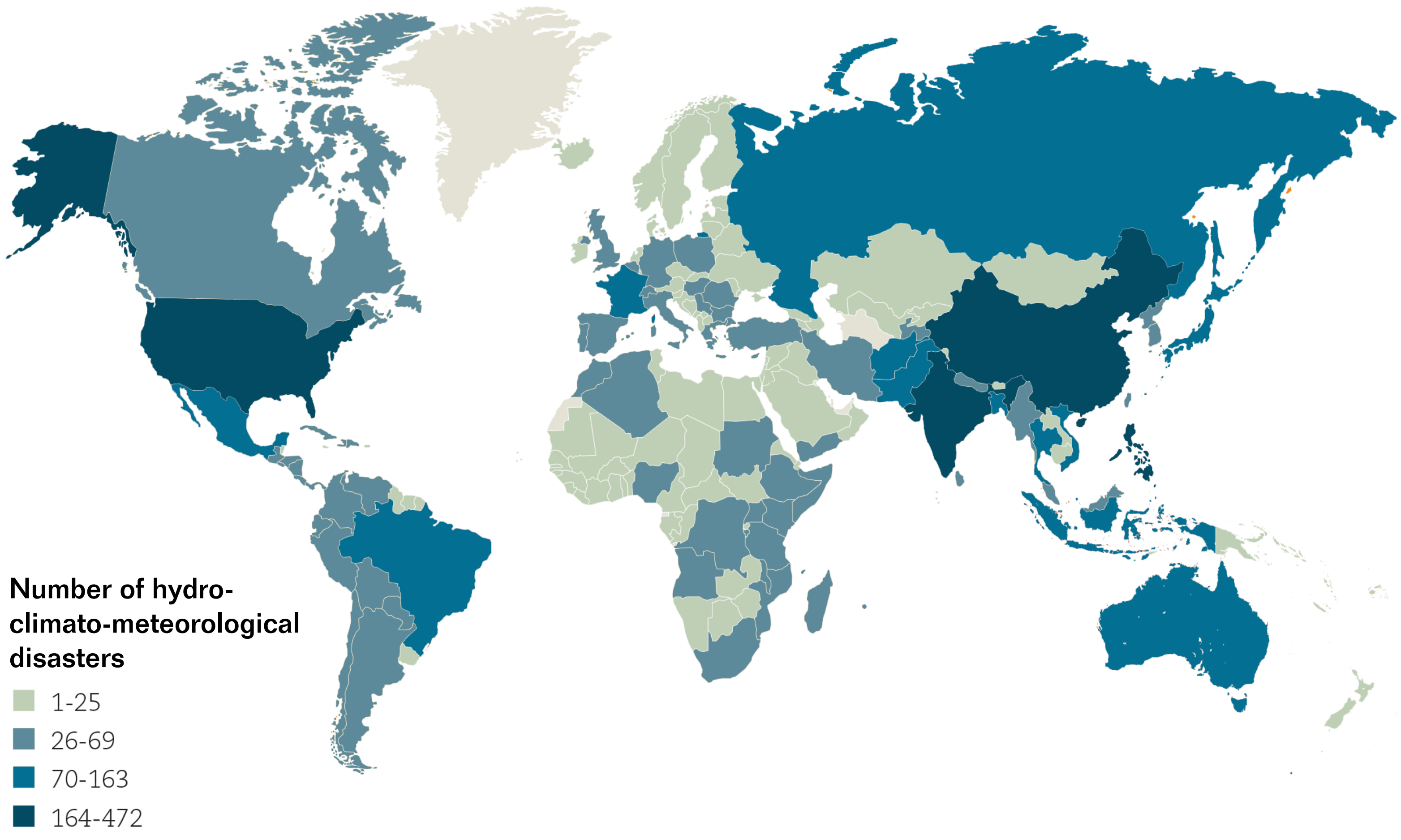
The maps of NASA Earth Observatory by Joshua Stevens, using Coral Reef Watch datas.

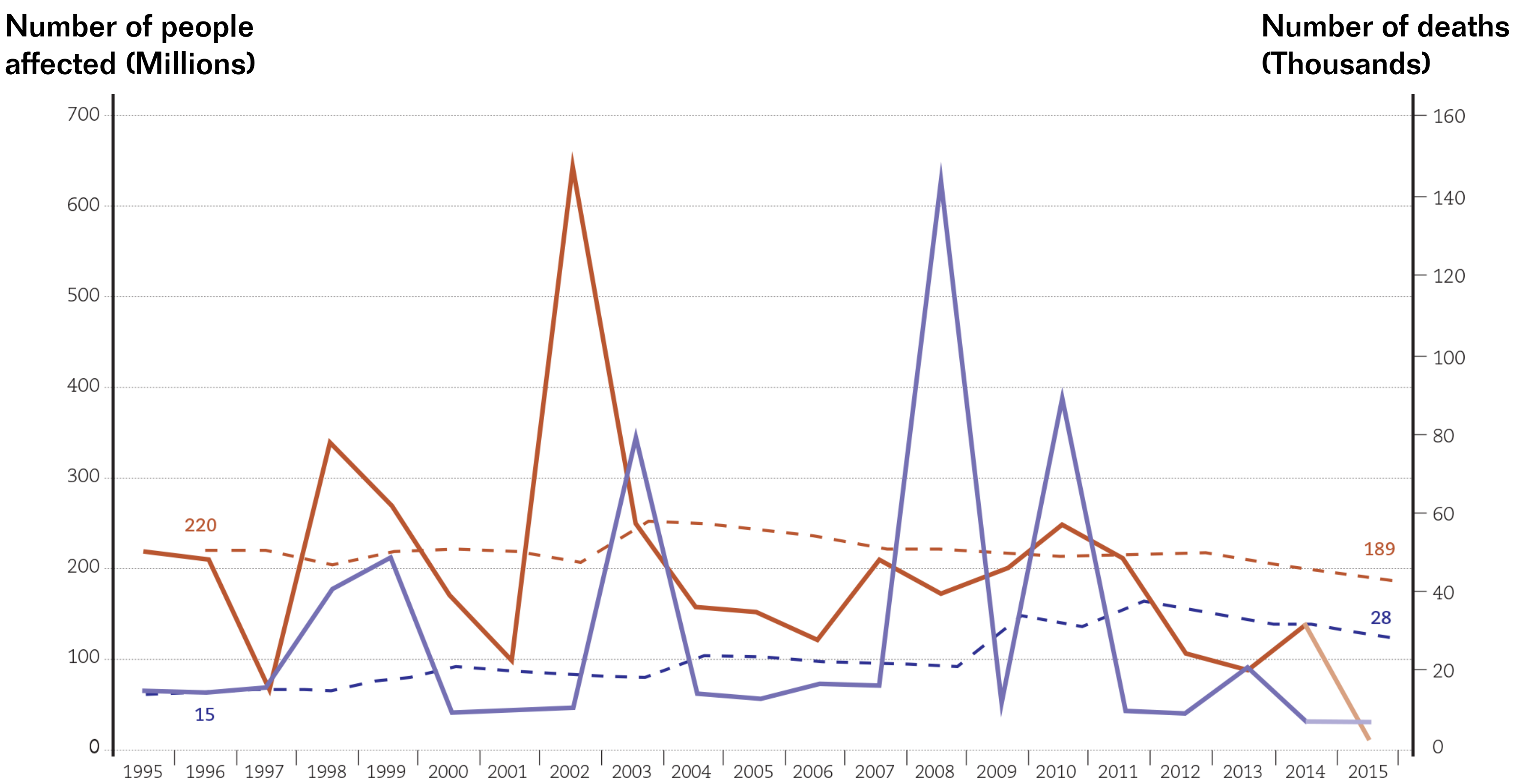
conditions. "Natural disasters kill on average 60,000 people per year and are responsible for 0.1% of global deaths." (Ritchie, 2014) In the last twenty years, the vast majority (90%) of disasters have been caused by floods, extreme storms, heat waves, earthquakes, landslides, droughts, fires and volcanic eruptions. Between 1995 and 2015, EM-DAT[9] recorded 6.457 weather-related disasters, which claimed a total of 606.000 lives with an additional 4,1 billion of people injured. On average, 205 million people were affected by such disasters each year, an average of some 30.000 per year, left homeless or in need of emergency assistance. The report compiled by the UN Office for Disaster Risk Reduction (UNISDR) and the Belgian-based Centre for Research on the Epidemiology of Disasters (CRED), shows that between 1995 and 2015, there were 3,062 flood disasters. Meteorological disasters are becoming increasingly frequent, mainly because of a sustained increase in the number of floods and storms caused by climate change. Floods are the most repetitive natural events, accounting for 47% of all weather-related disasters. To put it another way, 56% of all people affected by natural disasters are affected by floods. In the twenty years analysed from 1995 to 2015, 2.3 billion people were affected, the majority (95%) of whom live in Asia. On the other hand, the analysis shows that extreme storms have been the deadliest type of natural event been the deadliest type of natural event among these weather-related disasters, killing more than 242,000 people over the last 21 years, or 40% of the global total of all events. The 89% of these deaths occurred in the poorest countries, although they were subject to only 26% of all storms. Generally, floods affect countries in Asia and Africa more than other continents, but they also represent a growing danger in South America where 560,000 people (from 1995 to 2004) were affected on average each year by floods. In the following decade (2005-2014) this number increased to 2.2 million people. In 2015 more than 820,000 people were affected by the floods in this region. In addition, flood-related deaths in other parts of the world have also increased. In 2007, floods killed 3,300 people between India and Bangladesh, 2,100 people in Pakistan and 1,900 in China in 2010, while in 2013 about 6,500 people died in India. In recent years there has been a change in the manifestations of this event. Floods are now more immediate, rivers overflow with greater force and waves break more vigorously on the coast, flooding streets and neighbourhoods. Urbanization has made nature more ferocious for change, resulting in a significant increase in the effects of flooding, damaging farmland and resulting in a great loss of production in many parts of Asia, leading to food shortages and rural undernutrition. In rural areas of India, for example, children in families exposed to recurrent flooding have been underweight compared to those living in non-flooded villages. Children exposed to flooding in their first year of life also suffered the highest levels of chronic malnutrition caused by loss of agricultural production and disruption of food supplies.

The forecast is not optimistic, according to the analysis "In total, EM-DAT recorded an average of 335 meteorological disasters per year between 2005 and 2014, an increase of 14% compared to 1995-2004 and almost double the level recorded in the period 1985-1994. While scientists are unable to calculate what percentage of this increase is due to climate change, forecasts of more extreme weather conditions for the future almost certainly indicate that we will see a continuing upward trend in weather-related disasters in the coming decades". (Wallemacq, 2015) Rising population and uncontrolled construction will increase human vulnerability to extreme weather events. The total cost of such vulnerability is estimated at between $250 billion and $300 billion in 2050.

[9] CRED's Emergency Events Database (EM-DAT) contains the world's most comprehensive data on the occurrence and effects of more than 21,000 technological and natural disasters from 1900 to the present day. Details of EM-DAT's methodology and partner organizations can be found on website www.emdat.be

Number of weather-related disasters reported per country (1995-2015)





From: "The human cost of weather related disasters: 1995-2015" by Wallemacq P. and Guha-Sapir D.

1 - Europe_Venice (Italy) The flooded Piazza San Marco, the Doge's Palace (left), the Lion of St. Mark winged bronze statue and the Venetian lagoon after the exceptional overnight high tide water level, in November 2019.
Ph: Marco Bertorello/AFP/Getty Images
From www.theguardian.com/weather/gallery/2019/nov/13/flooding-in-venice-in-pictures, consulted on 25th May 2020.

2 - Asia_ Indonesia, flooding struck in areas of the city of Samarinda from around 22 May after a period of heavy rain.
Ph: BPBD of Samarinda
From floodlist.com/asia, consulted on 10th June 2020.

3 - Africa_ Residents stand on rooftops in a flooded area of Buzi, central Mozambique, after the passage of Cyclone Idai.
Ph: Adrien Barbier/AFP/Getty Images
From www.theguardian.com/world/2019/mar/20/cyclone-idai-rising-flood-levels-threaten-mozambique-disaster-relief-effort, consulted on 13th June 2020.

4 - America_ New Orleans after Hurricane Katrina in the 2005.
Ph:Michael Appleton/NY Daily News Archive/Getty Images
From: www.history.com/topics/natural-disasters-and-environment/hurricane-katrina, consulted on 25th May 2020.

5 - Oceania_ Floods in Central Division, Fiji, late April 2020.
Photo: NDMO
From floodlist.com/australia/fiji-floods-central-division-april-2020, consulted on 10th June 2020.

[10] "TecnoLogica" www.tecnologica.altervista.org/php5/index.php?title=Resilienza;

The meaning of resilience in different fields, introduction to the new trend

Resilience is a complex concept capable to be clearly identified with a single definition. A word that expresses an abstract state to pursue, a bit like love. However, in recent years, people have tried to achieve it as a goal or maintain it as a fundamental feature in several fields.
Over the years, the term "resilience" has gained a moderate presence in several areas. Initially used in purely technical environments, it was hidden from non-specialists.
In materials engineering and metallurgy, this construct identifies the ability of a material to withstand impact without breaking. As this technical property of materials increases, the degree of deformation that a material can undergo under the stress of dynamic loads without breaking and without presenting an irreversible condition of deformation is defined. "It is necessary to provide a high amount of energy to yield a cube of unit volume of a certain material."[10]
In the informatic field, the concept of resilience - or fragility index - translates into cyber resilience. "The cyber resilience refers to the ability to continuously deliver the intended outcome despite adverse cyber events" (Björck, 2015). By reference to a system that continues its usual operation, despite the anomalies. It identifies the propensity to adapt to wear so as to guarantee the availability of the services provided.
In biology, resilience is the ability of a living organism to repair itself and return to its state of equilibrium after a disturbing event.
Moreover, the term is widely used in the field of psychology. In this context, "resilience is the ability to resist, cope and reorganize one's life positively after suffering a negative event. Therefore, it is not a mere passive resistance, an unconscious and automatic reaction, but a conscious response, a reconstruction that translates into potential and prospects for growth. The resilient individual is not someone who ignores or denies difficulties, nor minimizes them. On the contrary, he is someone who is able to move forward, with renewed strength, with a deeper and more conscious self-knowledge"(Borzì, 2017). In other words, being resilient means to be able to transform any conflicting event of a particular person into a source of learning. By improving one's skills and the quality of one's life by continuing on the personal path of growth and fulfilment. However, the concept of resilience is full of ubiquity. "This ubiquity is potentially due to the fact that 'resilience' itself, does not say anything about what is good or bad;"(Petrescu, Trogal, 2015). "Undesirable systems, such as dictatorships or saline environments, can be very resilient. In such cases, the resilience of the system should be reduced" (Walker, 2015). Another example that places resilience through a negative connotation concerns the resilience of nature. In recent years with climate change it has been observed that human actions have altered the essence of the surrounding environment and to these actions are matched a systematic and complex counter-action of nature. More than man, the nature has this distinctive feature. In this case, nature's resilient attitude is a negative aspect for man: the effects of climate change are nothing more than the planet's response to the negative perturbations that man creates with it. Limiting the negativity of the results of man's actions would also reduce the negative responses that the Earth system grants him. In this context, it seems necessary to prepare a local strategy that considers these climate changes in order to define adaptation policies and actions and to adopt innovative solutions and technologies to cope with these changes. In this case, the resilience is identified in giving mutual support to the most vulnerable people, organisations and systems to resist and prosper from such unpredictable and destructive events. The concepts of resilience and adaptation are relatively new in this area, but they are extremely strategic to respond to the ongoing climate change. Precisely for this reason, in recent years, the word "resilience" has played a fundamental role in the language of the global community, along with an ecological and conservative tendency. New strategies of environmental resilience consist less in historical ecological processes and try to focus more on promoting self-sufficient ecological processes. "In this way, the concept of the savage is replaced by the self-sufficient or, if it is preferred, resilient." (Cantrell; Martin; Ellis. 2017)
In the various facets of the term the common aspect of resilience is the ability to adapt to conditions of external change and the maintenance of functionality and vitality at several levels: individuals, households, communities and regions. Resilience is a quality that is already defining the 21st century globally.

Architectural Resilience and the role of architects against the climate change

According to the Resilient Design Institute, "resilient design is the intentional design of buildings, landscapes, communities and regions in order to respond to natural and man-made disasters and disturbances — as well as long-term changes resulting from climate change — including sea level rise, increased frequency of heat waves and regional drought." The core principles of resilient design are survival and adaptability to changing conditions. The architectural resilience of a building looks at the real conditions of a post-carbon world affected by the climate change. Architect Craig Applegath[11] provides the basis for resilient design, creating a list of implementation that resilient architecture must adopt as its principles:

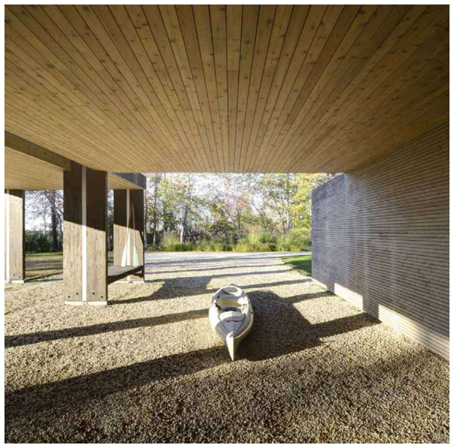
- **Use of low carbon materials and systems** - materials or systems that require significant amounts of energy or are derived from oil derivatives in their production will become economically uncompetitive as a result of rising energy costs, additional costs associated with potential future regulations or tariffs on coal capitalisation. Low-energy wood and masonry, on the other hand, are considered more appropriate building materials.
- **Design and plan buildings for low external energy inputs for ongoing building operations -** high energy efficiency required, adopting highly insulating building envelopes, triple glazing, passive solar heating through the accumulation of the inertial mass. LED artificial lighting systems in combination with natural light during the day. Allow natural ventilation or adopt simple low energy mechanical systems.
- **Design buildings for maximum day-lighting -** consider natural light as the main design input of the building's form. Narrower floor plates, internal courtyards, and atrium spaces are good examples of possible daylight effective strategies.
- **Design "generic buildings" for the future flexibility of use -** construction materials and the construction process will become increasingly expensive. These higher construction costs will provide an incentive for building owners to design for future building flexibility, so that subsequent renovation and modification work will be cheaper. The most effective strategies for designing flexibility are the use of modularity and standardization in space planning. Modularity requires construction spaces to be multiple of each other and the standardisation of spaces aims to provide common denominator spaces that can be used for many overlapping uses. Buildings should be designed for both first and future use. The form should not "follow the function", but instead follow many hypothetical future functions.
- **Design for durability and robustness -** to maximize the future resilience of buildings, the materials and the costruction methods must be durable in the face of more energetic weather, and increasing number of significant weather events that increasing climate change will produce.
- **Design for use of local materials and product -** the costs of non-local materials transport will significantly increase. This in turn should create greater demand for locally produced building materials and products.
- **Design and plan for low energy input constructability -** Promoting manual construction, without the need of machines or systems that require significant amounts of fuel for operation. Energy-intensive construction techniques may become less cost-effective, and the costs of manual labour will potentially be a less critical factor in the choice of construction techniques.
- **Design for use of building system that can be seviced and maintained with local materials parts and labour -** Climate change and peak oil will more than likely reduce global trade, and reduce easy access to materials, products and system from other countries. Therefore, building system should be designed to be serviceable through a local supply of parts and labour.

The two terms resilience and sustainability, although equally important, are not synonymous. Seeing the images after an environmental disaster, it doesn't really care if the crumbling buildings were LEED-certified, of course the ecological development of architecture is important, but in the face of such forces, other construction priorities have to be considered as well.

[11] Applegath is the founder and moderator of ResilientCity.org, a not-for-profit network devoted to exploring planning and building design strategies to help cities develop the capacities to adapt to the impacts of climate change and energy scarcity in the context of demographic change.

[12] "Resilient Buildings: The Techniques, Costs, & Benefits" on Viatechnik. From www.viatechnik.com/resilient-buildings-the-techniques-costs-benefits/

Photo by the authors - example of vernacular resilience. The pile-dwelling house represents one of the examples of resilience met in the city of Cartagena de Indias. It is located near the large beaches in the north of the Colombian city, in the neighborhood “La Boquilla”. Its structure raised from the ground floor allows shelter from floods or high tides. In addition, through a wise use of natural and local materials such as guadua, wood and palm leaves, it accentuates its resilient character and also gives a good example of sustainability.

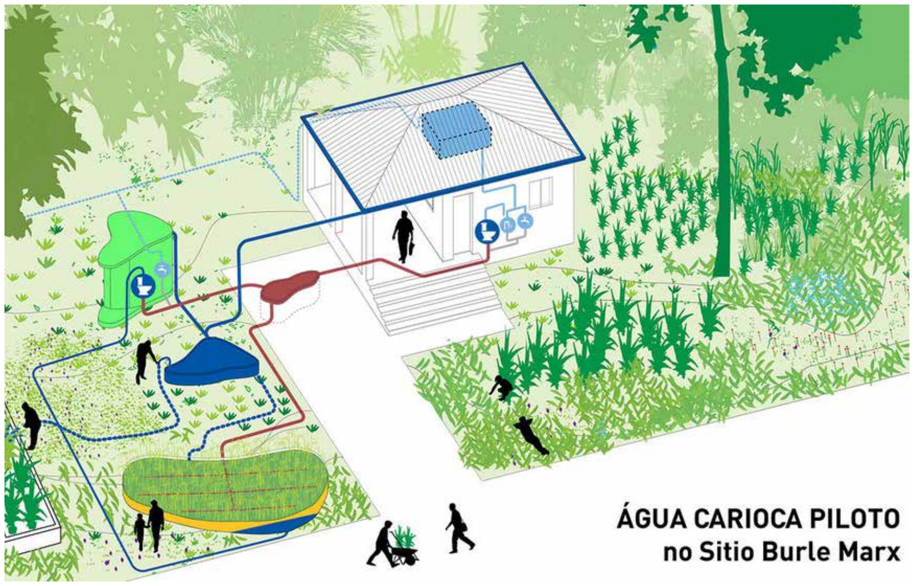


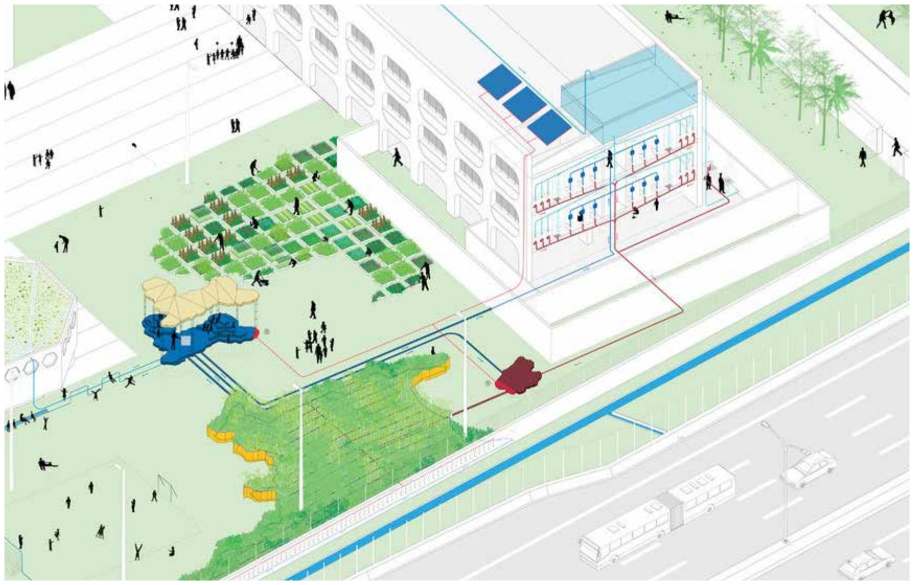
The Northwest Harbor Residence, East Hampton, NY - by Bates Masi + Architects. The house has a resilient approach with a contemporary aesthetic to counter flooding. On the ground floor of the residence there is a canoe for emergency use. From batesmasi.com/projects/northwest-harbor/

Between sustainable and resilient design there are points in common and points in parallel. On the one hand, the resilient approach to construction shows redundancy in multiplying a building’s energy supply systems. This is to prevent serious disruptions to general operation by aiming to maintain liveable conditions in case of prolonged energy or heating losses by reducing the energy load. A dependence on passive heating and cooling strategies (passive survival) and the possibility of manual replacements in case of malfunction or temporary power outages is preferred, reducing the dependence on complex building control systems. A key aspect of these buildings concerns water conservation practices, both through annual replenishment of the resource on site and efficient rainwater harvesting, used as primary or reserve water supply. The redundancy of supply and storage systems also takes place in the interest of the water resource so as not to be without it during emergencies. Furthermore, think about an additional disposal system for human waste in case the waste water system is not operational. For example, this could include composting toilets and urinals without water. The design includes an assessment of the environmental characteristics of the project site, including future climate change scenarios, for example through flood assessment plans in a flood risk area. Resilient buildings need to be more durable, considering functionality as an integration of rain protection details, windows that can withstand hurricane winds or internal materials that can dry out when wet, without the need to change them. On the other hand, the sustainability of a building is achieved through a reduction in the need of energy, the application of renewable energy sources, recycling and reuse of water for secondary functions, research and adoption of local materials, accessibility to public transport or the quality of the internal environment. The common ground between the two terms is that in both cases these buildings must be energy and water independent, that they use renewable resources and that these resources can be stored on site. In addition, a good analysis of the effects of the surrounding environment with which the building is connected must be ensured. Finally, community support, participation and interrelationships between people who live in the same environment and who enjoy or suffer from the same privileges or disadvantages seem essential. Adopting resilience in the design of buildings consists in a process thought with greater attention to future scenarios and not only to the past, to the typical use that will be made of the building; thinking also about the focal points of normal use, but also the most unlikely situations caused by any natural disaster that could lead to the integrity of the building or even more serious risk to the life of the occupants. The surrounding environment always poses a criticality when determining risk factors and obviously also a criticality when identifying the resilient nature that a building can satisfy in a given context. For this reason, resilient design is specific to different local contexts. In essence, sustainability is focused on protecting nature and the environment from human activities, while resilient design tries to protect the human being from the catastrophic responses that nature offers.

“[...] building to code is no longer enough, and neither is creating energy efficient homes. [...] But the challenge facing contractors today is creating homes, buildings, and communities that are resilient in the face of droughts, flooding and a whole host of other natural disasters.”[12]

In this way the architecture develops a more flexible connotation and adapts to respond to different context changes, to overcome the possible effects of climate change, catastrophic events or to adapt to new conditions. Basically, resilience adds a dynamic component to the design. On the one hand, designing a resilient building means finding an answer to the change that is taking place, but on the other hand it means integrating the architecture with the exterior and reducing the environmental impact. For this reason resilience and bioclimatic design, together with energy saving and sustainability, lead architecture to the most appropriate responses in the design of construction or building service systems.
An coherent example with the development of the themes discussed in this thesis and the principles presented in the chapter seems to be the Água Carioca project of the dutch study OOZE, proposed to the Brazilian city of Rio de Janeiro, in 2017. The mission of this group is to position themselves with their projects as catalysts for change. They seek to elaborate innovative projects to solve the controversial and complex contemporary challenges. OOZE's approach is collaborative and uses design to bring together stakeholders, maintaining holistic and strategic thinking through ready-to-use ideas as in the case of Água Carioca. This approach is applied to urgent challenges in the fields of hydraulics and agriculture. Água Carioca is considered as a project with a set of characteristics that combine resilience and sustainability. It addresses the lack of adequate sanitation in some informal settlements in the city of Rio de Janeiro, changing the way water resources are treated in buildings and consequently in urban areas. Basically, the sanitation solution adopted treats and recycles waste water without sending it to other places, but directly on site, improving its quality and saving on transport (no need for large-scale infrastructure works such as sewers, no transport of dirty water and 50% less transport of clean water). This solution is scalable and performs its function on isolated houses or multi-level buildings. In addition, it consists of several interconnected project scales, starting from the technological system of the single house to a community context. The system involves the use of three adaptive elements to different needs: rainwater collecting system, septic tanks and constructed wetlands. The latter consist of a proven natural sub-surface phyto-purification system that guarantees the impossibility of human contact with the waste water. The natural processes that take place between the wastewater and the roots of the plants located in this area reduce the pollutants present in the water. This system allows the decentralization of the wastewater disposal model, favouring through small local interventions, the closure of a circuit that cleans and reuses this water directly at the source. In this way the cyclical processes of nature are also restored.
What the project is focused on as a goal gives to the buildings a resilient character from the point of view of the autonomy of water supply within a context where the persistent problem is the lack of a traditional centralized infrastructure. Naturally, in this case the OOZE project provides a single





From http://www.aguacarioca.org/designproposals

Yanweizhou Park in Jinhua, eastern China 2014 by Turenscape.
From www.businessinsider.com/china-is-building-sponge-cities-that-absorb-water-2017-11?IR=T, consulted 25 June 2020.

plant engineering solution to buildings, but the solution seems appropriate not only to make buildings more respectful of the conditions of bioclimatic architecture, but also as a redundant and back-up proposal in those buildings that may be affected by disasters and therefore subject to disruption of the general water system.

The Urban resilience approach to develop a new way to rethink the cities

"Resilience transcends stairs," sets out the first principle of the Resilient Design Institute. The resilience feature of buildings is only one component in the design of a safer and more resilient environment in the face of climate change. On the one hand, strategies need to be applied to the scales of individual buildings, but it is also necessary that these principles can be scaled in communities and the larger regional and ecosystem scales. In addition, these principles also have effects at different time scales, from immediate to long-term. Generally the most anthropized places are also those that have a reduced ability to withstand the changes caused by environmental shocks and to resist damage caused by heat waves, floods or other types of extreme weather events. On the contrary, it has been observed that many natural places have a strong capacity to respond to stress and to adapt to change as a result of their resilience: trees thanks to their strong roots resist the strong winds of hurricanes, the tissue of their roots blocks avalanches; after an environmental disaster plants are reborn, animals repopulate the area, undeterred life is regenerated. In the last period planners and urban designers have discussed the theoretical concepts of reformulation of those anthropized environments that in the last period are subject to the risk of climate change effects. All cities are involved in these natural and artificial challenges, and as the world's population moves from rural areas to cities the risk increases significantly. Fortunately, the concept of resilience may also be applied to cities. Starting from the extreme events that an urban system can undergo, these can be divided into 4 categories (O'Brien et al., 2006), for each category corresponds to a different resilient response that the city offers. The resilience of urban systems considers different strategies including risk mitigation techniques, shock preparedness techniques and disaster damage restoration techniques.
Infrastructure resilience has been defined in several ways, the most widely used and the most objective being the National Infrastructure Advisory Council (NIAC), which claims:

"The resilience of infrastructure is the ability to reduce the scale and/or duration of disruptive events. The effectiveness of a resilient infrastructure or enterprise depends on its ability to anticipate, absorb, adapt and/or recover rapidly from a potentially disruptive event".

In some urban projects conducted in Europe, the concept of resilience reaches the metropolis by responding to certain topics and mitigating some risks. The transformations developed in some cities will show decisive results in the next decade. Cities such as Barcelona, Paris, Hamburg are witnesses of these urban actions, as much as Copenhagen, which represents one of the pioneering cities of this theoretical trend of urban development. These studies on the effects of climate change have produced for the city of Barcelona an operational programme "Climate change resilience and adaptation for the Barcelona metropolitan area 2015-2020", which prefigures the analysis of the main risks and the main areas of intervention through climate projections in order to increase their resilience characteristics in view of a possible climate emergency. In France, the Parisian region has already started an ecological greening process to alleviate its vulnerability to the flooding of the Seine. This process involves a redevelopment of the river banks through an innovative natural regeneration and requalification project. The city of Hamburg promotes sustainable mobility by activating a plan to drastically reduce car use by 2034 through different implementation measures such as the "Hamburg Green Network". This system involves a set of vegetated axes arranged in a radial pattern connected with two parks and different equipped green areas. This landscape plan restores nature within the city, adopting a multiscale approach from the green of the district to the green of the urban park and the green of the rural areas. "[...] to the 8 district parks are added 30 district parks, finally integrated by micro district parks, urban green areas and green spaces with linear development" (Tarquini, 2015). With this important project, the city of Hamburg presents a resilience not only in the quality of its public space environments, but also inherent in the "multimodal permeability" of the mobility network, and also fully embraces the concept of sustainable roads. In addition, the city increases its rainwater drainage capacity through collection tank systems associated with more permeable infiltration soils. As an additional resilient response to summer heat waves, the contribution of urban greening will lower the effects of urban heat island. In Italy, at the end of 2019, the city of Milan promoted desealing initiatives involving the replacement of cement and asphalt in some areas of the city with public green spaces.

These are not isolated actions, but a real strategic plan. The PGT[13] envisages a 4% reduction in land consumption compared to the previous Plan. " Green areas, considered for too long a purely ornamental factor, are now more and more a strategic element to face complex situations such as the adaptation of cities to climate change" - says Nada Forbici, President of Assofloro[14].

The term "desealing" refers more precisely to the paving and decontamination of the soil, dismantling the waterproofing layers such as asphalt and concrete or other materials of the hardscape of urbanized areas, encouraging the development of more landscape in the area. The process involves ploughing the soil below, in order to recover a connection with the natural subsoil. In the European Commission document: "Guidelines on good practice to limit, mitigate and compensate soil sealing", countless examples of good practice at political, legislative, funding programmes, local planning tools or information campaigns implemented within the Union for soil depletion are provided. This methodology favours the restoration of the capacity to manage cloudburst volumes caused by climate change, reducing the related risks of the cities affected. In addition, it substantially reduces the supply of clean rainwater to wastewater disposal conduits, reducing their purification costs. Finally, the restored soil will be able to store more organic substances and CO_2, facilitating the reduction of the urban heat island effects of large cities. By restoring fertility, the soil acts like a "sponge", filtering water and climate-altering gases into the aquifer.

The new urban frontier deals with the theme of urban resilience through the concept of "Sponge City". One of the pioneering nations of this urban development is China, being also one of the nations in the world most affected by natural disasters. The Asian government is increasing the use of capital for the transformation of densely populated metropolises in order to depaviment impermeable building systems by giving a more permeable surface to cities. The concept of Sponge City takes the form of green infrastructure, such as wetlands, green roofs and rainwater gardens, in other words the greening of all horizontal surfaces. Cities have to take on board the capacity to absorb the quantities of water produced by the most extreme events, trying to store it

[13] The Territorial Government Plan (abbreviated to PGT in italian) is an urban planning instrument introduced in the Lombardy Region by Lombardy Regional Law no. 12 of 11 March 2005. The PGT replaced the General Town and Country Planning Plan as an urban planning tool at municipal level and aims to define the layout of the entire municipal territory.

[14] Assofloro –The Trade Association of the Bodies and Associations of the Green, Landscape and Environment Supply Chains.

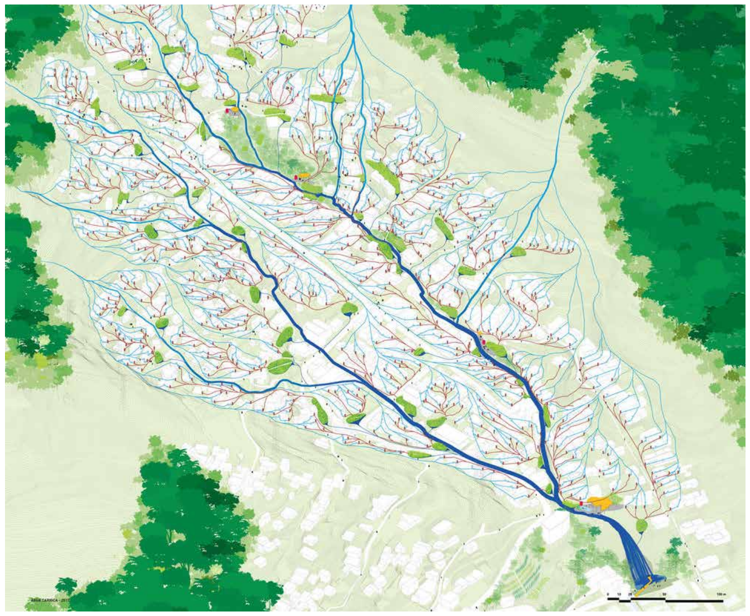
in systems that allow reuse afterwards. These systems constitute a “natural” set of actions to recover rainwater trying in this way to transform into a resource what until now has been one of the main urban problems, the excess of water. The current project aims at transforming about 80% of urban areas into drainage systems with the possibility of reusing at least 70% of the collected water. One of the Chinese cities that is succeeding in this project is Lingang New City, about 60 km from Shanghai. This city has an area of about 80 km2 and will become the largest “Sponge City” pilot area in China.
The project involved the construction of grass ditches, permeable pavements, green roofs and wetlands useful for rainwater storage. Within the project there is the presence of pools with scenic water, used to control rainwater and prevent flooding. The sidewalks are made of penetrating bricks that allow the water to cross quickly, reducing the grouping of water on the roads. Under each garden there is an underground pool, where rainwater is collected through ducts. The roots of the plants in the gardens purify the rain before channeling it into the pools. The purified water is used for self-service car wash systems installed in car parks. Projects of this type aim to make the neighbourhoods, streets and green areas capable of capturing and conserving rainwater in order to reduce both the impact of floods and the consequent flooding, but also to counteract the arid periods, when the climate is drier. What has been designed for the city of Lingang has also been adopted to rethink some informal neighborhoods by the OOZE study. As seen in the previous paragraph, the problem concerns the supply of water resources in the cities of Rio de Janeiro. The Dutch study proposes through the Água Carioca project a rainwater collection system adopting the idea of the Sponge Cities seen in China.

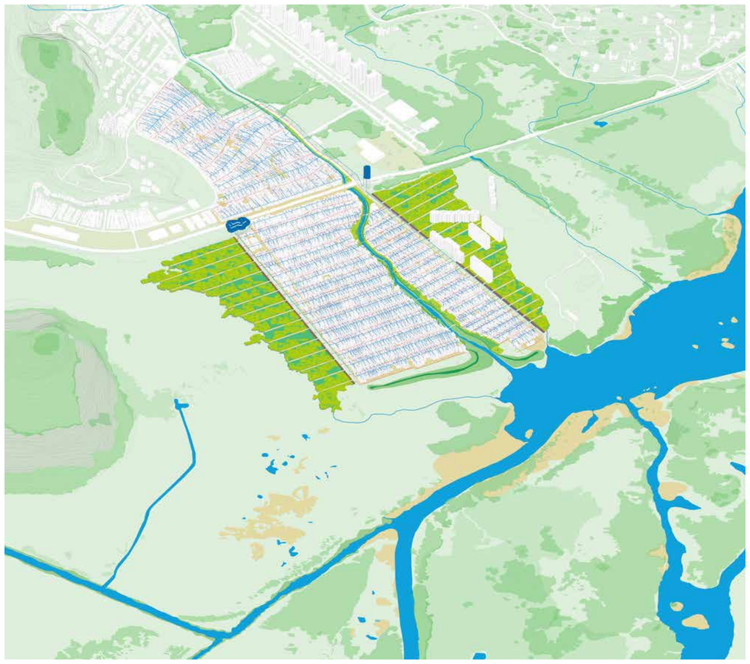
As in the case of the pilot project for the Burle Marx house (it represents the proposal with the “size XXS”), the system used consists of wetlands inserted in a wider context compared to the use of a single building, adapting to several urban areas. In fact, the study through the idea of multiscale system proposes different “ sizing” to be adopted in more or less large contexts. Size “S” is represented by a small community of the favela “Morro do Salgueiro”. The favela is located on the steep banks of the Tijuca forest. The proposal involves a community of about 160 buildings and 750 people with a water requirement of 106 m3 of water per day. The houses are connected in a chain system depending mainly on the slope of the land, with the wetlands located at the top of the site to serve the group of houses below. The other basic elements, together with the wetlands, are adapted to the community context, forming functional green spaces throughout the neighbourhood. The nature of the steep slopes provides green spaces and terracing that create common places for sharing, pedagogical spaces and community facilities such as the event pavilion.

Água Carioca applied to the ‘M’ scale takes into account a complex of 750 dwellings and 2900 persons with a daily water requirement of 347 m3 for the ‘Morro da Formiga’ favela. Within this district there is a waterfall river. The intention of the project is to preserve, through the usual chain system of rainwater storage and wetlands, the quality of the river water as it enters and leaves the complex of houses. The river will be made swimable by the intervention and usable by the inhabitants for recreational purposes and no longer as a landfill. In addition, the terracing foreseen in the project will act as a terracing, increasing safety from landslides during heavy rainfall. Finally, the building wetlands create a green and healthy environment to share public life and repopulate the urban space in front of the houses, contributing to a safer environment. As a last scale (size “L”), the project for the favela “Rio das Pedras” is designed for a proposal that will contain 10,000 buildings, for a total of 90,000 people with a water requirement of 12,780 m3 of water per day. The neighbourhood is extremely dense on a much larger scale. The plots are on flat land subject to flooding. The wastewater flow is directed away from the river, to wetlands peripheral to the community. The OOZE system also proves its flexibility at this scale, adapting to the context and using the extensive open space surrounding the built up area. Solar-powered pumps are used to return water to the community for reuse inside the homes and to feed the watercourses present. This project allows the river to recover the quality of its water, finally turning into a valuable natural public space, preventing wastewater from polluting the Barra Lagoon.
The approach of the projects in Água Carioca is taken as a reflexive input on the issues of resilience and sustainability of an intervention regardless of the scale

considered. The different conceptual ideas underlying the Dutch studio's projects such as multiscalarity, the Sustainable Urban Drainage Systems and the reuse of water resources locally reflect some of the principles that will be expressed in this thesis project.
The feature of resilience of these projects is not only inherent in the implementation process of the project, but especially in the new relationship and new sharing that the users will have with it. The interest in the social aspect of interaction between the resource, the environment and the occupants is fundamental. Developing interest in the community through active participation, workshops and seminars has been a strength of this project, resilience also lies in this, making sure that the project perpetuates its value through the people who inhabit it. "All our projects allow users to appropriate a space and use it as a tool to transform their culture of life. " (OOZE)
From these analyzed projects, it is possible to understand that resilience does not follow the abstract achievement of threshold goals as the only condition to be met. Eliminating all critical factors is not the only priority, because there could always be unforeseen conditions. However, it is clear that the creative and technical-scientific approach of architectural or urban design must necessarily dialogue with community cultures and connect to the social values of cohesion and cooperation to ensure an adequate result. This is called social resilience:

"A further approach to the concept of resilience of cities leads to the definition of social resilience; starting from the recognition of the essentiality and centrality of the community in the urban system, i.e. the predominance of the social system within the city system, able to govern the physical one, social resilience is defined as the ability of the community to withstand external shocks by positively governing the changes induced on the infrastructure, on the external environment, on the economic and social system". (Adger, 1997).





The images represent the different scales of the "Água Carioca" project by OOZE:
- Morro do Salgueiro project, "S"scale;
- Morro da Formiga project, "M" scale;
- Rio das Pedras project, "L" scale.

The images were taken from www.aguaca-rioca.org/designproposals

Chapter one: Nature-based Solutions for climate change adaption

Nature-based solutions state-of-the-art: what, when, why and how

"Adaptation means anticipating the adverse effects of climate change and taking appropriate action to prevent or minimise the damage they can cause, or taking advantage of opportunities that may arise."[1]
In the first moment when the issue of resilience became part of the field of study of architectural and landscape design, the solutions for adaptation to climate change have been traditionally entrusted to conventional engineering solutions, especially with regard to the subject of water (O'Hogain, 2018). Most of these, however, not only present cost and implementation issues, but are also problematic mainly in terms of maintenance and are not even completely sustainable in their production and installation. Furthermore, they are representative of a linear approach, based on the concept of **disposal after use**, as opposed to a circular economy approach, which is mainly based on the notions of **recovery** and **reuse**.

In the theoretical mark of circular economy, Nature-based Solutions (NbS) have been introduced as "natural and constructed systems which utilise and reinforce physical, chemical and microbiological treatment processes." (O'Hogain, 2018, p. IX) The concept was first introduced in the late 2000s by the IUCN (International Union for the Conservation of Nature) and then it was placed on the European Commission agenda in 2015 in the Final Report of the Horizon 2020 Expert Group on Nature-Based Solutions and Re-Naturing Cities, in which the importance of learning from nature is underlined: "NbS involve the innovative application of knowledge about nature, inspired and supported by nature [..] mimicking how non-human organisms and communities cope with environmental extremes."[2] All of these processes play a key role in the adaption to climate change, with a substantial decrease of the mechanical complexity required and a consequently

[1]The definition can be found in the EU commision document *Adaptation to Climate Change*
[2]The definition can be found in the EU commision document *Towards an EU Research and Innovation policy agenda for Nature-Based Solutions & Re-Naturing Cities*

lower impact on the existing ecosystem; furthermore the benefits can also include wastewater treatment, environment and biodiversity restoration. It is important to point out how Nature-based Solutions, if managed consciously within the project, are not simply and added value at an aesthetic level, but have important functional and environmental benefits. There are three main categories into which the NbS can be divided, mainly the final objective of their implementation and the different field of application:

- Restoring and protecting forests;
- Bring nature to the cities;
- Coastal habitat restoration.

As far as the research work is concerned, the main attempt is to introduce these tools in a different field of application from the properly urban one, trying to understand which ones can be applied in a context with a strong informal character and with which methods, the in order to contrast some of the climate change effect previously discussed, such as urban flooding, heat island effect, carbon emission and drought. In the article *The role of Nature-Based Solutions in architectural and urban design* (Mussinelli et al.,2018) it is underlined how within this concept, a number of solutions can be grouped together that vary significantly in their level of complexity: planting trees, realizing filtrating surfaces, installing green roof and green walls. Furthermore, it has to noted that each intervention is a single action characterized by a strong link with the contest in which it is performed, for this reason the Nature-based Solutions are fundamentally **place based**, as it is their effect and as it must be their design. In fact, precisely because of their nature, they are linked to the climatic and environmental characteristics of the place and at the same time must intervene on them, also taking into account social and economic factors. By identifying each of these systems as a single action, the concept of modularity also comes into play, introducing another fundamental feature: the possibility to create various and different complex system through single interventions. For example, an advanced application of the NbS are **Green Infrastructures (GI)**, defined by the European Commision as "a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services such as water purification, air quality, space for recreation and climate mitigation and adaptation."[3]
The complexity of these networks brings with it a whole series of features that define them, such as multifunctionality, multiscalarity and multi-objectivity; the last one, in particular, concerns the comprehending of all kinds of green and blue spaces. (Mussinelli et al.,2018)

Once understood what NbS are and how they work, it is important to emphasize, even before seeing some examples, how their design process must present some innovative traits, not always contemplated in the common processes. First of all it has to be considered that most of these solutions can not yet replace the hard ones already built and for this reason they have to adapt to them with the purpose of completing them. Therefore there is an obligation to tailor the intervention on the pre-existence, whatever it is, while at the same time taking into account the main concept of "**building the nature in"** (O'Hogain, McCarton, 2018, p.6). From this all the other characteristics can be drawn: the project has to consider multifunctional solutions and a degree of dynamicity, being natural processes not static or one-purposed. Furthermore a certain level of uncertainty must be considered, that can be addressed with a flexibile mind based on a **learning-by-doing** method that allows multiples tries and errors. Finally, an interdisciplinary collaboration is required, mostly because these projects always interests different stakeholders among which local people, which should be involved in the process; in fact "Local people know a lot about the area where they live, and their knowledge base can be very useful for understanding natural systems and processes, and how they will interact with hard engineering structures." (O'Hogain, McCarton, 2018, p.7). As a result, a **hybrid** professional figure is emerging who must be able to draw on a repertoire of different knowledge such as engineering, social and environmental science, and to work with the all of the other actors involved in the process. The role of the inhabitants and their involvement is discussed more extensively in the next paragraph, in which the role of the community in relation to the NbS projects is explained.

The most significant experiences related to Nature-based Solutions are those concerning **water management**, mostly in relation to the phenomena of increasing urbanization and soil sealing. Rainwater runoff drainage is often dealt without the necessary planning, resulting into overflow of the water bodies into which the networks discharge or even backflows and flooding due to sewerage sections that are not sufficient to dispose of the flow rates, even in non-exceptional rainfall events. In order to contrast this event without excessively modifying the pre-existing systems, green areas can take on a performative character when put in relation to water, combining into blue-green technologies or **Sustainable urban Drainage Systems (SuDS)**. SuDS are a type of Nature-based Solution whose purpose is "to slow down and reduce the quantity of surface water runoff in an area in order to minimize downstream flood risk and reduce the risk of resultant diffuse pollution to urban water bodies." (Davis, Naumann, 2017, p.125). The main advantages of these systems are: rebalancing hydrological systems and reducing the pollutant load of water bodies, helping in the process of transforming cities into sponge cities and building green infrastructures able to exploit all the benefits provided by the ecosystem services of natural solutions. Also for these systems, a fundamental concept is **multiscalarity**; in fact it is important to underline that for greater efficiency this innovative management of meteoric outflows should be widespread and applied not only to places of particular environmental criticalities, but to the spaces of the ordinary such as streets, squares and parks. In this way, even with small-scale interventions carried out by individuals in a context of community coordination, it is possible to contribute on a large scale. Additionally it has to be remembered that, however technologically advanced these techniques may be, they should always be designed as integrated with the traditional solutions, considering an embedded approach between hard and soft technologies.

In the *Sustainable urban Drainage Systems Manual* (Wood Ballards *et al.*, 2015) it can be found a detailed description of each different systems. Here follows a list of some of them with brief explanations drawned by this manual:

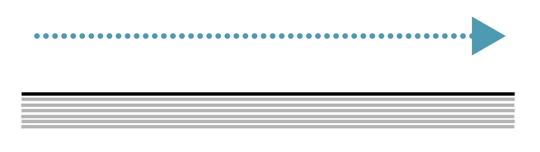
- **Rainwater harvesting systems_** RHS is the collection and storaging of rainwater from roofs and other impermeable surfaces runoffs for re-use; where required, water has to be treated in order to be used as an alternative supply for differents destinations. Implementing this system can reduce significantly the need for traditional water supplies, thus also presenting an advantage in economic terms in addition to environmental benefits.

- **Green roofs_** Green roofs are additional soil layers built on the top of buildings that provide a degree of retention and attenuation of a raiwater event. These systems have several advantages, especially at the building level such as the bioclimatic and aesthetic ones. Generally, due to the need for some added layers, green roofs are more expensive, but have different long-term benefits and an emportant ecological value. A more detailed description of green roofs can be found in the following praghraphs.

- **Pervious pavements_** pervious pavements are hard

Image 1: *Frailejones* on *the Páramo de Chingaza.* These plants capture the water vapor in their trunk and release it through the roots into the soil, a process that helps creating vast high-altitude subterranean water deposits.
Image 2,3,4,5: Authors' re-drafting of the lesson *Paesaggi costruiti resilienti dal punto di vista idraulico: permeabilità dei suoli.*

[3] The definition can be found in the EU commission document *Green Infrastructure and territorial cohesion*.



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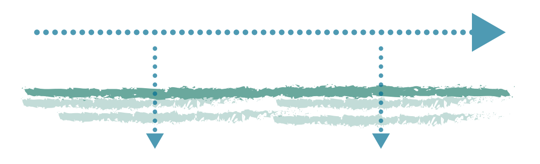

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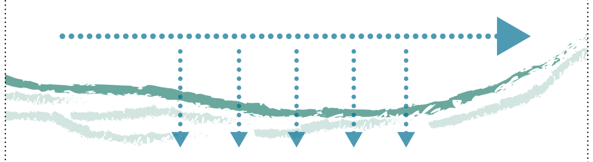

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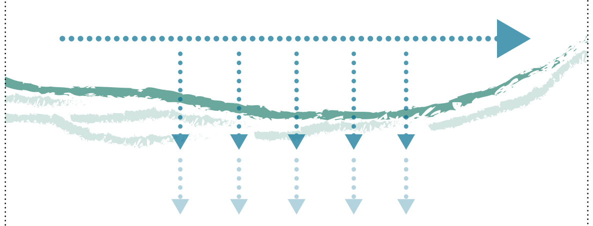

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surfaces for walking or driving that at the same time allow rainwater storage in the overlying surface before infiltrating in the soil or in the aquifer. The underground layers provide some treatment processes such as biodegradation and sedimentation. In particular, two different types of prevous pavements can be distinguished: porous and permeable. Whilst the first ones are made entirely of a material that infiltrate water, the permeable ones are made of materials that are impervious to water but whose laying guarantee the infiltration.

- **Bioretention systems_** Bioretention systems are shallow depressions tha reduce runoff rates and volumes, collecting it in a pond that with the passing of time filters through vegetation and underlying soils. There are specific soils that can be used in order to obtain a particular treatment for the infiltrated water that are usually collected in a specific underdrain system or infiltrated in the sorrounding ground, depending on the necessity and on the ground features. This category includes rainwater gardens, whose more detailed description can be found in the following praghraphs.

- **Detention basins_** Detention basins are vegetated depressions or hard storaged areas that present water only after an intense rainfall event. Only in the case where the surface is vegetated, there are main advantages that consist in the reduction of sediments and the absorption of part of the water by the vegetation. The quality of the water increases as the period of detention in the basin increases. A further advantage of these systems is that they can be used when dry, providing added value to the landscape.

- **Infiltration systems_** Infiltration systems are occupied in order to contribute to the process of infiltrate runoff water in the underground soil; these can take on different configurations, depending on where they are built and the degree of complexity. In particular these systems are divided into soakways, "excavation filled with a void-forming materials" (Wood Ballards *et al.*, 2015, pg 257), and infiltration basins "which are flat-bottomed, shallow landscape deppressions" (Wood Ballards *et al.*, 2015, pg 258).

Finally, all of the systems previously described may be divided in different categories, based on four main functioning principles:
• Collection (paved surface): the outflow is directed towards the infiltration areas or to the centralized disposal network. (Image 2)
• Collection (green surface): vegetated channels direct the outflow towards the infiltration areas or to the centralized disposal network. (Image 3)
• Infiltration: the outflow slowly infiltrates the underlying soil, after removal of a part of the pollutants by the plant root system. (Image 4)
• FIltration: the outflow is collected and stored temporarily, before being treated thanks to the passage through a series of natural filtering layers. (Image 5)

Nature-based Solutions for informal settlements: the social value of nature

Nature-based Solutions are carried out with the general aim of improving adaptation to climate change on a global scale, but act primarily on lower scales, such as the the block or neighbourhood, because the installation of any green area improves aesthetically and performatively the space in which it is located. The fact that there is an effect on a small scale proves that these interventions are held so that the inhabitants themselves and the ~~community~~ in general can benefit from them. Among all the factors necessary in a NbS project, mentioned in the previous paragraph, the involvement of the community is one of the most important, not only to ensure the acceptanche of changes imposed on the territory, but mainly because their knowledge of the environment in which they live is fundamental in the perspective of learning-by-doing design. "Therefore the interaction could be summed up as the **Community Participatory Approach** (CPA), where the community is involved in all aspects of the project." (O'Hogain, McCarton, 2018, p.7). This type of approach, however, may present different difficulties and limitations depending on the context in which it is applied; indeed, it is necessary to consider the level of development of the context in which these changes are to be applied. An intrinsic limit of the NbS, in fact, is the fact that they can be seen as simple operations of beautification of any area, whether public or private, because their effects in the medium-long term are not clear in the immediacy, especially to a public unprepared on issues such as climate change and water management. This makes their design and the involvement of the local population more difficult, especially in some particular areas. An example is the one of informal settlements, which present some other urgent issues, such as housing emergency and overcrowding. At the same time, addressing the climate change issue in this area is fundamental for their development, as it is stated in the UN Habitat document *Pro-poor Climate Action in Informal Settlements*[1]. These systems, in fact, can represent a fundamental tool to fight some of the main problems of this most populated areas: the scarcity of basic resources, including water, health risks, insecurity and lack of recreational vegetated areas. Each one of these problems is also aggravetad by lack of planning and the threats posed by climate change.

There are many Nature-based Solutions that are suitable for this type of settlements, due to the small scale of intervention, which ensures low costs and ease of implementation. Furthermore, in addition to the main effects of improving the sanitary condition of water and re-evaluating and re-functionalizing public and private spaces, NbS act at an economic and social level. In fact, these physical interventions on the territory must be complemented, when they not stimulate them themselves, by some public and management policies. The architect and lansdcaper Miriam Garcia in her dissertation *Hacia la metamorfosis sintética de la costa, disenando paisajes resilientes*, focused on adaptation to climate change in coastal areas defines some pills, i.e. individual measures that can be taken on the territory to fight coastal erosion. The term **pill** is adopted by the author because its purpose is to emphasize the importance of the effect of these solutions, not so much the solutions themselves. Although most of these pills are mainly concentrated on the geographical area of the coast, some are general resilience measures that can be taken in different contexts. Initially she makes a distinction between different kind of measures: *naturales*, *basadas en procesos naturales*, *estructurales* and *no estructurales*, the last one being the social processes referred to above.

Non-structural measures which complement and/or partially replace structural measures, include changes in public policies, management practices, regulatory policies and revenue policies. They essentially consist of a series of both physical and programmatic policies designed to meet the needs of a community and the level of risk it faces, with the objective of reducing this risk and improving (coastal) resilience. (Garcia Garcia, 2017, vol II, p.2)

In this context it is explained how these measures should be developed together with the physical solution, in order to ensure that there are some preparation and actions to help and accompany the community on the path towards adaptation to climate change. Some of these policies, however, can also be considered as direct consequences of the implementation and construction of Nature-based Solutions. For example, the concept of **new jobs associated with resilient infrastructure** appears to be not only a precautionary accompanying measure, but also a possible solution to the phenomenon of unemployment or irregular employment strongly

Image 6,7,8: The non structural pills of Miriam Garcia. (Garcia Garcia, 2017, vol II, p.17)
Image 9: The *Ecotecho* guide from www.meteoweb.eu/2015/06/ecotecho-un-innovativo-tetto-verde-realizzato-con-bottiglie-di-plastica-foto/463825/

[4]The definition can be found in the UN document *Pro-poor climate Action in Informal Settlements.*

[5] ooze.eu.com/en/urban_strategy/gua_paulista_so_paulo/

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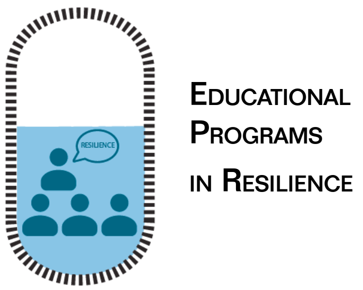

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present in informal settlements. In fact, if solutions of this type are built, a professional figure will be needed to manage, maintain and develop them. In the same way, emphasis must be placed on the production aspect, because the creation of green roofs and community gardens can encourage local cultivation at low cost, favouring the economic growth. Carolina Fornero in her thesis work seeks to quantify the economic benefit and vegetable contribution of vegetable production systems that were designed and installed on the roofs of priority interest houses located in the area of Altos de Cazucá, Colombia. In order to design these garden a study of the the climate region was carried out, together with the study of the physical structure of houses and the economic capacity of the homeowners. The aim is to underline the economic advantages of this type of urban agriculture, especially when its realized with waste materials such as plastic bottles. The important field work carried out by the author also translates into special communication methods that guide the inhabitants step by step in the implementation of the system. (Forero Cortés, Devia-Castillo, 2012)
Simultaneously, participatory planning itself promotes resilience education programs through community workshops and physical interventions in the area. As part of the 11th São Paulo Architecture Biennial 2017, Ooze was invited to develop a project investigating the potential of using rainwater collection, natural wastewater treatment and water recycling as basic measures to develop closed-loop water cycles in te city. The studio set up a programme to engage with local communities and experts to stimulate discussion, through three main events that took place in in the neighbourhood of Sapé, São Paulo. A community workshop which created a graffiti map exploring closed-loop water cycles, a decision makers workshop to interrogate implementation and management, and a lecture to provide a forum for public reflection and debate. Enthusiasm for the potential of Água Paulista was high among the community as well as other stakeholders.[6]
Finally, the enhancement of the local ecosystem through Nature-based Solutions can create a starting point for a **network of cultural endowments**, whose central activity could be the study of the local environment and flora and fauna; at the same time parks and green areas could be new focal points for **recreational activities**, chosen by the inhabitants themselves.

For all this to happen it is obviously necessary to adopt a non-paternalistic approach, but to stimulate partecipation arousing the interest of the community and to not force every techinique on the different territories with a manualistic attitude. The intervention must take into account not only the physical characteristics of the place, but also the socio-cultural ones. The NbS, in fact, can present themselves as activators of places, but also as destroyers, and for this reason the first step is to locate the interventions with the help of the community, if not even on their own request. The most important attention, moreover, concerns the use of local materials, with a view to reuse and recycling, but also of economy and feasibility.

Photos showing the community involving process of the project *Agua Paulista*. From ooze.eu-.com/en/urban_strategy/gua_paulista_so_paulo/

Photos showing how the Ecotecho system works and an inhabitant taking care of the plants. From www.meteoweb.eu/2015/06/ecotecho-un-innovativo-tetto-verde-realizzato-con-bottiglie-di-plastica-foto/463825/

Choosing between Sustainable Urban Drainage System: the multiscalarity

Among all the different systems, there are some that undoubtedly require highly technical preparation, especially those whose design concerns large areas of the city. Precisely for this reason, it is possible that their achievement may be limited not only by the individual's capabilities, but also by urban regulations. In this case two fundamental aspects that concern the areas of research interest of this thesis have to be considered:

- the informality;
- the auto construction.

It is therefore important to understand, among all the types of the Sustainable urban Drainage Systems described above, which ones are accesible to all the population and which one are not, at least theorethically. This reasoning concerns not only the aspect of pure technicality, but also those of operation, material composition and implementation. To identify the most suitable ones, it is first of all necessary to rely on two key features: modularity and multiscalarity, the latter being a direct consequence of the former. The simplicity of realization varies proportionally to two main factors: the base knowledge and the size of the object to be built. It is easier to have control of a small scale project, which can also function as a pilot experience, from the implementation of which the basic technical knowledge necessary for repetition is drawn, especially when a learning-by-doing approach is followed. In addition to the scale factor, the scope has also to be into account and since the single dwelling is the main field of interest of the inhabitant, only the systems directly applicable in a house are considered. However, it is important to underline that the very nature of these systems means that even if they are designed as single objects, they work if applied repeatedly on a large scale. For all of these reasons two main systems are analyzed: the Rain Garden and the Green roof, which are identified not only as the most common in different areas, but also as those that are more easily implemented autonomously and allows variations not only in methodology, but also in composition.

Sustainable Urban Drainage systems for urban flooding: rainwater gardens

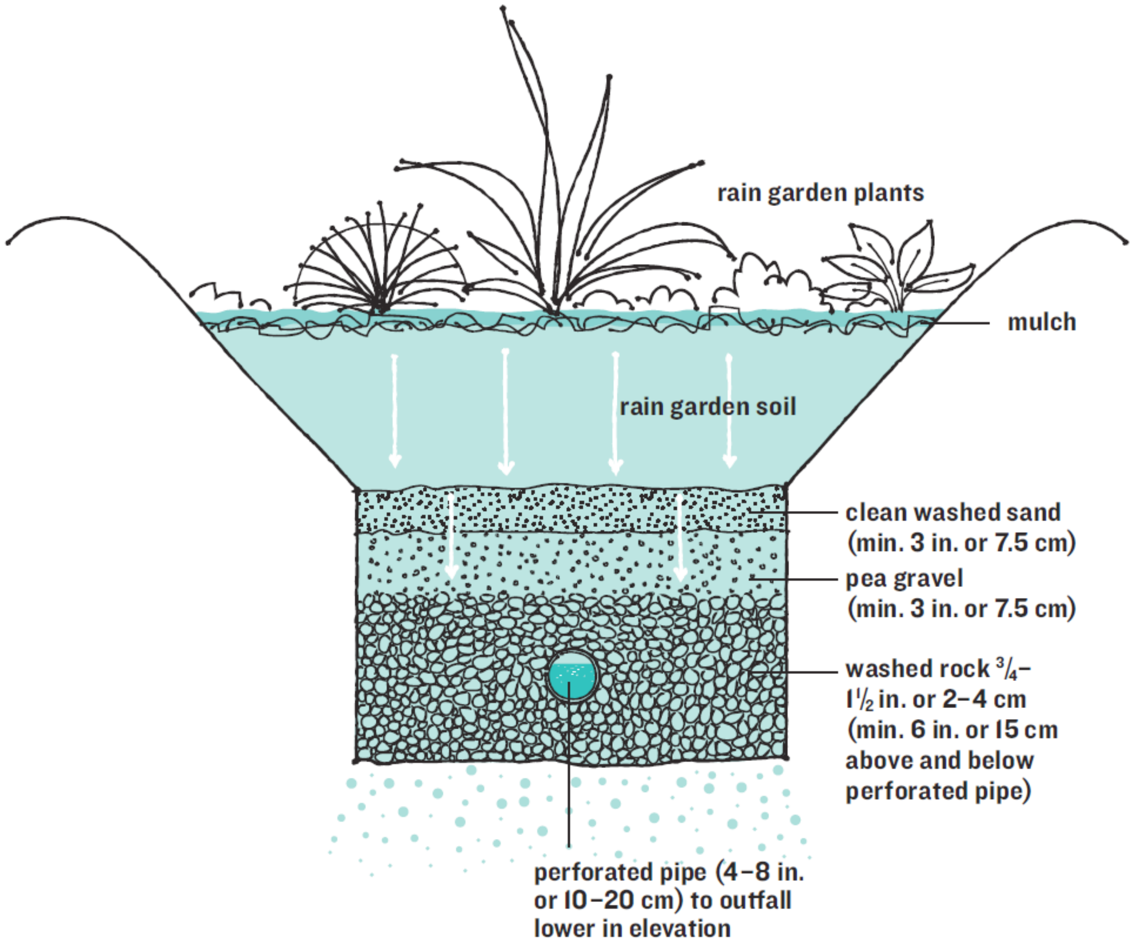
Rainwater gardens, a particular type of biorretentions systems, are artificial hollows created in the ground, in which plant essences are placed. Their purpose is to collect rainwater from the surrounding surfaces (such as roof, roads and car parks), which slowly infiltrates the soil below, after the removal of some of the pollutants from the plant root system. The main advantage is the reduction in the amount of rainwater run-off collected by traditional canalisation systems, using water as a resource for vegetation growth, altogether with the creation of small natural habitats, which develop biodiversity, and the cooling of the local microclimate. The filtered runoff can be collected using an underdrain system or fully or partially infiltrated in the underground soil, recharging the groundwater aquifer and allowing the white water disposal even where there is no underground canalization system. In both cases part of the volume of water entering the garden is eliminated by evaporation and by transpiration through plants.

Rainwater gardens differs from the traditional bioretension systems as far as the dimensions are concerned, in fact they are usualy smaller hollows that serve only one system, such as roofs or driveaways. Their size may also represent a limitation, as they only vary from 7 sqm to 36 sqm. When the calculations made for the dimensioning show the need for a larger surface area, it is preferable to create several smaller depressions. This happens usually when rain gardens do not collect only water flowing from the roof, but the otflow coming from the roof and other run-off surfaces. In any case, its size must never exceed 7% of the impermeable surface from which the run-off water comes and must be positioned in areas not shaded by tall vegetation. Likewise, it cannot be placed too close to the foundations as a minimum distance of 3 metres from them is required, in order to avoid structural problems that can be caused by water infiltration. Furthermore, the locations that should be avoided are: those higher than the bottom of the downspout, those located over the utility lines, slopes greater than 15% and poorly draining depressions. An important role is played by the soil at the bottom, which can be either fertile soil or, especially in order to improve soil infiltration, a layer

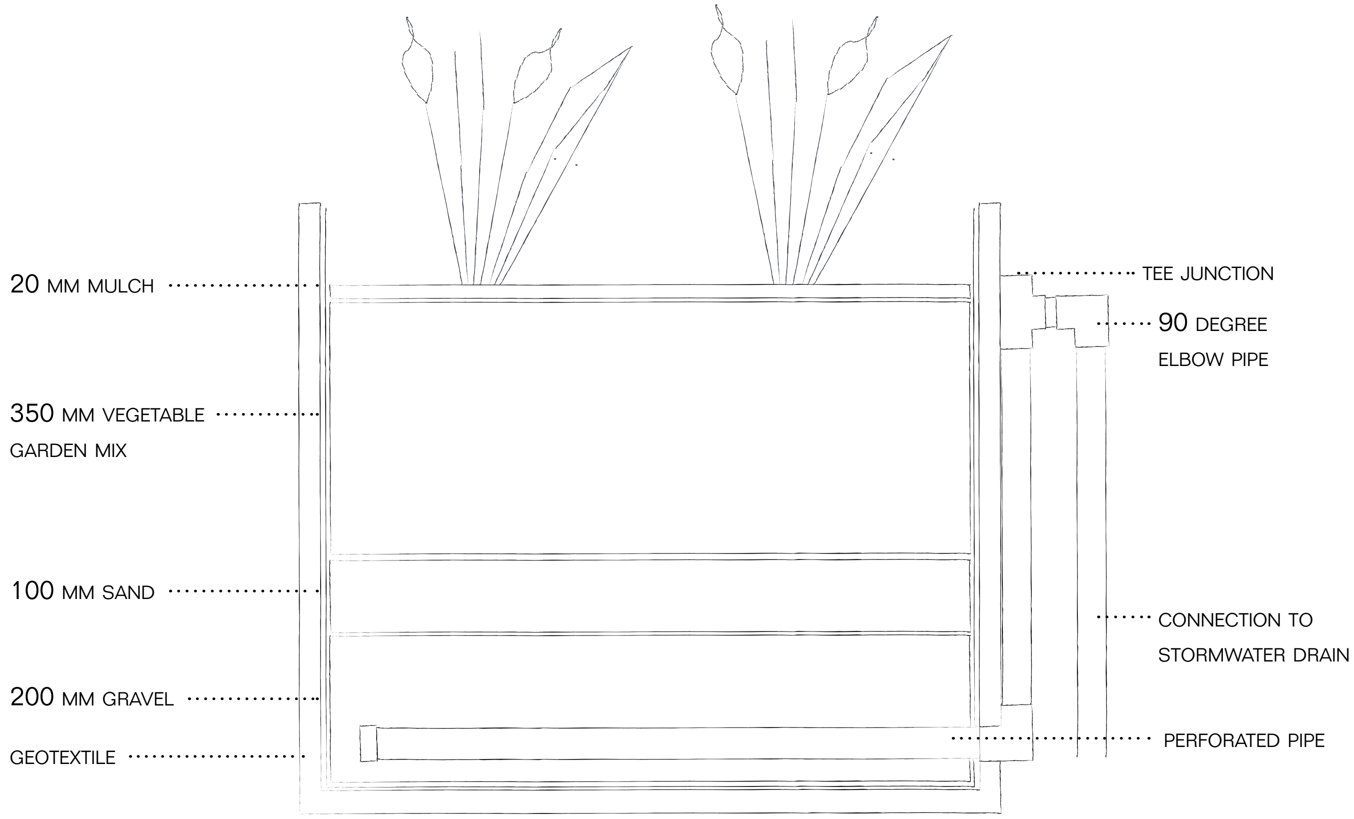
[6] The general procedure is given in the appendix *Rainwater Gardens dimensioning*, while the example of a rainwater garden sizing is given in chapter 4.

composed mainly of sand. In the first case it should have a maximum thickness of 45 cm, whereas in the last one it can reach 75 cm. The process of pollutant removal is entrusted to the root system and soil, so it is essential that the pH level is between 5.5 and 5.6. The maximum level of collected water above ground can vary between 15 and 30 cm. In order to ensure that all these variables remain controlled over time, a regular maintenance that mainly consist in removing sediments is necessary, thanks to which the useful life of a rain garden can be between 10 and 25 years. (Mazzotta, 2007)

It is interesting to note how the installation of rain gardens has developed, especially in recent years, as a do-it-yourself phenomenon, which is why several manuals by gardeners or landscape designers have appeared explaining step by step how to create a rain garden, particularly in the United States of America and in England. One of these manuals in particular is used as reference for the project phase of this thesis work: *Creating rain gardens: capturing the rain for your own water-efficient garden* by Woelfle-Erskine and Uncapher, which explain in detail all the different steps necessary for the design. In particular, all the steps necessary to calculate the run-off volume and, consequently, the size of the rain garden are explained in detail.[6] In the first chapter of the guide some of the advantages of building a rain garden are explained, and altogether with the one previosly explained, a cultural reason is underlined: “on the scale of a neighborhood or city, rain gardens can create new watershed relationships. Along with stream, lake, and wetland restoration and water conservation strategies like greywater reuse, rain gardens are a daily reminder of our dependence and influence on our local watery environments.” (Uncapher, Woelfle-Erskine, 2020, p 15). Finally in the general field of bioretention systems there is a particular model that can be assimilated to the rain gardens, but present a slight difference in the final purpose of water collection: the raised planters which are usually constructed above the ground surface. These are boxed systems, with a planted soil mix and an underdrain to collect the filtered water, usually not used as infiltration systems but to manage runoff from adjacent roofs, but their design phases and their elements correspond to those of the raingarden. (Wood Ballards *et al.*, 2015)



Section of a rain garden, indicating the layers that compose the stratigraphy. (Woelfle-Erskine, 2020, p 81)



Planter box_ Planted tub of collection and biofiltration of rain water as a means of delay of the discharge of water rain in the pipes sewerage. The water purified can also be accumulated and reused for non-uses potable. (Wood Ballards *et al.*, 2015)

Some US cities, like Portland have initiated actions to encourage the implementation of rain water gardens, both at the public and private level. From www.portlandoregon.gov/bes/78921

Sustainable Urban Drainage systems for urban flooding: green roofs

A green roof is a flat or sloping roof of a building partially or completely covered with vegetation. In addition to aesthetics and usability, green roof present other advantages, mainly related to climate change adaptation issues.

These coverages can be additional space for specific outdoor activities and at the same time they contribute to the aesthetics of the urban landscape.[7] The other advantages are:

- Allowing the recovery of a portion of meteoric precipitation and its return, through evaporation and evapotranspiration, to the **water cycle** in the urban ecosystem. As other Sustainable urban Drainage Systems, they slow down runoff and reduce the amount of water to be conveyed into the traditional drainage networks artificial;
- The stratigraphy, understood as the set of vegetation and soil layers and also the other materials of the technological package, guarantees the **thermal comfort** conditions of the rooms.
- The additional layers of the stratigraphy guarantee an extension of the **durability** of the covering.
- Lowering the air temperature in the immediate vicinity particularly when each green area is part of a systemic network of Nature-based Solutions
- Depending on the type of stratigraphy the green roof can assume a **productive** function, allowing the cultivation of fruit and vegetables even in contexts where it is not possible, due to lack of space or soil composition. Often the productive function is combined with events and educational programs, which support sustainable agriculture, even with the distribution of zero kilometer products.

The standards divide green roof into:

• **Extensive** green roofs_ systems using plant species that can adapt and develop in the environmental conditions in which they are placed, requiring minimum maintenance. The species are characterized by a high settlement capacity, by means of reproductive efficiency, frugality, resistance to water and thermal stress, both winter and summer. The layer thickness varies between 8 and 20 cm, which results in a relatively low weight. In this case, the roof can only be used for maintenance, which is generally required once or twice a year, while irrigation is only required during the rooting phase and in cases of emergency. They are the most suitable for retrofits intervention, mainly due to the system lightness and simplicity.

• **Intensive** green roof_ system using plant species that can adapt and develop in the environmental conditions in which they are placed, albeit with the necessary maintenance of medium and high intensity, depending on the associations of plant species. The layer thickness varies between 20 and 150 cm, which results in a heavier weight. In this case, the roof presents a full usability, just like a garden, but at the same time it requires costant maintenance and irrigation, usually with a fixed system instalthat is part of the stratgraphy. A large variety of plants can be grown, either directly on the ground or within planters, and the roof can include water features and storage of rainwater for irrigation. A specific type of intensive roof is the blue one tht is designed in order to store water.

This storage can be designed as attenuation storage (with water released in a controlled manner), as storage for use such as irrigation (potentially of adjacent green roof areas), cooling water (for use in reducing the temperature of the roof on hot days, or for internal cooling plant) or non-potable use within the building, and/or for recreational opportunities. (Wood Ballards *et al.*, 2015, p. 23)

There are also green roofs that present reservoirs underneath the soil, **blue-green rooofs**. As far as this typology is concerned, it is essential to check the structural capacity of the roof, considering the weight of the maximum amount of water that can be stored. With regard to the possible problems encountered in the installation of a green roof, there are first of all structural problems related to calculation errors of the system, problems of water infiltration due to damage or incorrect positioning of the waterproofing barrier and insulation problems. In addition, the malfunctioning of the drainage layer can lead to excessive water accumulation, while the use of unsuitable arable land causes poor water retention. These issues are the result of poor design and execution and can be avoided following the rules contained in the different standards of each countries. Following a description of all the elements that make up the general stratigraphy of a green roof, based on the of the S*uDS manual* (Wood Ballards *et al.*, 2015):

[7] Most of the informations were taken from the lesson *Tecnologie e soluzioni* "*Nature Based*".

• **Waterproof membrane_** waterproof membranes can be made of different materials, i.e. polyvinyl chloryde, synthetic rubber and high density polyethylene. They should be heath resistant and have a good resistance to temperature changes and to mechanical damage; for this reason the membrane usually need to be anchored to the roof.

• **Root barriers_** root barriers are used to prevent roots from damaging the waterproof membrane.

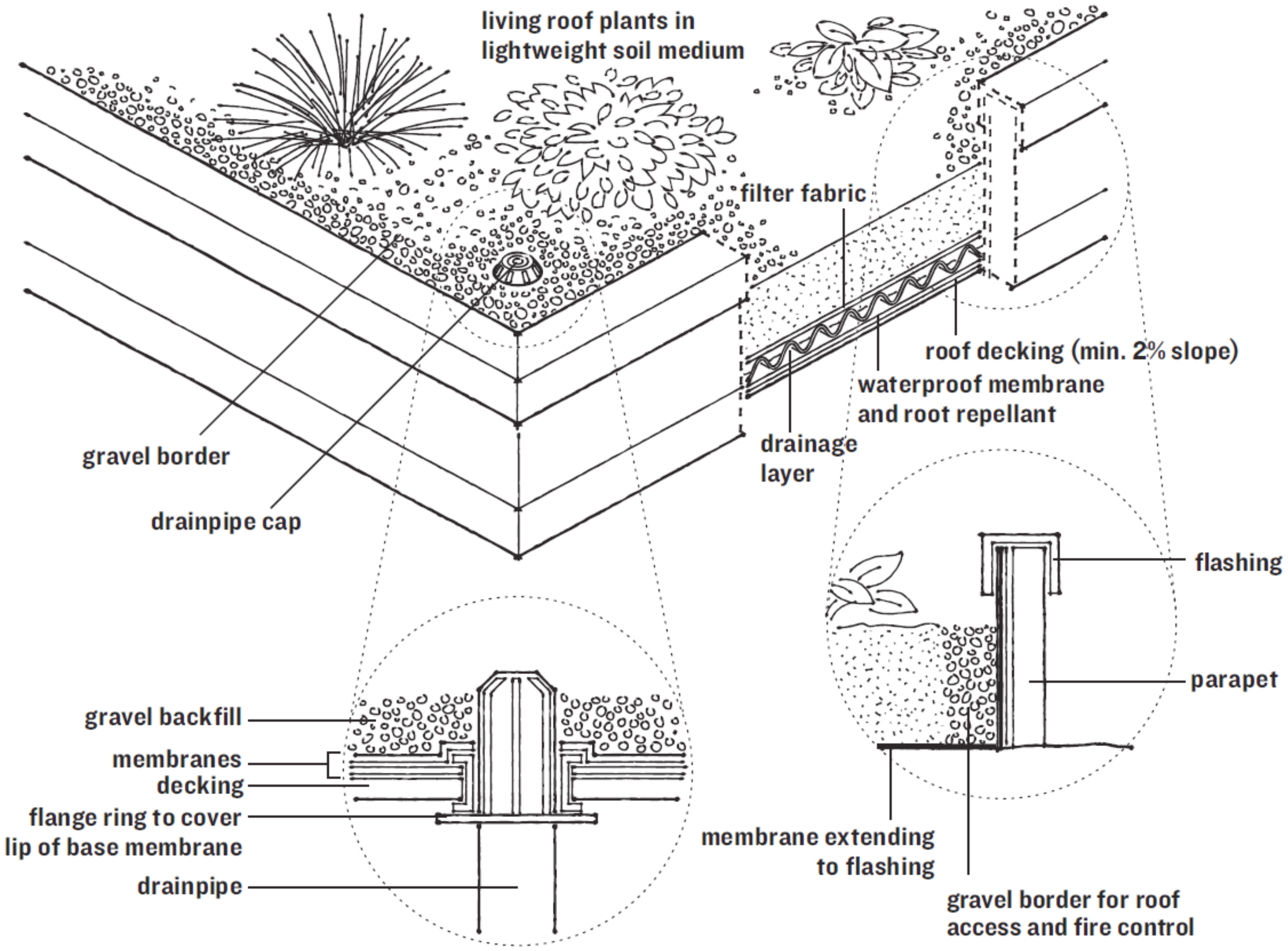
• **Drainage layer_** the drainage layer principal function is to drain excess water from the roof and it is designed accordinlgy to the specific volumes of water that need to be retained. At the same time its purope is to retain some water for plants when the rainfall is low. It can be connected to gutters and downpipes in order to allow the overflow of the water in excess.

• **Geotextile layer_** geotextile prevent clogging of the drainage layer by separating the growing medium above. It should allow the passage of water, providing at the same time stability to the growing medium.

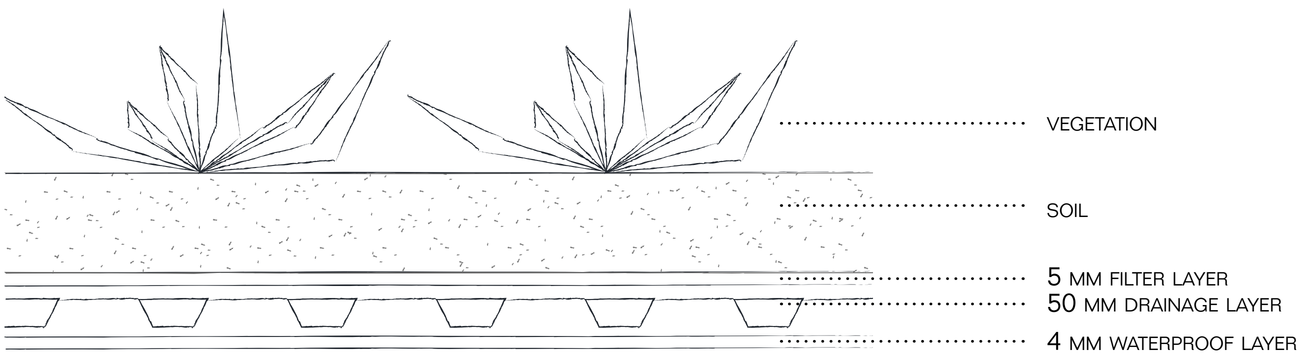
• **Growing medium_** the characteristics of the growing medium depend mainly on the vegetation chosen for the green roof. Typically a minimum of 8 centimetres thickness is required to give a reasonable variety of plants, although greater depths can give better effects as far as the stability, insulation and rainfall storage are concerned.

• **Vegetation_** To be able to survive, vegetation shoul be perennial, throught tolelant and self-sustaining because it has to deal with periodic rainfall alterning with hot and dry periods. There are four methods of instlling green roof vegetation: pre-grown vegetation mats, potted plant, cuttings and seeds. The pre-grown vegetation mats are pre-germinated and provide immediate full plant coverage and erosion control.

Some of the main materials with which the individual elements are made are listed in the 'Catalogue of a blue green roof module elements' in chapter four of this thesis work, focused on the creation of a blue-green roof module prototype.

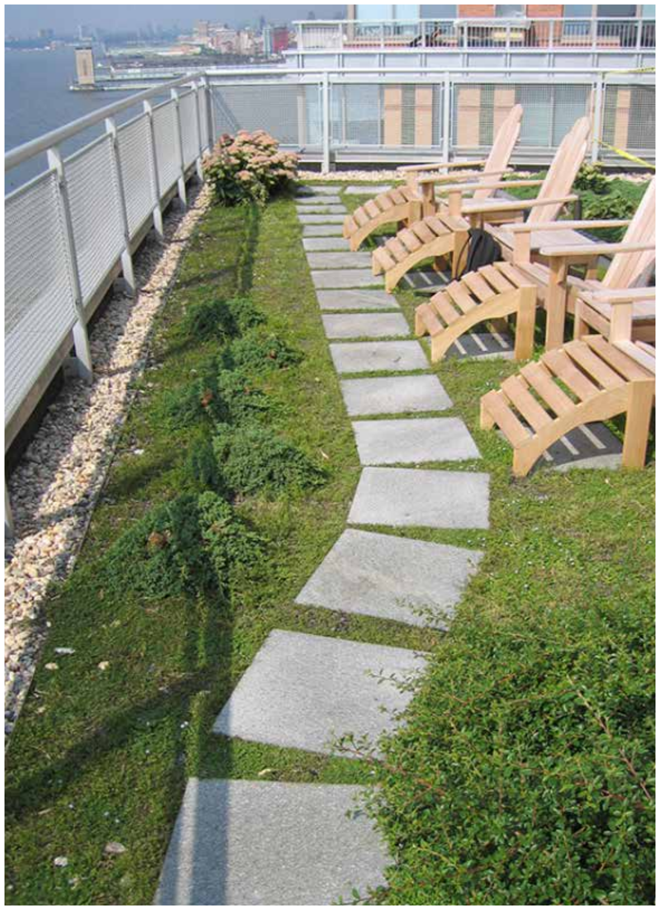


A typical green roof system. (Woelfle-Erskine, 2020, p.156)



Typical stratigraphy of a green roof. Drawing by the authors.

The vegetated cover of the Solaire, one of the first green residential high-rise building in the United States. From www.balmori.com/portfolio/the-solaire#anchor



Appendix: Rainwater Gardens dimensioning

(Woelfle-Erskine, 2020)

The step zero to design and obstruct a rain garden, once the positioning has been decided according to the criteria illustrated above, is to test the drainage of the soil. If the composition of the soil in which you want to build the basin is not known, out a practical test must be carried out, consisting in measuring how long a certain amount of water infiltrates a certain portion of land. This step can be skipped in case there is the intention of building a raised plant, in which the soil is previosuly chosen and therefore all the properties are known.

The first step consist in calculating the catchment area, but relating it to the run off coefficient, which generally depends on the material in order to calculate how much water is actually water. The second step is to calculate how much rain falls during the largest storm event that has to be captured that can be done using the rainfall charts available for every city and region. An example of how to read a rainfall chart is given in the chapter 4, where each of this steps are applied to the designing of the rainwater garden of the project. Then, because a rain garden should be able to infiltrate all pooling water within 24 hours, the drainage rate must be converted from centimetres per hour into centimetres per day in order to establish the maximum pooling depth (step 3). The last step is to calculate the surface area.

CATCHMENT AREA (1)

$$A_c = \text{length} \times \text{width} \times P_{rain} \times c_{runoff} =$$

P_{rain} = percentage of rain that ends up in the downpipe; the project provides only one downpiper por slope, so it is considered 1 (100%).

c_{runoff} = runoff coefficient.

If there are more than one catchement area, the total catchement area (A_{Ctot} is the sum of the different A_C

RUNOFF VOLUME (2)

$$V_{runoff} = A_{Ctot} \times [I_{mm}/(t \times (1\ m/1000\ mm))] \times t$$

I_{mm} = average peak precipitation in 24 hours.

t = time period considered for the duration of an event.

1m / 1000mm = conversion of the measurement units.

MAXIMUM POOLING DEPTH (3)

d = SOIL DRAINAGE RATE (CM/HOUR) X 24 HOURS/DAY

THE AREA OF THE RAINGARDEN (4)

$$A_{garden} = V_{runoff} / [d \times (1\ m/1000\ mm)]$$

Chapter two:
Case study_El Pozon, Cartagena de Indias

[1,2] www.ifad.org/en/web/operations/country/id/colombia
[3]it.wikipedia.org/wiki/Cartagena_de_Indias

Cartagena de Indias, Colombia: the territorial and social framework

The different social groups that over the centuries have interacted on the territory of Colombia have brought with them their own culture, customs and lifestyles, contributing to the ethnic diversity of the nation. Although this condition was recognized by the state in 1991, race-related conflicts are still present today, as well as imbalances due to the state's lack of cooperation. Even referring to recent history, the peace process between the Government of Colombia and the Armed Forces only ended in November 2016 with the signing of the deals. Despite this progress in reducing the scourge of violence and the wealth of natural resources in Colombia, a large part of the inhabitants still suffers from food insecurity, malnutrition and risk of infant mortality; for all these reasons, the internal populations are displaced and are continually forced to move in search of better living conditions. In particular in 2018, 27% of the total population is affected by poverty and of this percentage 35% is composed by people who live in rural areas, mainly composed of indigenous and African descendants: "Today, in rural Colombia, 7.2 per cent of the population -3.5 million of citizens- live in extreme poverty."[1] For this segment of the population, the opportunities for access to adequate education and employment are minimal. In addition, there are significant migration flows from other neighbouring countries, mainly from Venezuela (currently more than 1.4 million Venezuelans live in Colombia) affecting the living conditions of the poorer segment of the population. A number of national development plans have recently been approved with the aim of economic growth and social inclusion of the most vulnerable groups such as women, rural and indigenous populations. In this context, agriculture represents an important means of livelihood, contributing to 6.3% of GDP and 16.4% of employment.[2]

In addition to these problems there are also environmental difficulties, mainly caused by the rising temperatures and the sudden changes in rainfall, which affects the vulnerability of coastal areas, increasingly subject to frequent flooding. One of the area where the popultion is mainly affected by this issue is the Bolivar department, bordered to the North by the Caribbean Sea and the ocean Atlantic. In fact, the territory is characterized by the Momposina depression, a flooding area which coincides with the lower part of the Magdalena river, one of the North-South natural boundaries of the department. The different tributaries of the river carry an important quantity of water that pours into the main body of water very quickly, especially in case of important precipitations. The numerous bodies of water characterize the territory, causing the creation of different marshy areas, which flood easily. With a 25,978 km^2 extension, the Bolivar district is part of the most touristic and cultural Caribbean group of the territory; the capital *Cartagena de Indias* has 1,028,736 inhabitants, according to the 2018 census[3], making it the second-largest city in the region, after *Barranquilla*. The rural area of Cartagena is also the fifth-largest urban area in the country and the capital is one of the colombian city whose society and current history fully reflects this social and economic inequality. "Throughout decades, there has been a persistent lag in the promotion of integrated and adequate living conditions and in the access and availability of infrastructure and urban services, in theframework of the new socio-economic and culturally emergent dynamics."(Hernadez Correa, 2020, pg 290)

Colombia_ Territorial framework

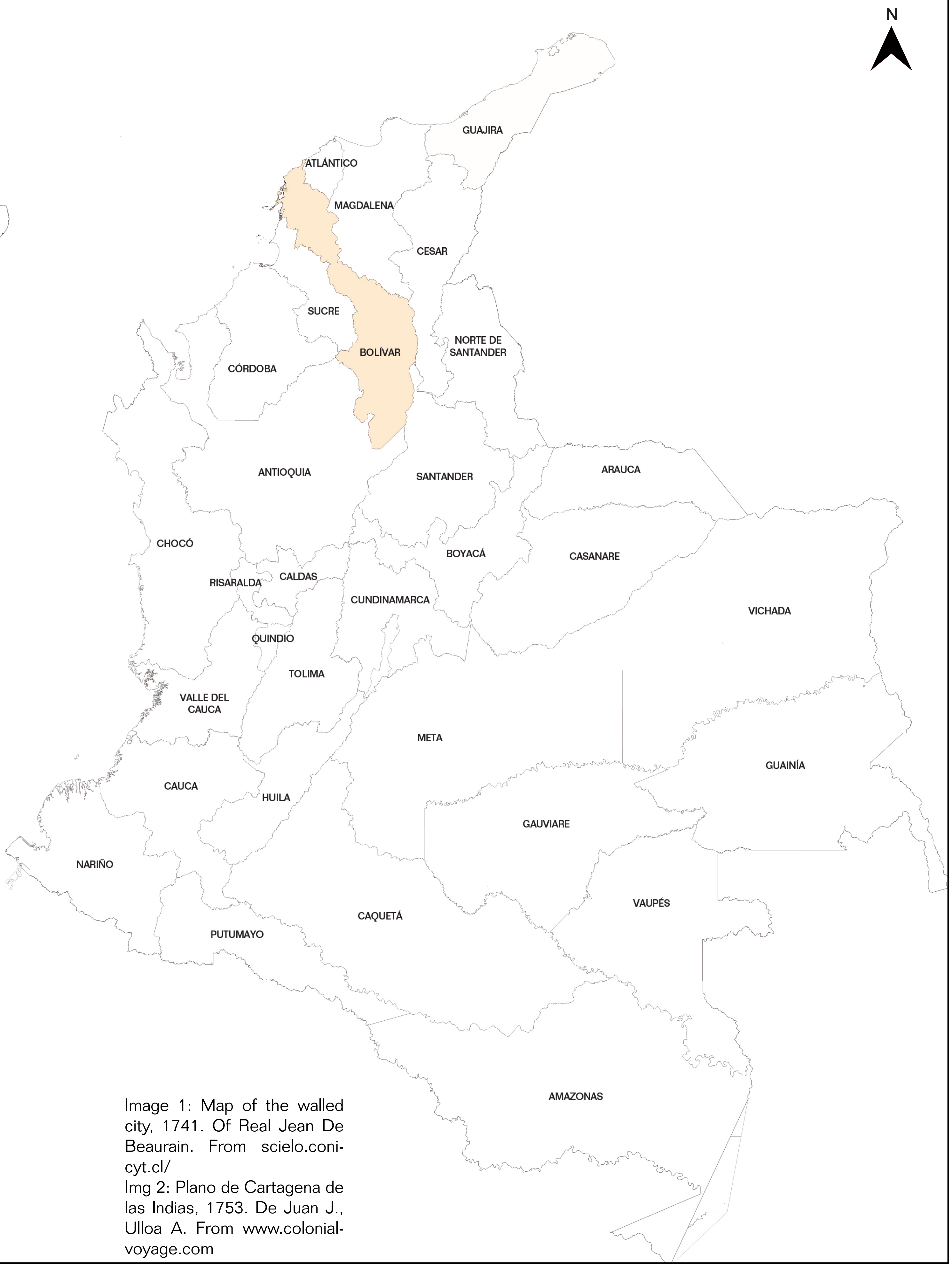


Image 1: Map of the walled city, 1741. Of Real Jean De Beaurain. From scielo.conicyt.cl/
Img 2: Plano de Cartagena de las Indias, 1753. De Juan J., Ulloa A. From www.colonialvoyage.com

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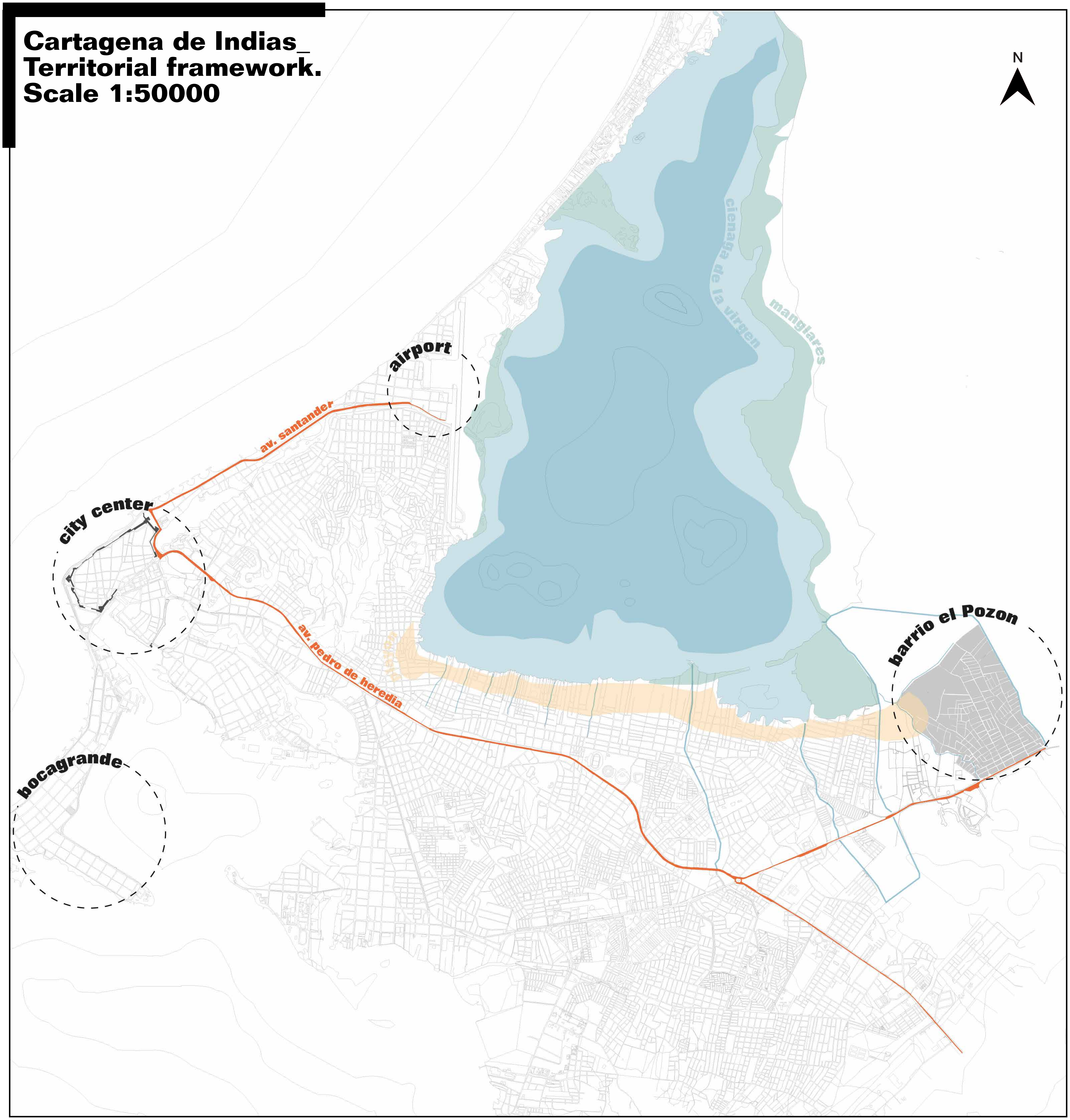
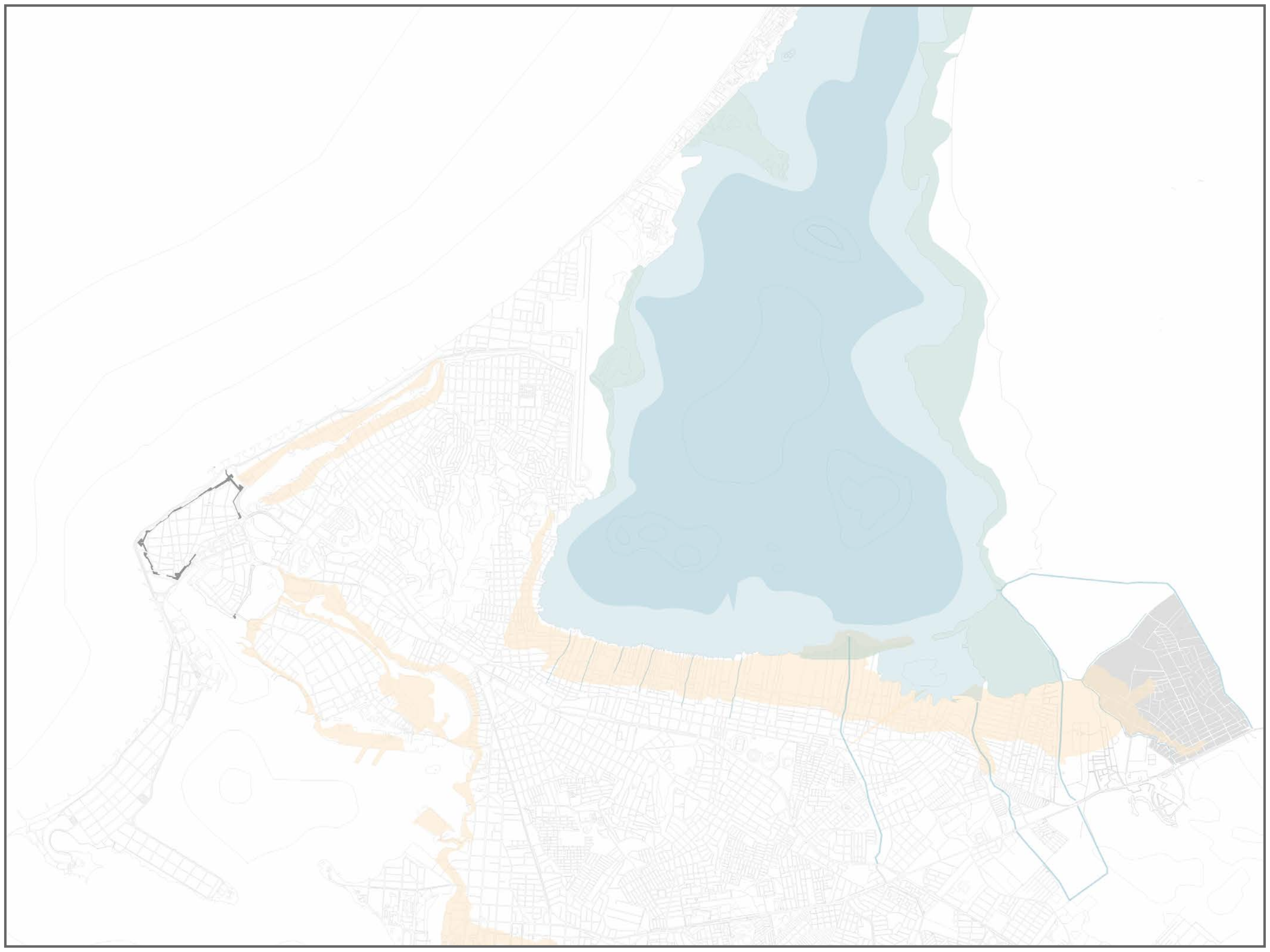
2

However the city also presents an immense cultural and historic value. The indigenous populations lived in the caribbean territory until the end of 1400, when the arrival of the colonists has not destabilized the natural context of the land. Their arrival also caused the outbreak of some epidemics that led to a decimation of the native population, mainly in the coastal areas. The city of *Cartagena de Indias* was founded on June 1st, 1533 by Pedro de Heredia, and throughout the Spanish vice regal period it was the economic and most important commercial fort in all South America. In a short time the city becomes a slave and commercial port of good demand for ships traveling from Peru to Cuba and then to Spain. With the growth and prosperity of the city the attacks by other countries and pirate ships to the city begin, and for this reason it was decided to equip the city with a wall and forts around between the sixteenth century and XVIII, becoming the most protected city in South America. In the early 1600's the Inquisition arrived in Cartagena as one of its three headquarters in Latin America to cover the cases of heresy in South America, since its other facilities could not cover so many cases. In 1811, Cartagena became the second territory to declare absolute independence from Spain in present-day Colombia and after the two months siege by Simon Bolivar, on October 10, 1821 it was declared indipendence from Spain. The end of the 19th century gave the country political, social and economic stability, and it was during this period that the total transformation of the nation in the drafting of the 1886 Constitution began. In 1984, UNESCO declared the Port, fortresses and monumental complex of Cartagena de Indias, as Historical and Cultural Heritage of Humanity. (Forero, 2016) With such conditions, the city has tried to protect its historic center until it became the most important tourist nucleus in the country. However, investigating the city's most recent history, it can be noticed that it's value and potential are not taken into account when it comes to handling the growth of the population and its need of housing. In the unbalanced context of this city, arise all the problems that affect most of the contemporary Colombian cities such as insecurity, poverty, deficit in services and infrastructure, corruption and a growing environmental problem. It's very importat to underline that the history of the city and its geographical location have heavily influenced its current situation, creating a very serious imbalance between the more central areas and the outskirt. This problem begins to arise at the beginning of the XX century while the nation economic and social structure make it impossible to access to urban land and housing through institutionalized and legally valid methods. At the beginning of 1900, in fact, the city experienced a rapid population growth, reaching almost double the population compared to the XIX century, when settlements were limited to the area within the walls. From this moment on, spontaneous informal neighbourhoods began to form in different parts of the city, in particular the *barrios Cambachù*, *Cerro de la Popa* and hose on the border of the *Ciénaga de la Virgen*. Especially in this last area the expansion is characterized by modifications to the natural boundary of the lagoon to increase the edificable area. (Secci, 2017) One of the most famous neighborhoods in this area in the far north-east of the city is *El Pozón* , whose history is representative of this invasion phenomenon. The invasion remains today one of the most representative means of space occupation in popular sectors of the city of Cartagena, generally areas of suburban or rural expansion established out of bounds of the aministrative borders.

Cartagena de Indias_
Territorial framework.
Scale 1:50000



Cartagena de Indias_ Sea level rise flooding and stormwater flooding.



El Pozón: from the foundation to the present day

As seen previously, Cartagena de Indias is defined by a huge social segregation, mainly due to its geographical position and its history. One of the most marginalized communitie's lives in *El Pozón*, a perimetral neighborhood formed in 1969, with a non-planned growth carried out through self-construction near the *Ciénaga de La Virgen*, an important part of the city´s ecosystem. The birth of the *barrio El Pozón* dates back to the 60s, when, approximately between 1965 and 1969, these areas on the outskirts of the city were invaded by the inhabitants of the rural areas of the departments of *Bolivar*, *Cordoba* and *Sucre*. The main reason for this migration was the violence that was spreading throughout Colombia in the second half of the 20th century, mainly in the countryside, the scene of the most intense internal clashes between the army, guerrillas and land owners. At the same time, the consequences also affect social areas such as education, work, housing and healthcare, mainly due to administrative corruption. For this reason, the *campesinos* have been forced to abandon the countryside and take refuge in coastal towns such as *Santa Marta*, *Barranquilla* and *Cartagena de Indias*, which they presented as centres of attraction due to their strategic location and favourable social and economic conditions. The latter in particular was one of the favourite destinations, as it had established itself as one of the main centres of exchange since colonial times, as well as being in a particular phase of development of industry and tourism. At the same time, however, it was not prepared for the heavy migratory flow that was undergoing. In particular, *desplazados* chose territories such as *El Pozón* because of the availability of land and the possibility of building their own house without having to pay rent, while at the same time settling in a permanent residence. This phenomenon is accompanied at the same time by a different type of migration within the same city, called *inter-barrial*, or generally inter-urban mobility. The reasons for this type of displacements are different and are not codified in literature, but are often found in the search for more suitable living conditions.[4] Moreover, during the intervews with the residents, it was found that one of the main reasons was the desire for independence from tenants and the possibility of building their own houses, without having to adapt to living conditions imposed by ditions imposed by others. In general, these massive displacements have led to overcrowding in these areas, which the inhabitants have illegally occupied without prior planning.

In addition to the problems arising from the uncontrolled occupation of the area, the environmental conditions in this area of the city have not helped the develo ment of the district. The main problems, in fact, derive from the fact that the land is low and flat, as well as being crossed by numerous canals, mainly due to the proximity of the *Cienaga de La Virgen*. Therefore this area of the city has always been susceptible to several floods, especially in the rainy season. The unplanned relationship between nature and construction exposes the buildings at the risk of direct flooding, causing irreparable damage and forcing inhabitants to move or to rebuild their homes cyclically. For this reason, having initially settled in the areas closest to the swamp, most of the inhabitants moved to the center of the neighborhood, what today is known as the *Sector Central*. The inhabitants says that at the beginning there was only one street, the *Calle Central* and other streets identified only by small paths corresponding to *Calle Jerusalén*, *Primero de Mayo*, *19 de Febrero*, and *Corazón de Jesús* , names that today identify the entire districts created later with the expansion of the neighborhood. The neighborhood grew in size, but not as a structured urbanization; rather, as each person bought, they built their own houses, mainly made of boards or other low-quality construction materials. The first processes of regularization began, between 1970 and 1976, thanks to the local government and the administration of Álvaro Escallón Villa, which later, by resolution of the incorporation N. 001571 of 8 July 1977 of the Land Code, legalised the land, thus recognising the first residents. In 1981, with the help of the former governor of Bolivar Alvaro Escallon Villa, the neighborhood was partly connected to electricity and running water, and in 1986 Manuel Domingo Rojas brought light to most of the houses in the neighborhood.[5] The waste water collection system is still not widespread throughout the area. To date, the process of legalization of the land and the census is still a challenge in this neighborhood, since almost 35% of

Img 3: Mirian Correa, social leader of *El Pozón*. From www.eltiempo.com/colombia/otras-ciudades/estos-son-12-colombianos-que-estan-cambiando-el-pais-de-el-tiempo-de-buenas-noticias-300670
Image 4: Merlys Valdez, social leader of the Isla de Leon. From www.eluniversal.com.co/suplementos/facetas/leon-una-isla-que-no-es-paradisiaca-249342-JWEU359527
Img 5: Gabriel Muñoz Tovar, previous leader of the neighborhood *Isla de León.*

[4] The information is taken from *El Pozon entre fango y pavimento*. barriosdelcaribe.wordpress.com/2012/12/04/el-pozon-entre-fango-y-pavimento/

[5] The information is taken from *Factores asociados a la nueva dinamica urbana.* rigocaspe.blogspot.com/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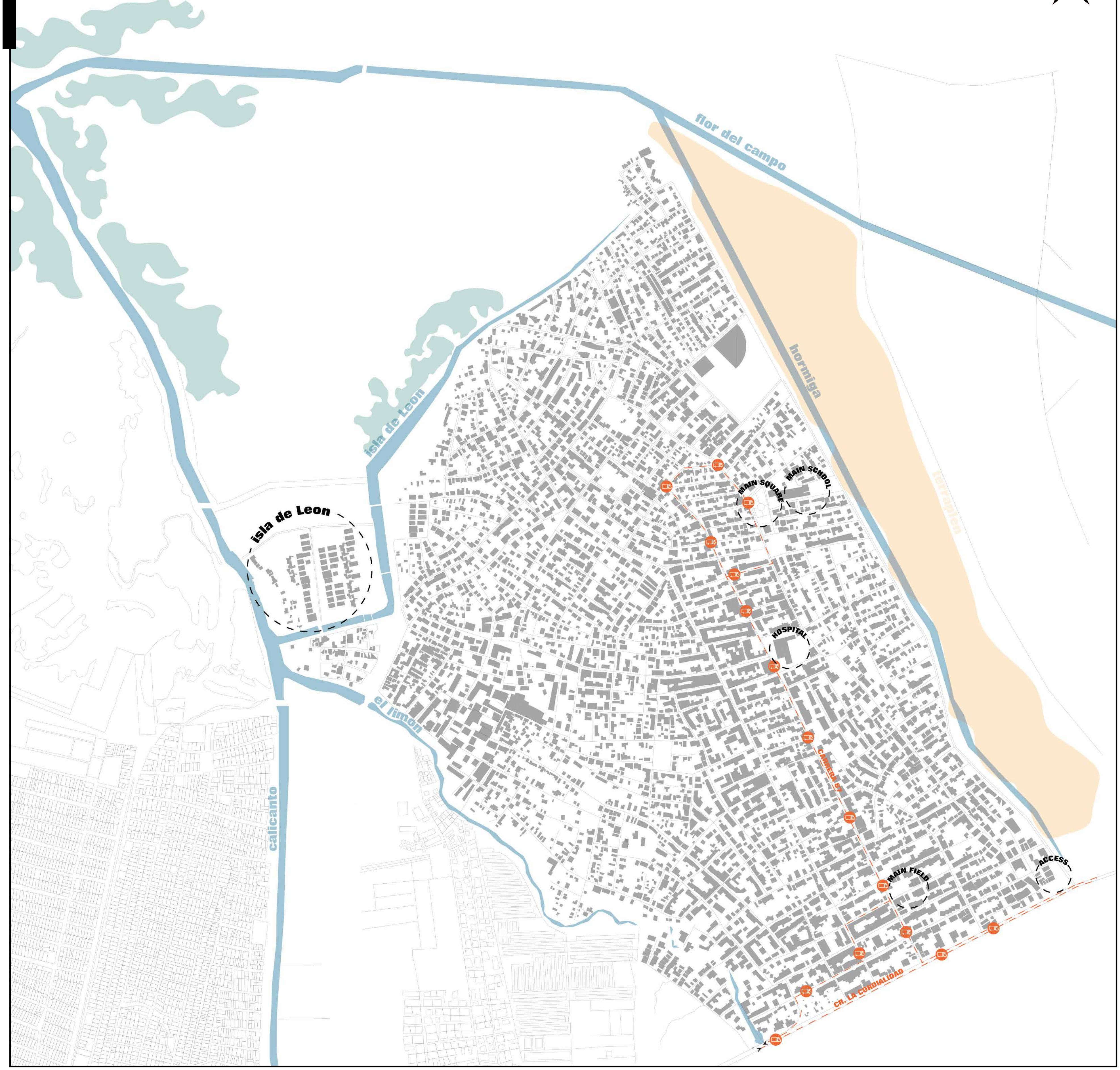
4


5

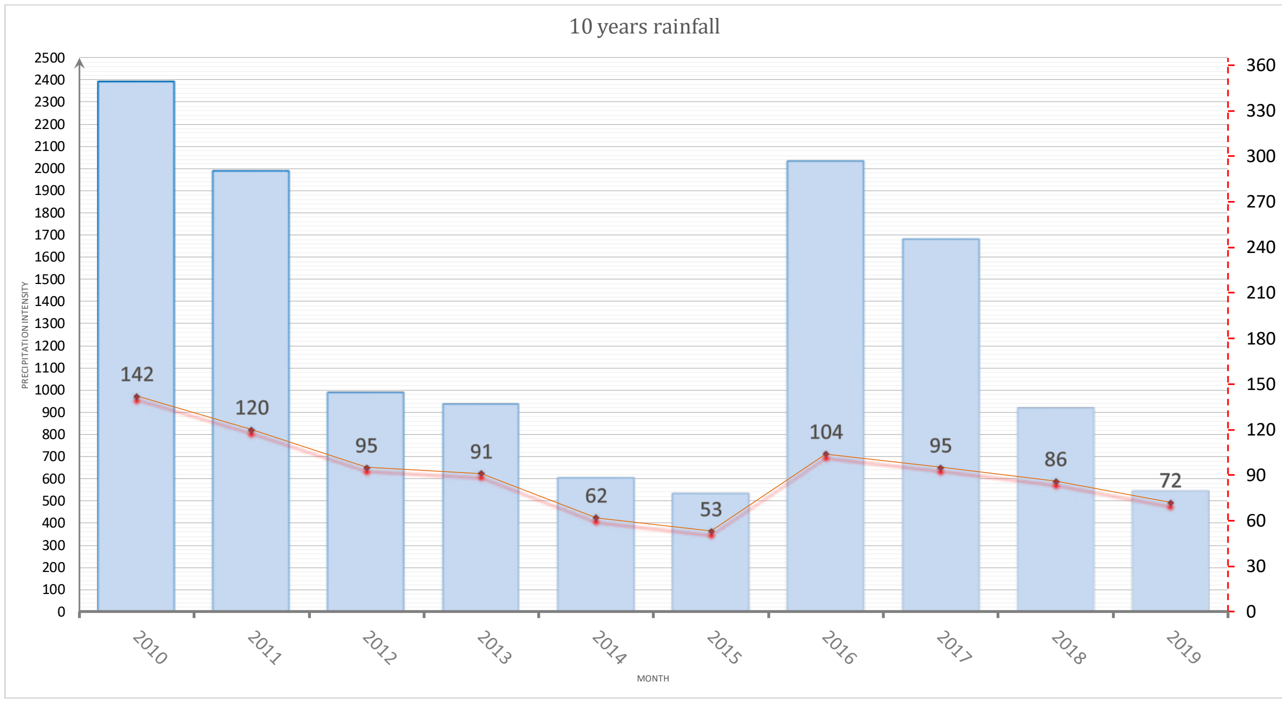
the land is not yet legalized. Nowadays *El Pozón* is one of the largest and most densely populated districts of the city, reaching over 40,000 people. Furthermore, although conditions in the neighborhood have improved, not only thanks to the work of social corporations that have been created in recent years and aid from some non-profit organizations, the neighborhood continues to present several problems: insecurity, informality in work and housing, lack of primary services and facilities suitable for education and social aggregation.In fact public space is almost non-existent, having less than 10 square meters per habitant, creating a lack of cultural spaces for the community. There are some outdoor gathering places, such as soccer fields and some gardens, but their incorrect design makes them unpopular and impossible to use during the day due to the extreme heat. This problem is aggravated by the presence of inequality within the same neighbourhood, which can also be perceived simply walking along the streets of *El Pozón*. The areas closest to the city center, in fact, are different from those behind the ones along the edge of the swamp; the *Sector Central* develops along the main road which is paved, served by public transport (the *Transcaribe*) and has houses made of material, i.e. bricks and concrete, which represents one of the main signs of wealth for the community.

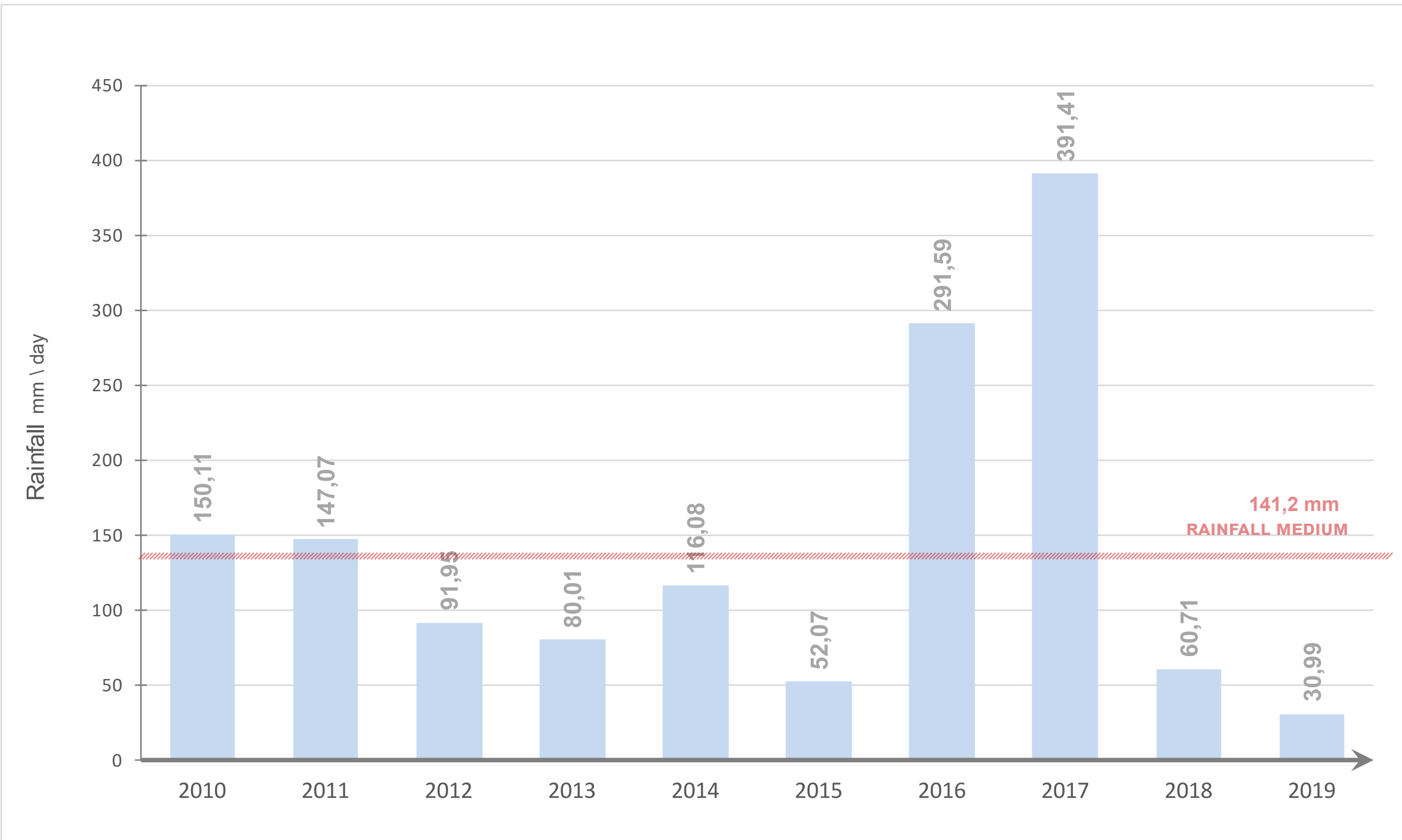
The theme of the identification of the inhabitants with their own home is a fundamental social theme, which has inevitable implications on the architectural sphere. Self-construction is a recurring feature of the *pozoneros* dwellings, regardless of the district. This concept is linked to the one of the ownership: it is very common that moving from more developed areas is linked to the desire to own a lot and build a house, even under the condition of lowering one's lifestyle, moving to less healthy and more insecure areas. This sense of belonging to the property can also be seen from the behaviour of some inhabitants in the face of one of the main environmental problems faced by the neighborhood, i.e. the frequency of flooding. Although this problem has now been reduced, mainly because the streets have been filled and a second canal has been opened preventing the neighborhood to be flooded, the population is still marked by one of the latest catastrophic events, which occurred in November 2016. According to some witnesses the roads were completely flooded and in some cases the water level exceeded the level of the doors. Despite this, most of the community decided not to move and to repair the damage caused and in some cases even completely rebuild the houses. During the inspections carried out for the project, it was discoverd that this feeling is still shared today. Despite the fame of the neighborhood, the community is characterized by a positive and proactive feeling, a reality that is also reflected in the various interventions that are carried out in the neighborhood, mainly by corporations led by the figures of social leaders. These same figures are at the same time active participants in the processes of study and research of El Pozon, and accompany various groups on visits to the neighborhood, sharing information that would otherwise not be available from any other source.

El Pozón_
The neighborhood.
Scale 1:10000.

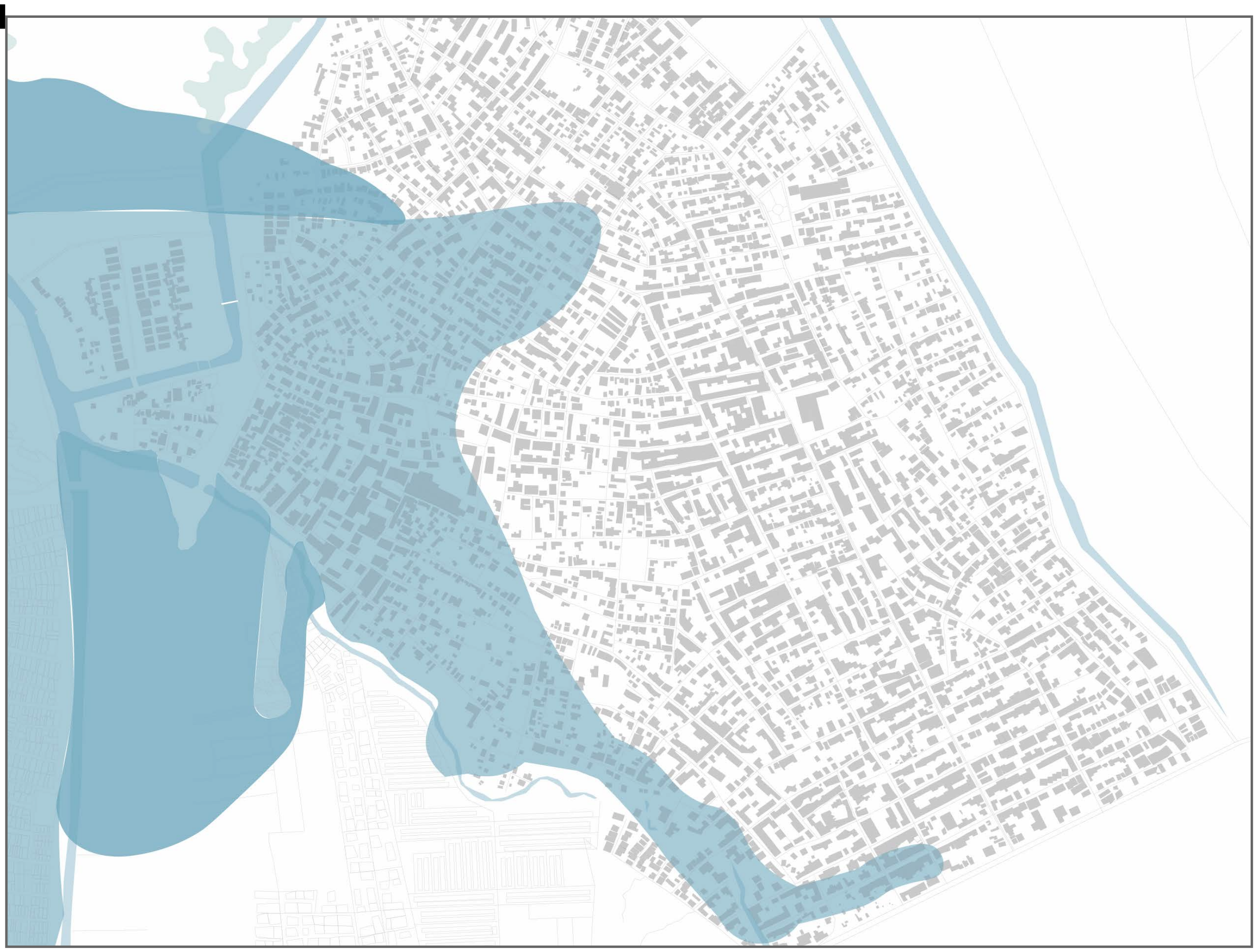


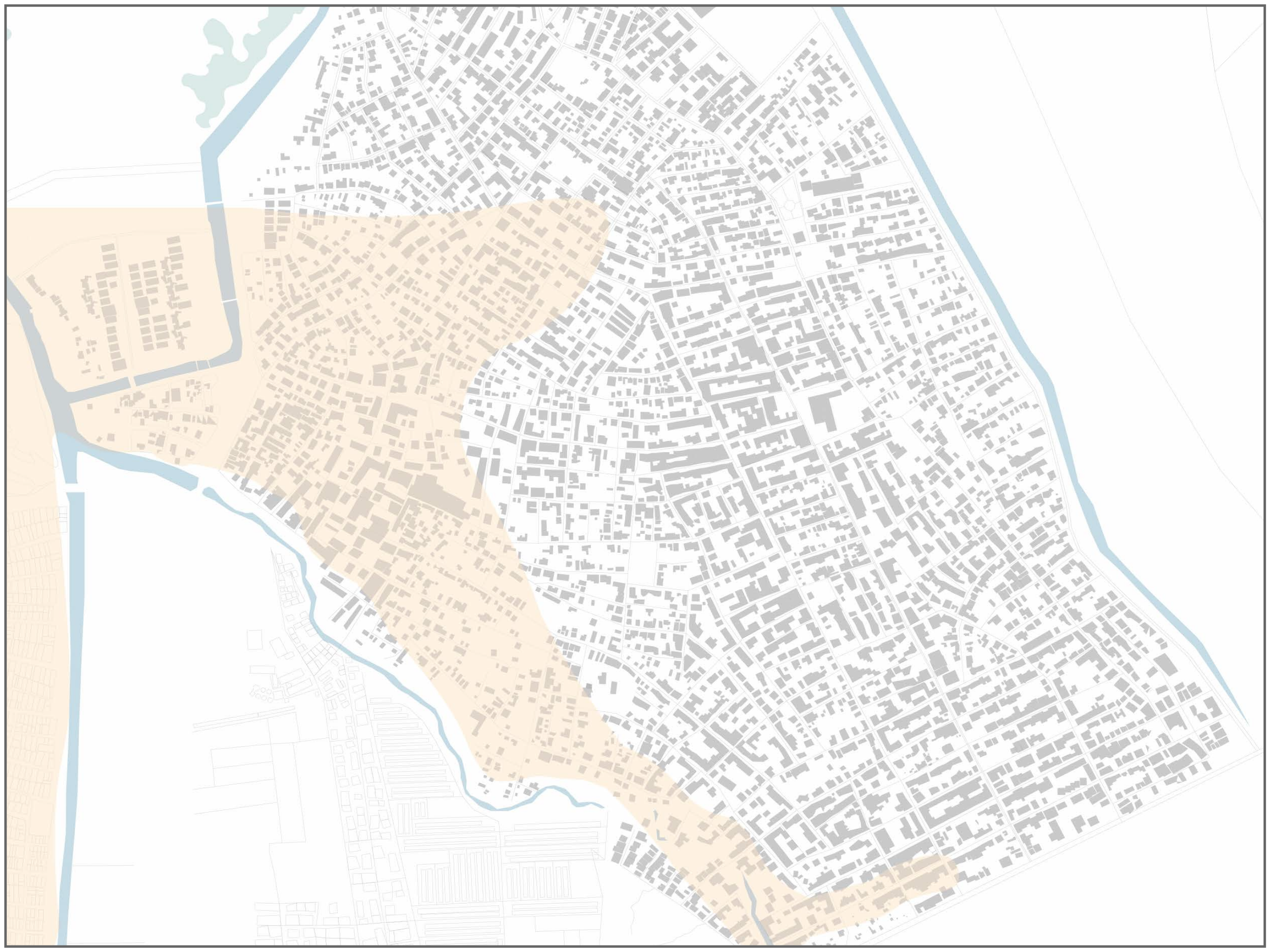
The graphs were elaborated by the authors based on the informations found on www.epacartagena.gov.co.





El Pozón_ Sea level rise flooding and stormwater flooding.





[7]observatorio.epacartagena.gov.co/

[8]*Ciénaga de La Virgen: Humedal Vulnerable de Extinción.* calidris.org.co/cienaga-de-la-virgen-humedal-vulnerable-de-extincion/

[9]*Mangroves.* www.mangrovealliance.org/mangrove-forests/

[10]*Plan4C, Cartagena Competitiva y Compatible con el Clima.* plan4c.cartagena.gov.co

The environmental crisis of the Ciénaga de la Virgen

The environmental problems that characterize the neighborhood date back to its foundation. The first houses, in fact, were built directly next to the *Ciénaga de la Virgen*, in a lower area called playon, necessary as a buffer zone for the raising of the body of water and as a temporary deposit of water during the flooding period. This more marshy area was filled with solid waste in order to make possible the construction and continuous informal expansion of the neighborhood. This zone is made up of unstable soil that is unadequate to construction and with strong problems of rising water from underground aquifers. (Macario Ban, 2018). As it was said before, the name of the neighborhood itself suggests the nature of the territory on which it is built, from which the major problems concerning water derive. It is estimated that more than 300,000 squared meters of the *Ciénaga* riverbank have been drained, filled in and converted into consolidated land.[7]

In general, the main environmental problems concern the whole *Ciénaga de la Virgen*, which, while not being one of the physical boundaries of the neighborhood, heavily affects the living conditions of citizens. From the 1940s onwards, the swamp became the main receiving body for 60% of the total discharges generated by the city, discharging nearly 100,000 m3 of wastewater into the sewage system every day. Made to the open air and without any treatment, the system generated unhealthy conditions in the human settlements nearby and pollution levels that exceeded the capacity of self-regeneration of the water body.[8] Despite the fact that in 2013 this discharge was verted elsewhere, there is stil concern about the balance of this ecosystem, mainly because this is given by the mixture of salt and fresh water; previously, fresh water was supplied by seven natural springs, which are now illegally blocked by the surrounding farms. On the other hand, the channels that supply the swamp are in a great state of deterioration, some of them being completely clogged, whilst others highly contaminated. All these factors are causing the loss of depth and oxygenation of the lagoon, exacerbating the desalination process. The contamination of the *Ciénaga* also affects the local flora and fauna. "The mangrove system is crucial for both the environment and the economy, as it plays an important role in the protection of biodiversity, carbon storage, food security and the livelihood of the community itself."[9]

Another problem concerns the soil itself, which for the above mentioned reasons is impermeable and not suitable to receive the heavy rainfall to which it is subject, especially during the rainy seasons. By the year 2040, according to Plan 4C, Cartagena Competitive and Compatible with the Climate, the increase of the average level of the sea will be of 15 to 20 cm, putting at risk more than 80% of the districts of the city if the necessary works of adaptation are not made.[10] While this issue used to be a major contributor to the heavy flooding in the neighbourhood, it is now a key issue in the general theme of urban water treatment. The introduction of permeable green areas within the neighbourhood can bring several environmental benefits: such as contribute to lower temperatures to a proper management of rainwater, or rather its disposal in the sewerage system, where present.

Inspections and interviews: "Como me cuido yo, tengo que cuidar de mis plantas"

Thanks to the leader of the foundation for the environment, Mirian Correa, it has been possible to carry out several inspections in the neighborhood, where it is usually not recommended to go without a local guide, due to the high level of insecurity of some districts. The inspections were mainly concentrated in the *Isla de León* district, where it was possible to interview some inhabitants about the themes of the research. Some additional interviews were carried out in the areas behind the hospital, which roughly coincides with the *Sagrado Corazón* sector. The main objective was to collect as much information as possible on the topic of water management in the neighbourhood, through questions and surveys inside the houses. It is important to underline how this process was carried out after studying the environmental context of the neighbourhood and in an advanced momentum of research. It was therefore already decided to create a green module on the roof and the intention of the inspection was to understand what the inhabitants thought of the proposal and what could be the most suitable materials, trying to establish a dialogue on the advantages and disadvantages of the idea. For this reason the questions concerned not only the theme of water in general, but also pre-project proposals for the solution illustrated in the following chapters, based on previously studied examples.

Before analysing the interviews, it should first of all be pointed out that *Isla de León* is perhaps one of the less developed areas of *El Pozón*, mainly because it was invaded more recently and therefore presents a more recent history. Founded approximately 20 years ago with the name *Villa del Carmen*, placed in 1994 by the first settlers, was prone to flooding by the water currents coming from Santa Rosa. In 1995, it suffered a heavy flood due to a downpour, forcing the inhabitants to move to other parts of the city. At that time, the neighborhooud was still very disorganized and after this event the mayor's office began work on the pipes that come from Turbaco. Only the founder, whose surname was León refused to abandon the land where he was living and started to fight for what was now his home. In his honour the the settlement took the name of *Isla de León.*[11] Nowadays most of its inhabitants have been in the community for 4 years, in what they already consider their lands, since this place has become the shelter of different people forced to move in the recent years, for the differemt reasons already explained previously. The neighborhood has acquired a great value for the inhabitants, many of whom come from different parts of *El Pozón,* looking for a piece of land to build their house. The feeling of the inhabitants is summarized by the current *leader social* of the neighborhood: "People around here don't want relocation. If you can't live in *Isla de León*, you can't live in another sector of *El Pozón*, or any other sector of *Cartagena*, like *Bocagrande*. There the streets are also flooded, the difference is that here they become mud and there is cement."[12]

At present, *Isla de León* has more than 120 families and is in a process of consolidation as a community and is gradually developing a sense of belonging. The main guide in this area is Merlys, the current leader of the community, who told how there are still problems with the water and electricity supply. There is no sewerage system, the water supply is present only for some streets through a common pipe that connects to a meter installed on the bridge the main point of acces to the island from the rest of the neighborhood. Most houses do not have a proper toilet, but a pit in the patio behind the houses. The streets has no pavement, as do most of the houses inside. Here too, however, there are some inequalities between the different houses, which mainly depend on when the different families moved into the district. For this reason the number of houses made of recyclable material, such as wood, cardboard and plastics is higher than in the other areas visited. Houses made of bricks with a zinc or eternit roof in good conditions, called by the inhabitants *casas de material*, can be found, although they are less common than in other parts of the neighborhood. Almost all of the land is still occupied illegally and a process of compiling an accurate map of the area by the company TECHO is in progress.On the contrary the area behind the hospital, where the last interviews were carried out, was formed with the expansion of the *Sector Central*, broadly following the main history of the neighborhood. In this area most of the streets are paved and there is a sewage system, which obviously affects the configuration of the water management in the houses and also the attitude of the inhabitants towards the resource of water.

[11] mapcartagena.wixsite.com
[12] *León: una Isla que no es paradisíaca*. www.eluniversal.com.co/suplementos/facetas/leon-una-isla-que-no-es-paradisiaca-249342-JWEU359527

The images shown during the interviews with the inhabitants illustrate different types of modular green roofs, whose complexity varies according to the project. Later on, a model for the application of a system made with plastic bottles was shown, illustrating a possible vegetated roof garden. This drawing is based on an example of a settlement in Isla de Leon.

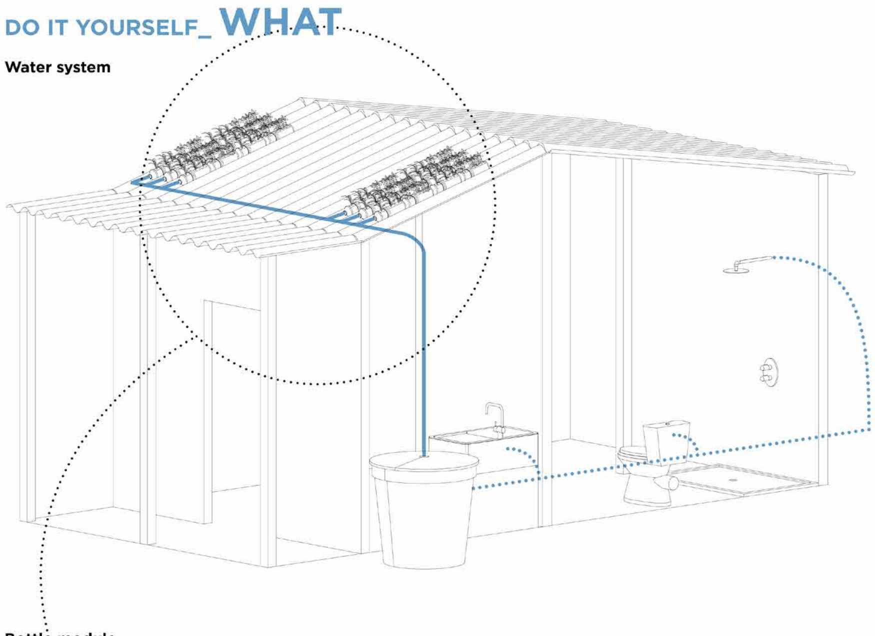
Ecotecho

Shed - Eco House

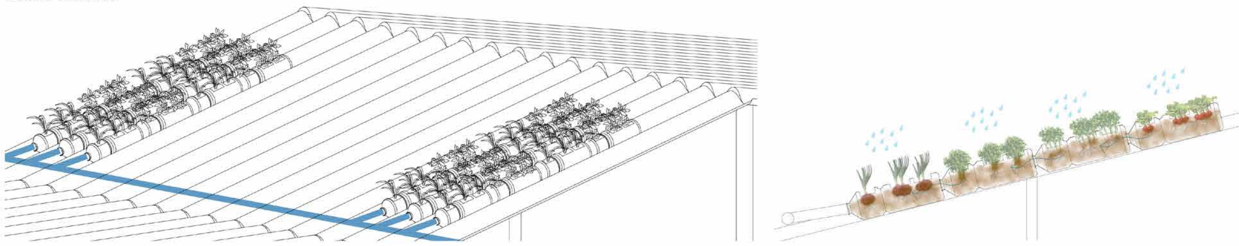
Yazzie Residence

DO IT YOURSELF_ WHAT

Water system



Bottle module



The information obtained from the interviews is not purely scientific in nature, not only because of the nature of the place where they were conducted, but mainly because they took place as conversations about the topic of the survey. The community feeling of the inhabitants allowed the interviews to take place with particular interest of most of the subjects, who not only gave sincere opinions, but also expressed doubts and suggestions. It was also possible to enter the houses, to take pictures and to record most coversations. A total of 10 households were interviewed, six of which were residents of *Isla de León* and four in the remaining area. For some houses it was possible to interview several family members, whose answers coincided on average, mainly because they concerned common family habits. Most of the houses had the same composition, for an average of about two children and three adults each.

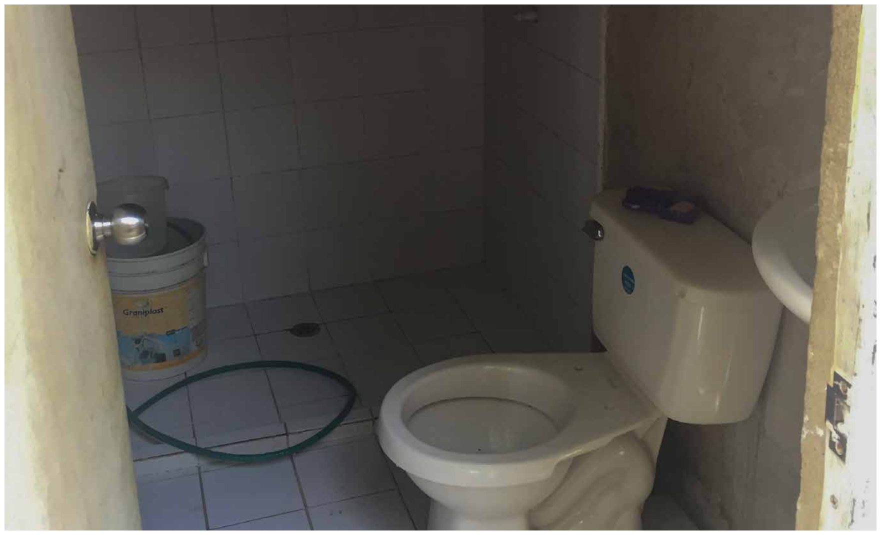
The questions asked are mainly four:
1) Are you in the habit of collecting rainwater?
2) How the water system in the house works?
3) Would you be interested in a green modular rooftop water collection system?
The images were shown and three main advantages of the system were explained: the possibility to collect rainwater, the ability to grow a roof garden and the bioclimatic advantage.
4) What are the main materials you use in the house and then throw away?

The answers have been summarised:
1) Six out of ten claimed to collect rainwater, although the habit has decreased since houses were connected to a drinking water network. The water is mainly used for secondary uses, such as cleaning the house, but also washing dishes or clothes. A curious fact is that many have explained how in their villages of origin the habit was much more ingrained and that water was also drunk, after having thrown the first layer that is always more dirty. Some at the beginning kept this habit, which has been decreasing, especially after installing a cover in eternit because of the toxic component.

2) Only one of the ten houses is not equipped with a drinking water supply system or even a bathroom, whose inhabitants claimed to use the one in the neighbouring house, belonging to a relative. In other houses the water supply system works mainly through a single tap, usually identified with the dishwasher in the kitchen, Only three subjects were willing to show the bathroom, which in two cases consist of an external cylindrical brick and an additional one and an additional one, generally located in the back of the house. Only three subjects, all oh them residents of the *Sagrado Corazon* sectors, were willing to show the bathroom, which in two cases consist of an external brick structure containing a toilet and a shower, while in the other one it is inside the house but with the same composition. The others intevieews (5 out of 10) have an outside pit located in the back patio. Three out of ten subjects also have a washing machine with manual water supply. In general, it should be noted that all inhabitants have the habit of collecting drinking water in buckets for use in the rest of the house, as well as filling an additional one in case of need. It also happens from time to time that water and electricity fail due to problems with the central network.

3) Only one subject said that it was not interested in the roof systems and that he would have preferred a garden on the patio. The rest (9 out of 10) were in favour of the system, mainly appreciating its aesthetics and advantages regarding the indoor climate of the house. All the subjects identified as a problem the climate of the area, characterized by a dry and rainy era. For this reason, the system could be affected by long periods of drought and, above all, by direct solar radiation that would damage the plants. To solve this problem two people suggested the use of a dark cloth to cover the plants. The best fruit and vegetable species for planting, suitable for the climate and short root, have also been suggested: chives, eggplant, cabbage, coriander. It was also said that is common to irrigate plants in the early hours of the morning during the dry period, while in times of rain there is no need for additional watering. None of the parties stated that they would not be willing to take care of the plants, including irrigation and maintenance. Most respondents already own a garden or some plants, but complain that the soil is too dry and hard to grow some species. However, questions were asked about the feasibility and maintenance of the project in houses with an unstable roof structure. Regarding the possibility of using a tank placed on the

The photos taken during the inspection show the hydraulic system configurations of the houses in the neighborhood.



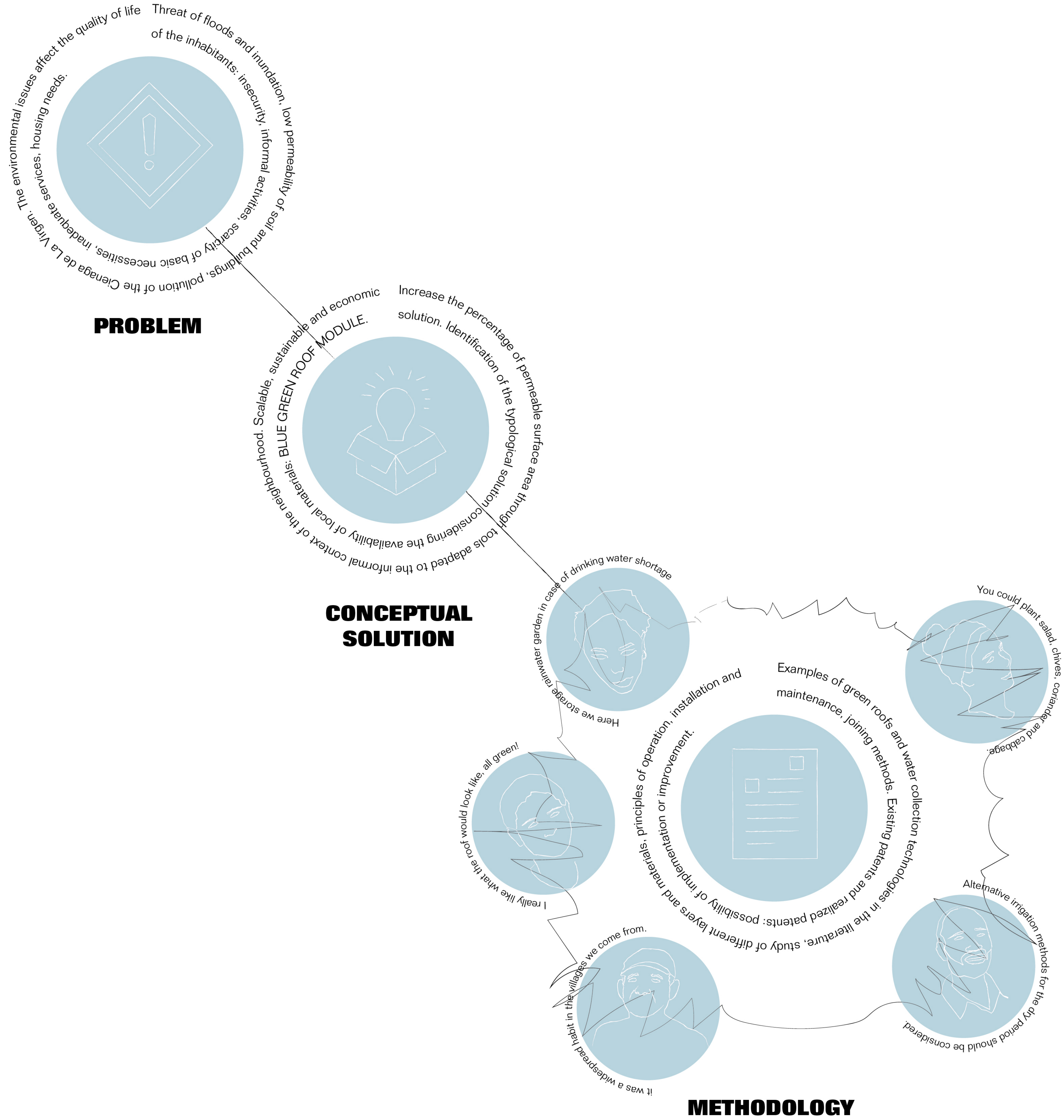
roof for irrigation, in particular, one person suggested a structure on the side of the house on which to place it in case it is not possible to use the cover surface. Finally, only three out of ten people preferred a hypothetical module built with wooden or other assemblable material boxes, while the rest of the interviewees expressed a preference for bottles, mainly because of the recycling component and the lightness of the system. It is interesting to note that one of the people interviewed raised the issue of security, arguing that if a house was equipped with this system, it would be necessary to install a house locking system.

4) As far as the use of materials is concerned, on the other hand, it has been found that most people keep building materials inside the houses, as the houses are constantly under modifications. In some cases the materials come from companies for which some work, while in other cases they are materials purchased in large quantities for a favourable price. In any case, it was possible to deduce from the interior inspections of most of the houses, especially those in Isla de Leon, that the recycling of building materials is a common practice in the neighborhood. This aspect has also helped to understand how strong the self-building aspect is for the whole community. In 2006, TECHO built a raised rear extension for a number of families, mainly made of wood. Two out of the ten inhabitants interviewed dismantled the building and reused all the materials to fit out other parts of the house or make extensions according to their own taste. The most reused materials in construction are wooden pallets, plywood and waterproofing membranes. As far as everyday objects are concerned, the most commonly used plastic bottles are gas bottles, especially large ones. In general, four out of three respondents said that plastic waste is the one that accumulates the most inside the house, whilst most other containers, such as glass bottles, are delivered empty to shops and then reused. The scouting phase of the materials is described more precisely in the fourth chapter, especially because it obeys some precise criteria that derive from the knowledge of the characteristics that they must present. In particular with regard to waste materials, it was useful to visit the *terraplen*, the area on the side of the North East canal that delimits the district. It is in fact common for the inhabitants to deposit waste on this plain, which also spills into the canal, blocking the possible outflow of water during flooding. This is a problem common to all areas on the edge of the *Ciénaga de la Virge*, whose canals are blocked by debris, which in some cases are dragged into the lagoon and aggravate the pollution situation of the body of water.

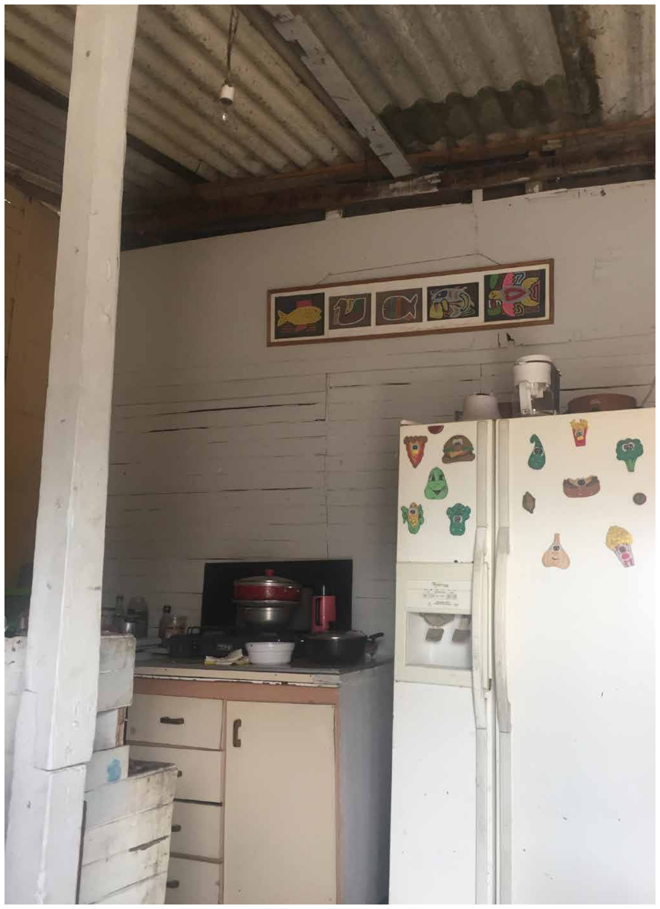
In general, the project proposal was welcomed by all the inhabitants interviewed who showed interest in the topic, in addition to a deep knowledge of the environmental conditions of the neighbourhood, in particular about flora and climate. At the same time, the inspections partly guided and stimulated the design phase, thanks to the continuous dialogue with the inhabitants. In addition to assessing the interest and feasibility, in fact, the attempt to include the community in the process, even at an advanced stage of design concept, has had a strong impact in the definition of the final model, mainly as far as the choice of materials was concerned. In fact the inhabitants themselves raised important issues for the possible implementation in the neighborhood, also showing interest in technical details. Although the sample of people interviewed is not very large, mainly for reasons of time and for some conditions dictated by the social and climatic characteristics of the neighborhood, the duration and level of depth of the each interviews, has made it possible to better understand not only the context of the project, but also the the project itself. The main contribution was that of the various people who, once they understood the intervention, asked questions about its implementation. In addition to the interviews carried out in the houses, during the inspections it was possible to get to know the neighborhood and talk to different people who made the process of getting to know *El Pozón* interesting and engaging. Most of the information gathered here and many others are the result of different conversations that took place mainly with Mirian Correa and Merlys Valdez, but also with other people who would share deliberately some informations about the place where they live.

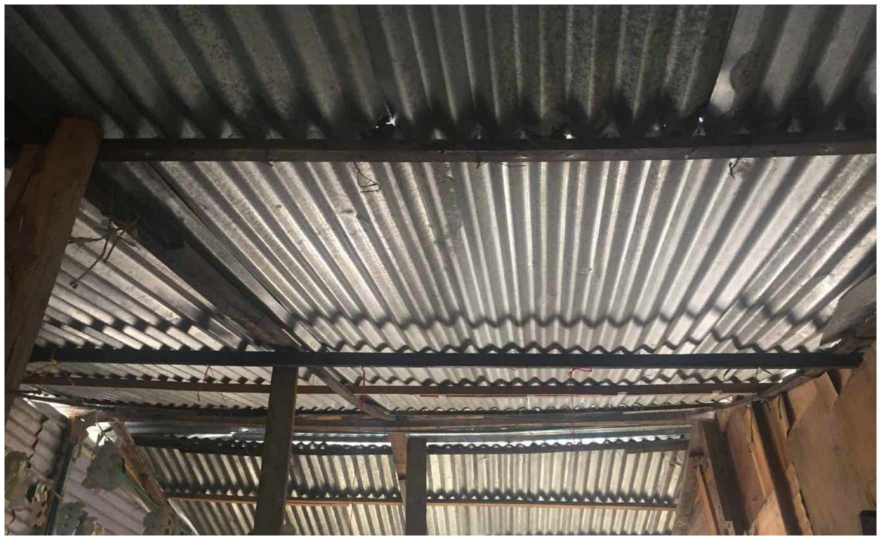
The photos represent some of the main moments of the interviews with the community.

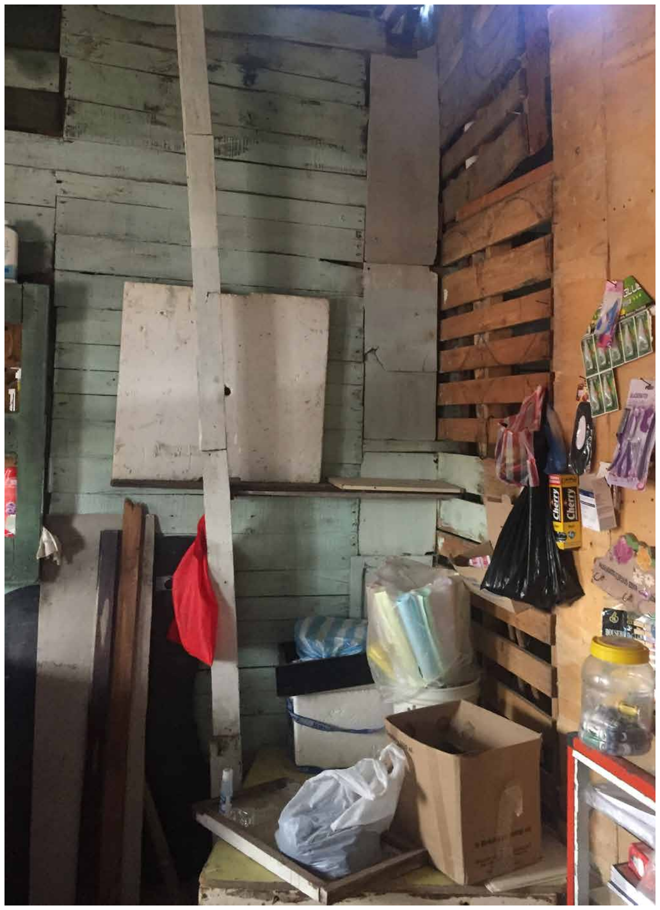
The project flow chart



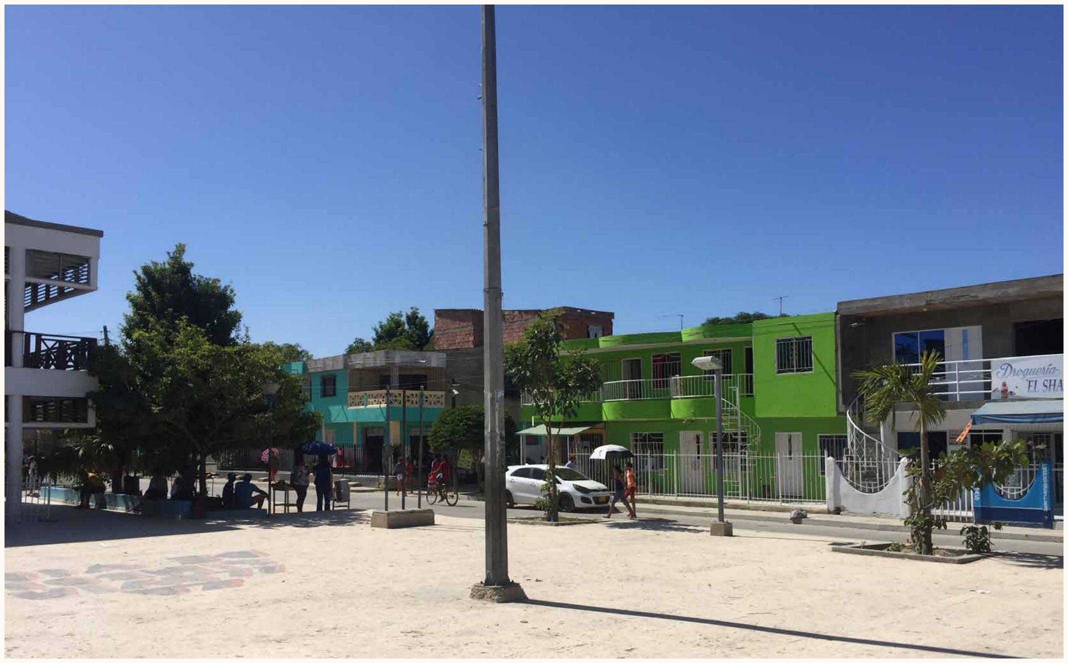
The photos show some of the main materials occupied for the construction of the houses. Wood seems to be the most common one, together with zinc for the roof.

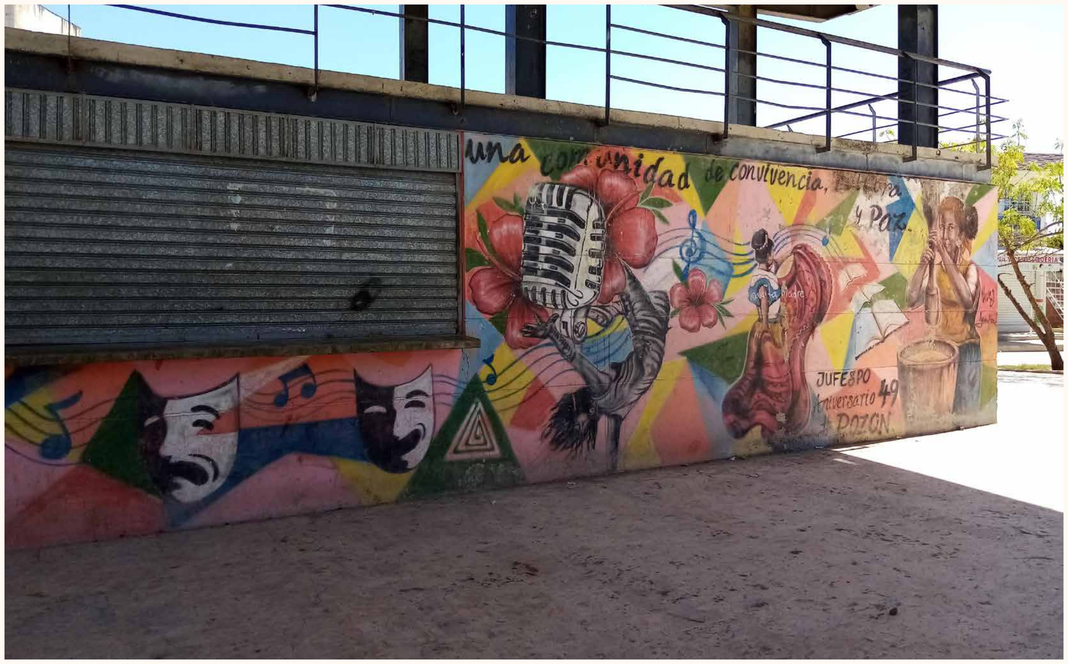






Photographic reportage

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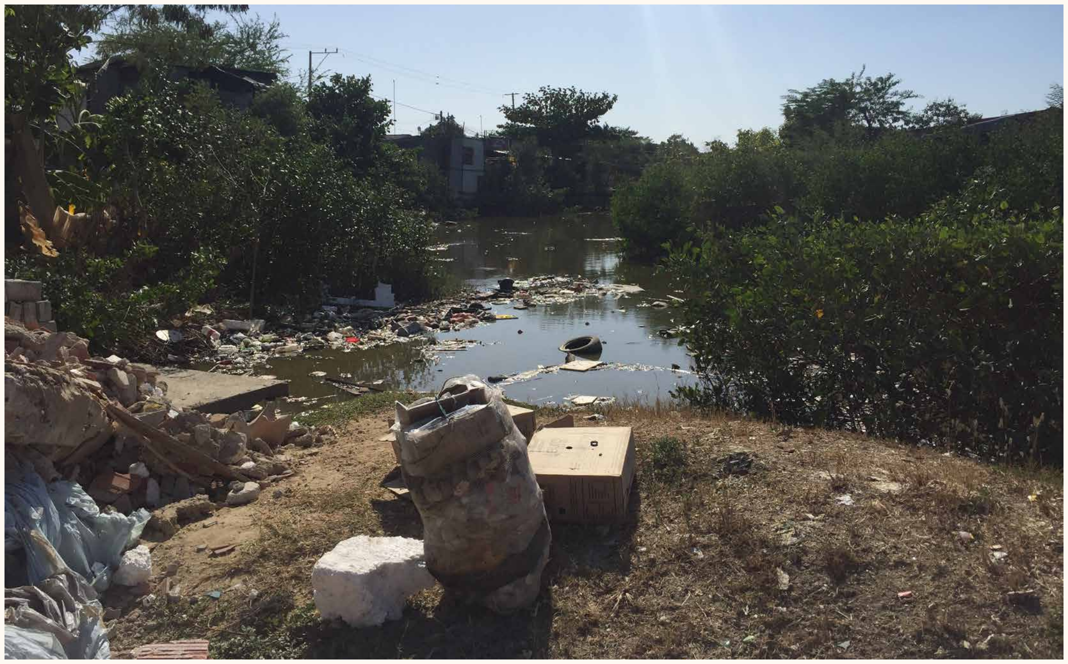



UPER SEMANA
DEL AHORRO
LA CASONA
Nestlé
TENEMOS PRECIOS
ESPERAMOS...


Variedades

Introduction to the chapter:
The reasons for the choice of the Reference Project

The research of the reference case was determined by several factors. The main prerequisite for the selection was the adaptability of the reference case with the project proposed by the authors of this thesis. In particular, this adaptability had to be found on an already constructed building in the case study area (analyzed in the previous chapter) of the *El Pozón* district in *Cartagena de Indias*. However, the houses visited during the inspections, especially in *Isla de Leon*, appeared too ephemeral to ensure that the proposed intervention was not inconsistent and too anticipatory compared to the work really necessary (such as structural work) for these types of habitations. For example, in most of the cases visited, the roofs of these houses had no technology capable of supporting the weight to be considered for the intervention for a long time. However, considering this idea and not wanting to propose something unsustainable, it was preferred not to consider a house already present on the site, but instead to consider one destined for it.

Starting in 2018, the Polytechnic University of Turin, together with the Pontifical Javeriana University of Bogotà and Oxford Brookes University, participate in the design of a social housing for the district of *El Pozòn* in *Cartagena de Indias*. Over the years, students and professors of the Polytechnic have contributed to several activities with the specific responsibility of reaching objectives regarding the sustainability of the housing module. The achievement of these objectives has been the subject of studies and research that has engaged the team of the Polytechnic in these two years. In addition to the commitment of the studies previously conducted on this housing module, this house has basic design features regarding sustainability and resilience of living in accordance with the themes transmitted by this thesis. In addition to the participation in the different steps of the design, participating in the construction phase during the Solar Decathlon - Latin America and Caribbean 2019 competition provided a complete knowledge of the entire building. Therefore, after the inspections of the final destination site of the project, it seemed pretty reasonable to consider implementing the prototype described in this chapter to add a further contribution to the generative cause of the project.

Chapter three: Reference study_the *Maquina Verde* project

1.

Solar Decathlon Latin America and Caribbean - Cali 2019

The competition: location, the sustainability aspects and rules

The Solar Decathlon is an international competition[1] established by the U.S. Department of Energy in which universities from around the world work to design, build and manage a grid-connected, energy self-sufficient home that uses solar energy as its only energy source and that is equipped with all the technologies that enable maximum energy efficiency.

The Government of *Valle del Cauca* through the Financial Institute for the Development of Valle del Cauca – INFIVALLE and the Department of Energy of the United States Government - DOE, signed in October 2016 a Memorandum of Understanding (MOU) to organize the second version of the Solar Decathlon Latin America & Caribbean (SDLAC)[2], which was held in December 2019 in *Santiago de Cali*, Colombia.

During the final phase of the competition university teams assemble their houses at a central location and then open each competition prototype house to the general public, while undergoing the ten contests of the competition.

The objective[3] of the SDLAC 2019 organization is to promote knowledge and diffusion of solar and sustainable industrialized housing. In this way, raising the students awareness of the benefits and opportunities offered by the use of renewable energy and sustainable construction, challinging them to think creatively to develop innovative solutions that contribute to energy savings. On the other hand, the competition aims to encourage construction professionals to take a more sustainable view. It seeks to promote the use of materials and systems that reduce the environmental impact of the building throughout its lifetime, optimise its economic viability and ensure the comfort and safety of its users.

Showing off the prototypes during the weeks after construction seeks to educate the public about responsible energy use, renewable energy, energy efficiency and related technologies available to help them reduce energy consumption.

During the competition, the evaluation criteria was focus on four main categories: social housing, urban density, rational use of environmental resources and regional relevance.

The competition premises provided for the realization of a house with a gross floor area of at least 60 m^2 and no more than 80 m^2. The architectural design had to meet the needs of a family of 5 members (minimum 3 adults and 2 children), with a direct cost of construction for housing units for less than USD 40,000. The proposals also had to have an optimised urban footprint by achieving a conceptual density of 120 housing units or more per gross hectare through collective social housing, with buildings up to 8 floors high and with high standards of accessibility. The accessibility of people with disabilities to public spaces and upper floors of buildings were challenges to be addressed in this SDLAC 2019 competition. An urban masterplan was planned to clearly demonstrate the distribution of blocks, public areas, accessibility and urban structures.

The competition consisted of 10 separate scoring contests[4]. Each of these contests could correspond to one or more sub-competitions adopting different criteria or evaluation tasks:

- Architecture - the architectural proposal had to be coherent with the principles of the competition. For this reason a great deal of attention was paid to the materials used and the sustainable technologies applied, considering the environmental context. Moreover, the attention was mainly directed to the correct functionality of the various parts that made up the body of the house. In addition, the spatial design had to show an adequate correspondence between what the project was in the pre-construction phase and later what the building showed. An important requirement of this category was the lighting design and the quality of light in the different rooms.
- Engineering & Construction - focused on the coordination and management of the assembly period and the structural design of the house. The construction solutions had to guarantee the highest internal comfort, paying attention to the design and assembly of the hydraulic and electrical system and finally to the design and construction of the solar thermal system.
- Energy efficiency - concerning the coherent consumption of systems within the house in accordance with the limits imposed by the competition. It was expected that electricity consumption at the end of the total energy balance examination period should be less than 90 Kwh and energy transport losses should be minimal. In addition, this competition assessed the determined solar energy efficiency of the solar energy system and the solar thermal system considering in addition the integration of the latter with the house. In addition to the energy analysis of the dwelling, more specific analyses concerning Embodied energy and efficiency of the appliances were also evaluated considering the increase in efficiency due to the management.
- Comfort conditions - evaluating the indoor temperature, humidity, acoustics and lighting in the house.
- Innovation - in the fields of architecture, engineering and energy efficiency, urban design and affordability.
- Electricity balance - measures the self-sufficiency of electricity in the house. The best result in this competition was to achieve a net zero energy building (NZEB) in which the electricity balance is zero. In addition, there was a correct function of the electrical system avoiding power peaks in the electrical grid, an important aspect for the correct management of the energy load.
- Operation of the house - Considering an average energy use in a modern house, all uses of common appliances within the house were assessed with different tests of functioning during the weeks following construction. The tests included: refrigeration, freezing, washing and drying clothes, microwave, mixer, kitchen test, domestic electronics, social activities such as dinners, water consumption and hot water operation.
- communication, marketing and social responsibility - focused on the evaluation of communication and marketing strategies used to raise the project awareness and generate interest and social sensibilities to generate relevance regarding the use of clean energy and the benefits of using it in one's own home. The effectiveness, efficiency and creativity of the media used for these purposes was rewarded.
- Urban design and affordability - had to guarantee a housing budget that can be built with 200.000 USD or less. Present a masterplan of 1 hectare with a density of 120 residences (or more) for a maximum of 8 floors. Assessed the affordability and profitability, the cost of the prototype with all materials and any direct cost of construction.
- Sustainability - assesses the degree of sustainability in the architectural field through the evaluation of materials and principles used (renewability of materials and their origin, bioclimatic, eco-compatible approach and intervention strategies). In the engineering field: Life cycle Assessment (LCA scenarios), water management, Design for disassembly (DFD), flexibility of the structure. In energy efficiency through acoustic performance, indoor air quality, reduction of energy requirements. Lastly, in urban design and affordability, the flexibility of the houses, the maintenance requirements and the reduction of construction costs were evaluated.

[1] for more information about the Solar Decathlon competition visit the website: https://www.solardecathlon.gov/;

[2] more specifically information about Solar Decathlon Latin America and Caribbean 2019 visit the website: https://solardecathlonlac.com/;

[3] for a more complete overview of the objectives and rules regarding Solar Decathlon - LAC 2019 it is possible to download the complete guide at this web address: https://solardecathlonlac.com/competencia/reglas/;

[4] In this paragraph the rules have been summarized, but in the solar decathlon - LAC 2019 guide it is possible to see the several scores assigned for each of the sub-competitions.

The design proposal

1. Imaginary scenario - the image developed by the students of the *Pontificia Universidad Javeriana* of Bogotà shows one of the main ideas of the project. The community's approach to nature, interacting with the surrounding environment, enriching it without disfiguring it.

Introduction on the PEI's project: the conceptual idea

In this chapter is represented the Maquina Verde project. The work involved several students who have participated in the last four years in the class of Professor Carlos Hernandez Correa, director of the PEI office of the Pontifical University Javeriana of Bogotà. The attribution of the design and ideas for the urban, architectural and technological project was the responsibility of these students. The work produced mainly by the authors of this thesis concerned the hydraulic and water collection project of the Vivienda, a fundamental subject for the development of the themes expressed in this thesis.

For the 2019 edition of the Solar Decathlon of Latin America and the Caribbean, the team formed by the PEI project of the Javeriana University of Bogotá, the Polytechnic of Turin and Oxford Brooks University, faced the challenge of habitability for the most vulnerable populations of the Colombian Caribbean as a strategic intervention of great opportunity to rethink the conventional urban and architectural schemes of these territories. The team aimed to develop the project on the basis of 2 concepts, which claim to support the reflection from the territory to the retail. First of all, "The Ark" metaphorical reference of the house as a "container of life" that by its nature is facing unfavourable conditions, transforming them into opportunities for the development of the project. The Ark is considered as a cultural reference of temporary shelter and with immediate attributes of social cohesion. Secondly, the concept of "green machine" refers to a multi-part device that performs a specific function as a productive reactivation system. The strategic intervention takes place within the expanding urban limits of "*El Pozón*", a district located in the south-east of "*La Ciénaga de La Virgen*"; a sector of the city with serious social problems and especially at risk of flooding (the most serious episode of 2011). The proposal articulates productive and environmental relations from a self-sufficient urban project in terms of infrastructure and sustainability. There are enormous possibilities to regenerate the currently fragile conditions of this sector and to orient the trends of an urban planning and conventional architecture that until now has not generated an adequate response to its context. The team's commitment was therefore to support and demonstrate that the paradigm shift in the model of habitability is completely possible and applicable through a new system of employment in socially and environmentally fragile territories, where extreme circumstances and catastrophic opportunities are no longer assumed as irreparable impediments and consequences, but as enormous opportunities to face the challenge of climate change, exceeding the sustainable expectations of ecosystem actions.

"Humans can have a positive impact in the environment where live if we change our current destructive patterns of living into productive and preservative co-living cycles."

PEI - Màquina Verde - El Arca

The Urban proposal[5] and the affordably approach of the project

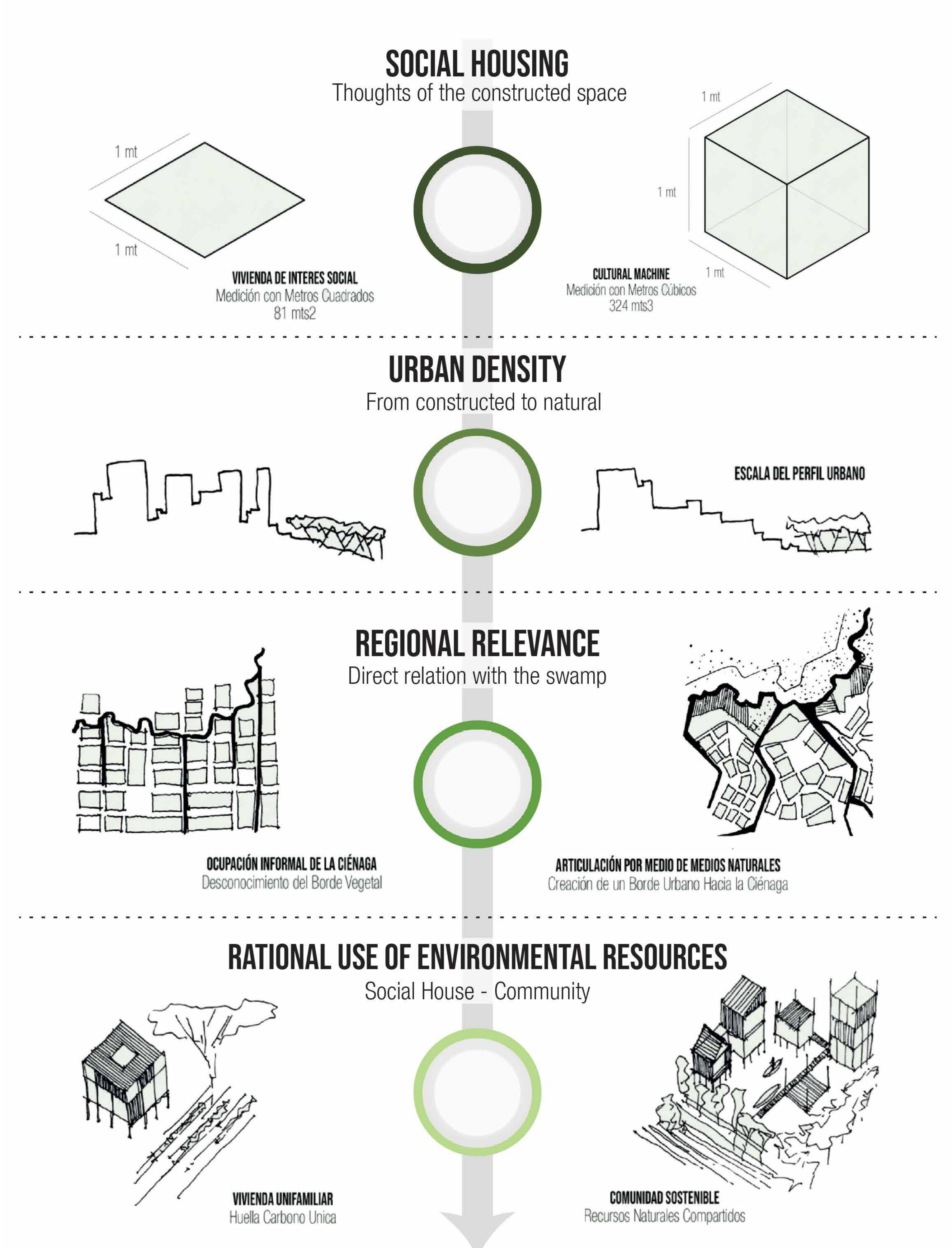
One of the main principles is directly related to the main architectural theme: social housing. Following the recognition, analysis and understanding of the critical episodes that cross the social, economic and community culture on which the team has worked in recent years, it was decided to focus on two essential themes: social and family habitability. After several activities, surveys and visits to *Cartagena*, the dynamics, relationships, working and basic needs of the population of El *Pozón* were determined, managing to find appropriate proposals, launch analysis and production of cartography, imagery and projection resources, with different scale systems that together form the Urban Master Plan. One of these postures it's very similar to the one that Sou Fujimoto takes in his work "Primitive Future", in wish he contrasts two architectonic archetypes: "The Nest", that operates like a projected model to one specific and absolute function, and "the cave" like a space that it's not conceived like an element with limited habitability options, but that allows multiple ways of appropriation. This, along with a posture that understands the social housing like a functional artefact that's spatially extra limited, with a philosophy where dignity comes above rentability. From this perspective understand and built an option for the future. On the other hand, from the analysis and recognition of the unique environmental conditions of *El Pozón*, the *La Virgen* swamp it's diagnosed as a deteriorating mangrove ecosystem caused by uncontrolled urban growth, consequence of informal, self constructed housing. this way, the sector continues to expand approximately a hectare each year, reducing the initial area and affecting, irreversibly, the ecosystem. Therefore, as an answer to this problem it's proposed a transition between urban expansion and the fragile ecosystem, thinking in a regional relevance articulation and adaptation throw a archipielago system, along with the creation of an Urban Boundary for Protection and Control of the swamp. At the same time, it's projected a reconnection of the human - nature relationship, transforming the population in inhabitants of the swamp with sustainable utilization techniques that will allow to regenerate the economic development and balance cycles of renovation of the ecosystem. In this way, the team manages to understand the metropolitan area of *Cartagena* with it's vegetation, hidric and maritime structure as one whole ecosystem that interacts constantly and armonacly with mobility, flows, commerce, economy and cultural relations dynamics, hoping to generate an adaptation and improvement to the context in wish the project is located.

Regarding renewable energies and high energetic performance, the project uses solar energy as the only source of electric supply, developing other ways that allow to capture and take advantage of the huge amount of solar radiation in the zone, synchronized throw a recollect - reuse system that starts in each household to be redistributed to community functioning. At the same time, from architectural design, natural materials are incorporated, with the propose to reduce the typical environmental impact that production and construction of housing generates in latin america. That's the reason proposed and implement the use of local materials with the potential of being directly extracted and manufactured by the community.

The Urban Master Plan starts with the synthesis that the team accomplished after determining spatial, structural and urban conditions that can be managed when propose a dense, compact, dignified, efficient and sustainable urbanism. Basing in this, the proposal emerge as a result of a laboratory though-out as a mean to find valuable answers, inspired by the book "50 Urban blocks" and other multiple efforts to give practical answers in diverse projects and national and international contests, getting to similar conclusions as Alejandro Aravena and his team, ELEMENTAL.

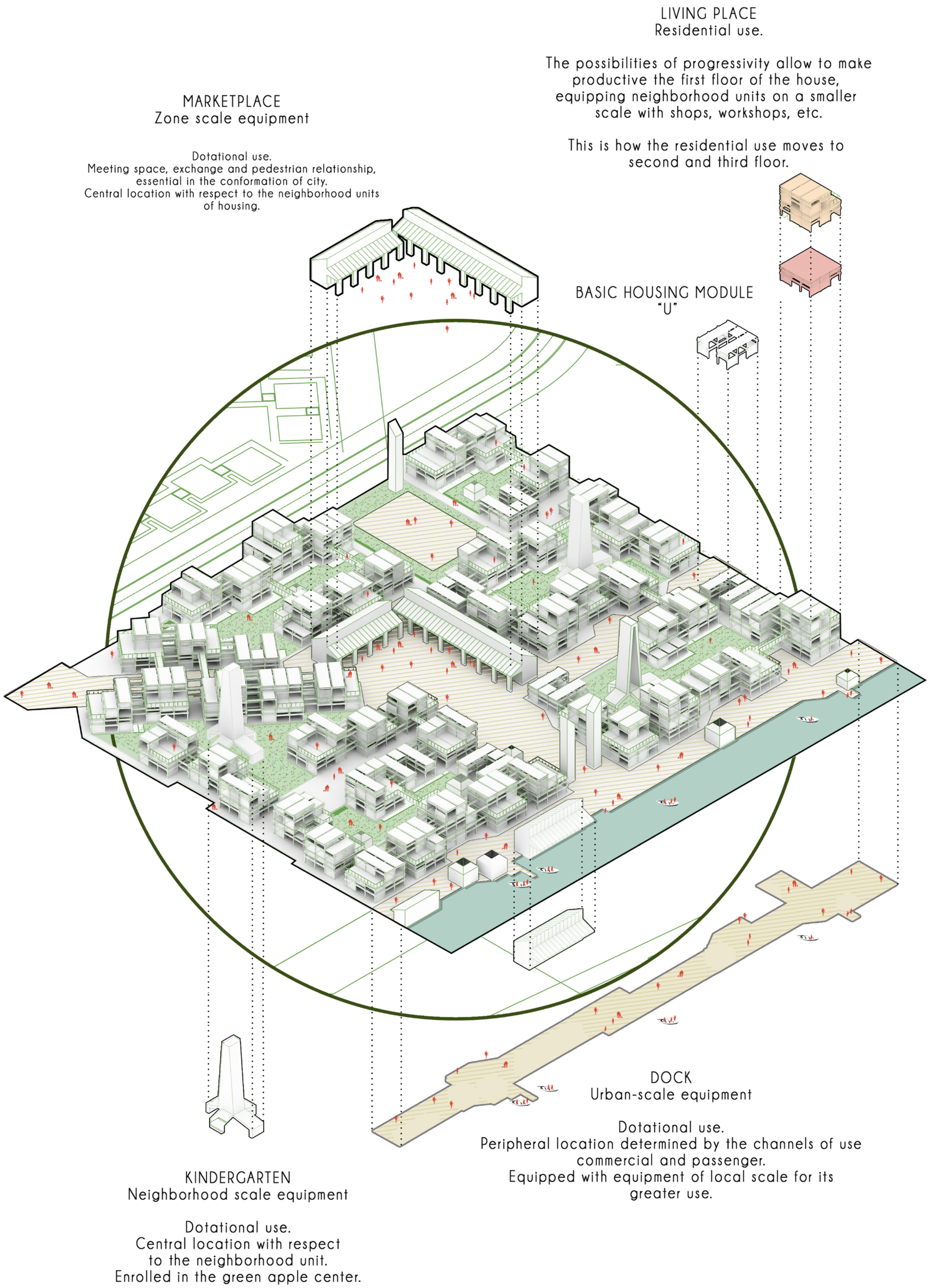
[5] the urban proposal has been a work carried out by the PEI office with different classes of the *Pontifical Universidad Javeriana* of Bogota during the last 4 years.

Conceptual drawings on the main objectives of the *Maquina Verde* project - made by the students of the *Pontificia Universidad Javeriana* of Bogotà extrapolated from the Project Manual delivered for the Solar Decathlon competition - LAC 2019.



Collecting Housing Building Axonometry

Even in the same context is fundamental to mention that the project seeks to ensure a respectful development where density can be accomplished without extending the intervention footprint, avoiding to affect the bioclimatic conditions. In the particulary case of "archipelago the *Pozón*", the team decided to reach the density of 120 households per hectare implementing a system of piled habitational units that could generate a cozy and healthy urban environment to the social development of the community. From a typological point of view, the grouping is the piling and overlaying of proposed bi-familiar modules, in blocks that are progressively added and not lined to generate megastructures able to add or subtract volumes inside itself. Instead of implementing a system of towers or isolated habitational units that occasionally could generate some kind of urban enclosure, the team preferred to experiment with a much more spontaneous system, in wish social housing takes place, that initial or finally can occupy 40m², that can share area with another household within the same spatial structure of 80m². This way, the reflection around density and the urban proposal is about understanding that sometimes, the enlargement models and the spontaneous volume additions frequently presented in vernacular and popular self-built architecture, typical of those fragile and precarious boundaries of Latin America and the Caribbean cities, are excellent references to develop a system that goes against erratic and unhumanized models that are produced by the real estate industry, occupying the totality of the territory or even forcing communities in vertical structures disjointed from their context without generating healthy and productive relations with the city.



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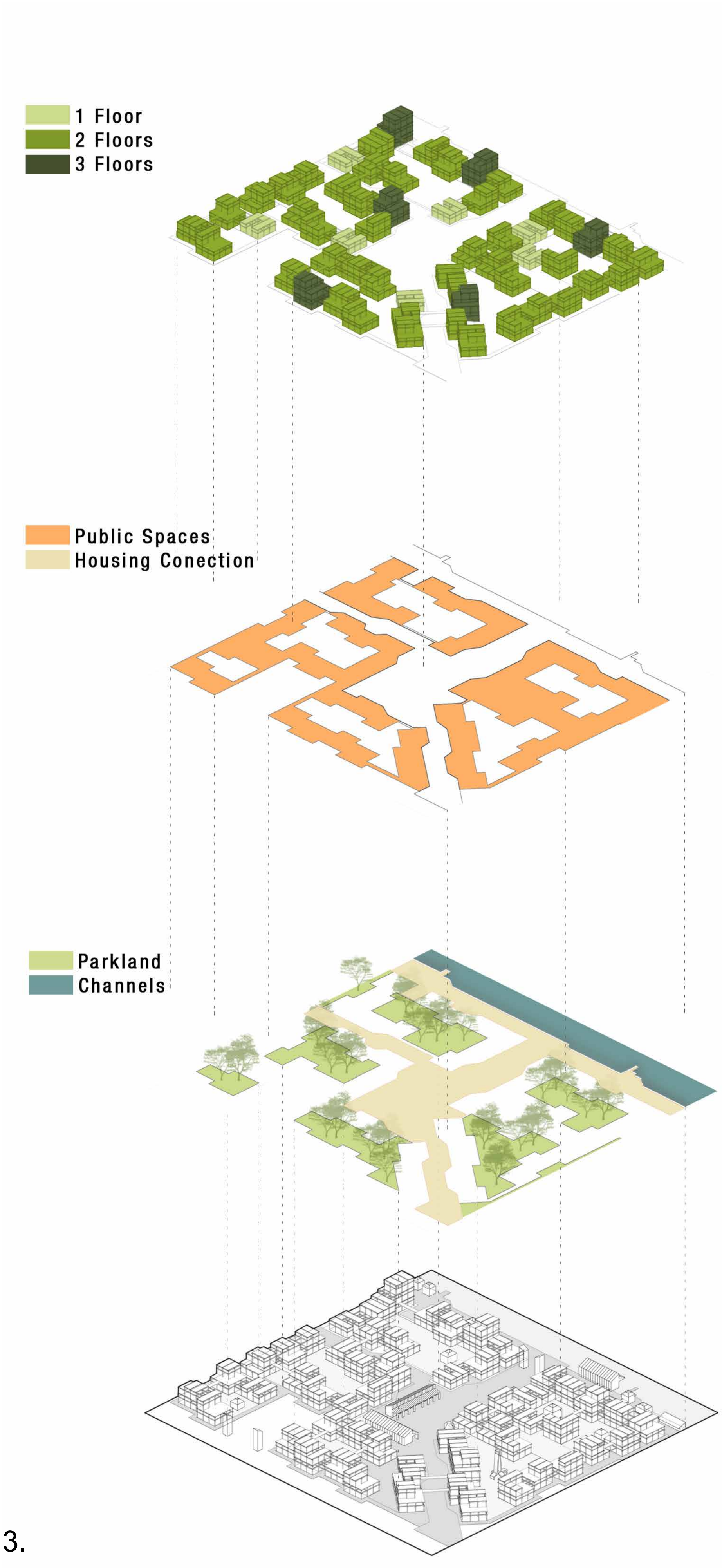


3.

On the other hand, the project accomplish to synthesis a flexible interesting relation between green areas of free public and collective use and construction occupied area. For example, in 1 Ha, the average accomplished relation is about 30% to 40% of the block´s green area destined to public and semi public space, leaving a 60% to 65% of the remaining area to be used in house and equipment occupation. In this way, the conditions demanded by the contest organization were respected and the spaces destined to conserved vegetal use could acquire a social and collective character, besides generating passages, terraces and balconies that placently enrich the caribbean urban environment.

However, from a landscape point of view, the relation that the project established with its natural context propose the generation of those spaces or porosities so the centralities of all its urban pieces may be richly impregnated with endemic vegetation. Enfaziting the natural environment, faced environmental conditions are identified considering the contrast between high temperatures that oscillate from 24°C to 31°C, with a relative humidity in an average from 78% to 82%, and floods that are presented in the sector for several months of the year. First of all, starting in the transition proposal between Urban Expansion and La Virgen swamp, it is required a considerable implementation and distribution of the projected vegetable mass in the blocks centers and the green zones and corridors correspondent to the 40% previously mentioned, that possibilitate at the same time the cooling of the wind stream. Besides, the distribution and separation of the households in groups allows the wind flow and independent control, answering to climatic parameters and specific requirements depending of use, quantity of people, housing location, among others.

In second place, taking into account risk and vulnerability conditions that may generate flood cycles, agrupations are disposed as palafitico units connected through platforms, allowing water circulation to go below, contemplating different levels of flooding along the urban proposal.


Planimetry of the
Urban Project Hectare.
Off-scale

2. Axonometry - the drawing shows some of the main uses within the considered hectare of land according to the rules of competence - made by the students of the *Pontificia Universidad Javeriana* of Bogotà extrapolated from the Project Manual delivered for the Solar Decathlon competition - LAC 2019.

3. Axonometric exploded - the drawing shows the territorial composition of the project's hectare of land - made by the students of the Pontifical University Javeriana of Bogotà, drawing revise from the files in the archive delivered to us by project manager Sebastian Rojas of the PEI team.

4. Territorial Plan - the image shows the Masterplan of the urban air project of el Pozon in Cartagena de Indias - made by the students of the Pontificia Universidad Javeriana of Bogotà extrapolated from the Project Manual delivered for the Solar Decathlon competition - LAC 2019.

5. Bird's eye view - the render shows the volumetric design of the Masterplan on the southeast bank of the *Ciénaga de la Virgen* made by the students of the Pontifical University Javeriana of Bogotà, drawing revise from the files in the archive delivered to us by project manager Sebastian Rojas of the PEI team.


4.


5.

6.

7.

8.

The renders produced by the students of the PEI team of the Pontifical Universidad Javeriana of Bogota, extrapolated from the Project Manual delivered for the Solar Decathlon competition - LAC 2019:

6. The image represents the common environment within the archipelago, it was imagined how social life can be generated in a healthier way within this natural environment not too far from their homes.

7. The image shows the close relationship that the project could favour with the channels connected with the *Ciénaga de la Virgen*.

8. The image shows the connection environment between the archipelagos as a place where they can carry out lucrative activities of social interest.

[6] This chapter does not cover all the various parts of the *Vivienda Solar* project proposed for the Solar Decathlon - LAC 2019, but only a brief overview of the main aspects of the house. For more information about the prototype, it is possible to consult the Project Manual prepared by the PEI team communication group.

The Architectural proposal[6]: ***una casa para todos***

The architectural process has been developed through three main phases: study and analysis of different case studies in similar conditions, personal interactions with the users to whom the project is intended, design of the house. Following an architectural analysis of some projects during the New Territories course proposed by the PEI office of the Pontificia Universidad Javeriana in Bogotà, the architectural proposal was conceptualized following an idea that aimed to achieve the objectives of a socially sustainable architectural work. Understanding sustainability not only as a merely environmental issue, but also in its social and economic dimensions, thus considering the close relationship between architecture and the community that inhabits it.

Studies have shown that the community is the key to achieving the sustainable design needed for *Maquina Verde*, the next step had to be interaction, understanding and listening to that community. For this reason, over the last three years, several groups of teachers and students have visited the project site to gather not only architectural but also anthropological information, in order to design properly, following a genius loci as real as possible.

The project was elaborated following some concepts taken from the direct experience of the inspection in *El Pozón*. First, the porch and the patio are the heart of Caribbean life, and the project had first of all to include these spaces in the design. The house was initially conceived as a large portico, with a central patio that encourages circulation, ventilation and exposure to the sun. The patio is the central place of the house. Centrifugal fulcrum of a volumetry that starts and develops in a modular way to create a light, transparent and easily controllable environment, similar in fact to a portico.

The concept of frame is predominant in the project, useful to respond to the different needs identified by the interviews made to the different families present in this neighborhood. The frame is opposed to the static nature of a house, allowing designers to follow the different needs. There is no regular family model, everyone has different needs to have economic stability, therefore, the house is conceived as a structure that can be filled according to what a specific family requires, a subjective container, an ark. This is why reconfigurable features are indispensable for *Maquina Verde*.

Finally, the Vivieda takes on the concept of progressivity. This concept is fundamental in informal public housing as the economic dynamics require it. In contexts like this, it has been clear how indispensable it is to provide the opportunity to guarantee such a flexible and progressive space. As the members of a family increase, the population of a community consequently follows the increase in the necessary volumes. The frame allows vertical and horizontal additions. The living space changes over time. The reconfigurability is present in every aspect inside the house. All the furniture is mobile and can modify the interior spaces, making them larger as needed. Facades opening towards the outside can expand the patio by mixing the internal reality of the house with the outside, ensuring complete permeability. Finally, the mobile roof allows the use of the loft, increasing the useful surface of the house.

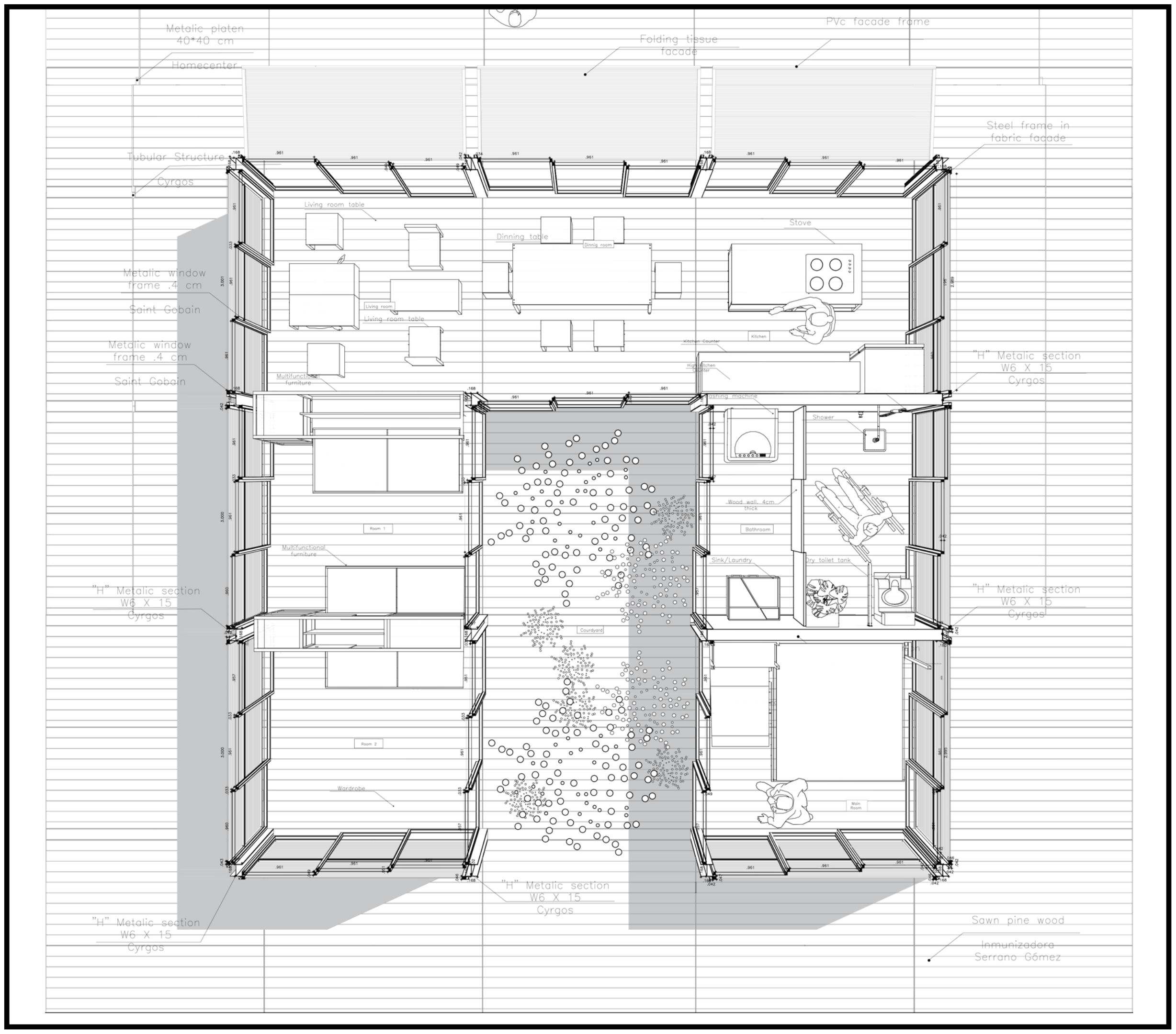
The structural design takes into account the assembly process, if at first it was initially designed in wood, then the material chosen was steel, while for the secondary structure remained wood. It had been established that wood would not be a feasible material, due to the amount of metal elements needed to join the various parts of the structure in the time foreseen for the competition.

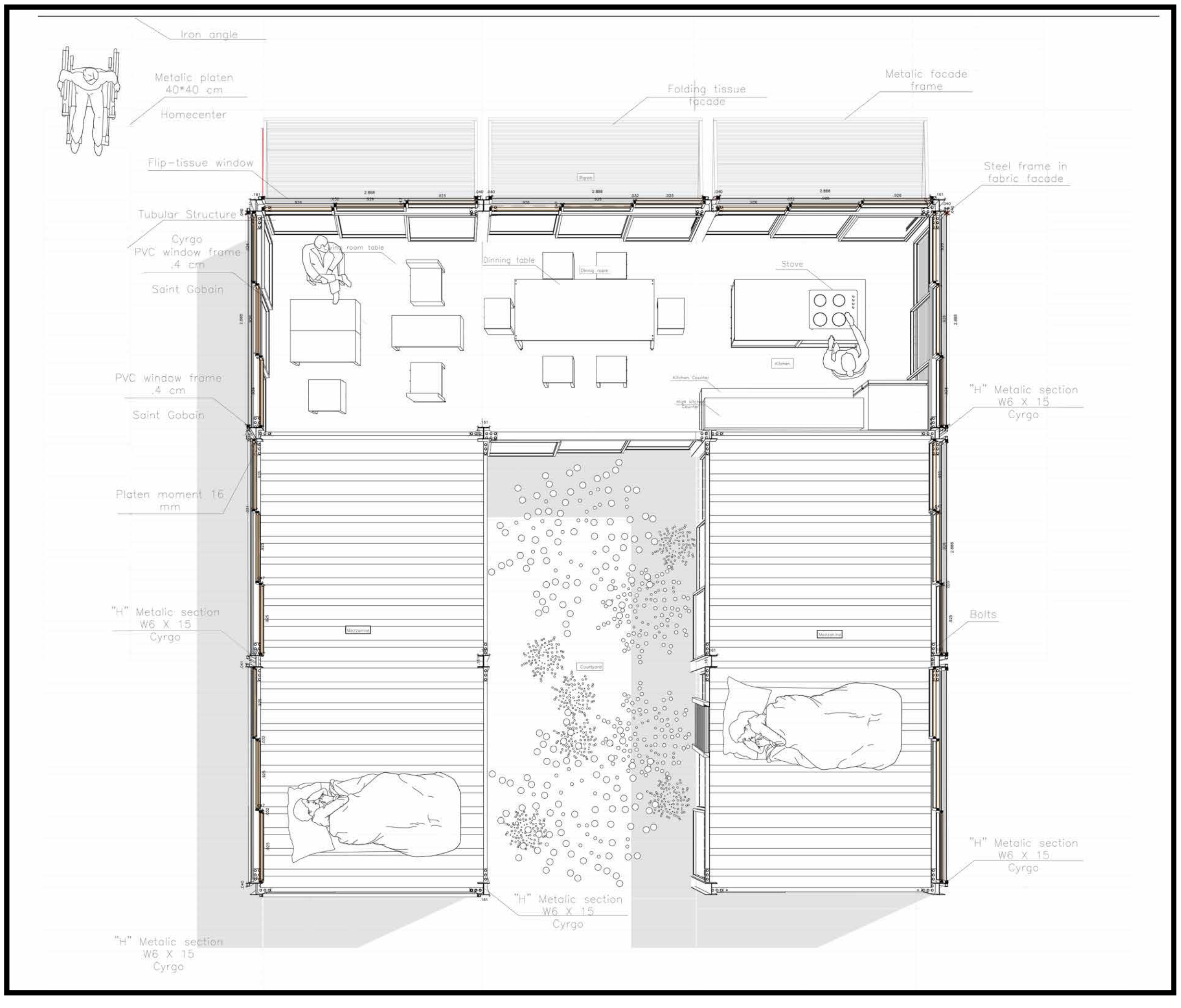
The *Vivienda Solar* uses passive technologies for ventilation, heating and cooling of the rooms through the correct configuration of the openings that favour the exploitation of the prevailing wind and the most correct orientation of the facades according to the exposure to sunlight.

The energy needs are satisfied by 10 photovoltaic panels placed in the south-east part of the house, precisely on the fixed roof of the social area. The need for hot water is guaranteed by 5 prototype panels of the PEI energy team that act as solar collectors and do not require electricity for operation. These panels occupy an area of 9 m2.

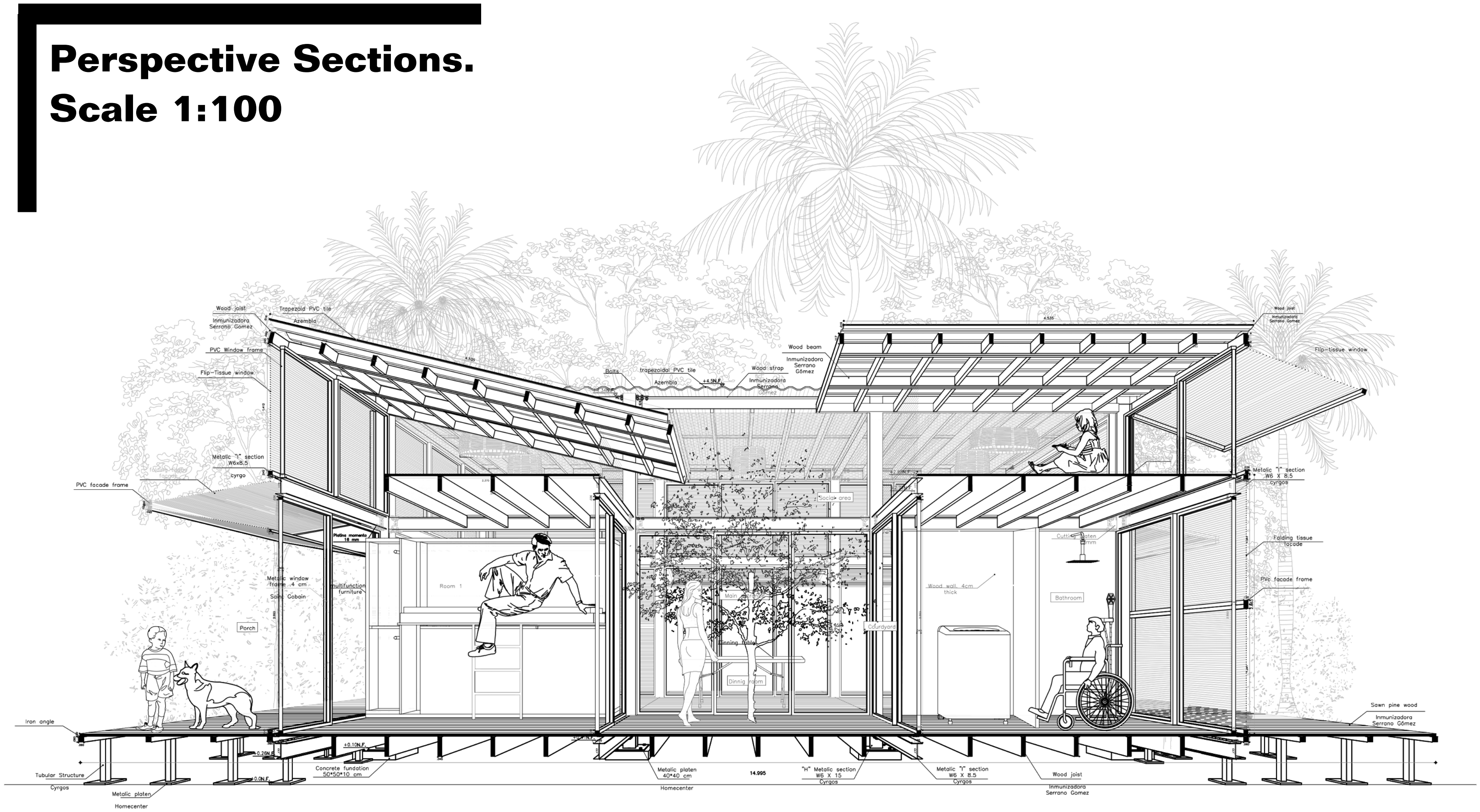
Perspective Sections. Scale 1:100

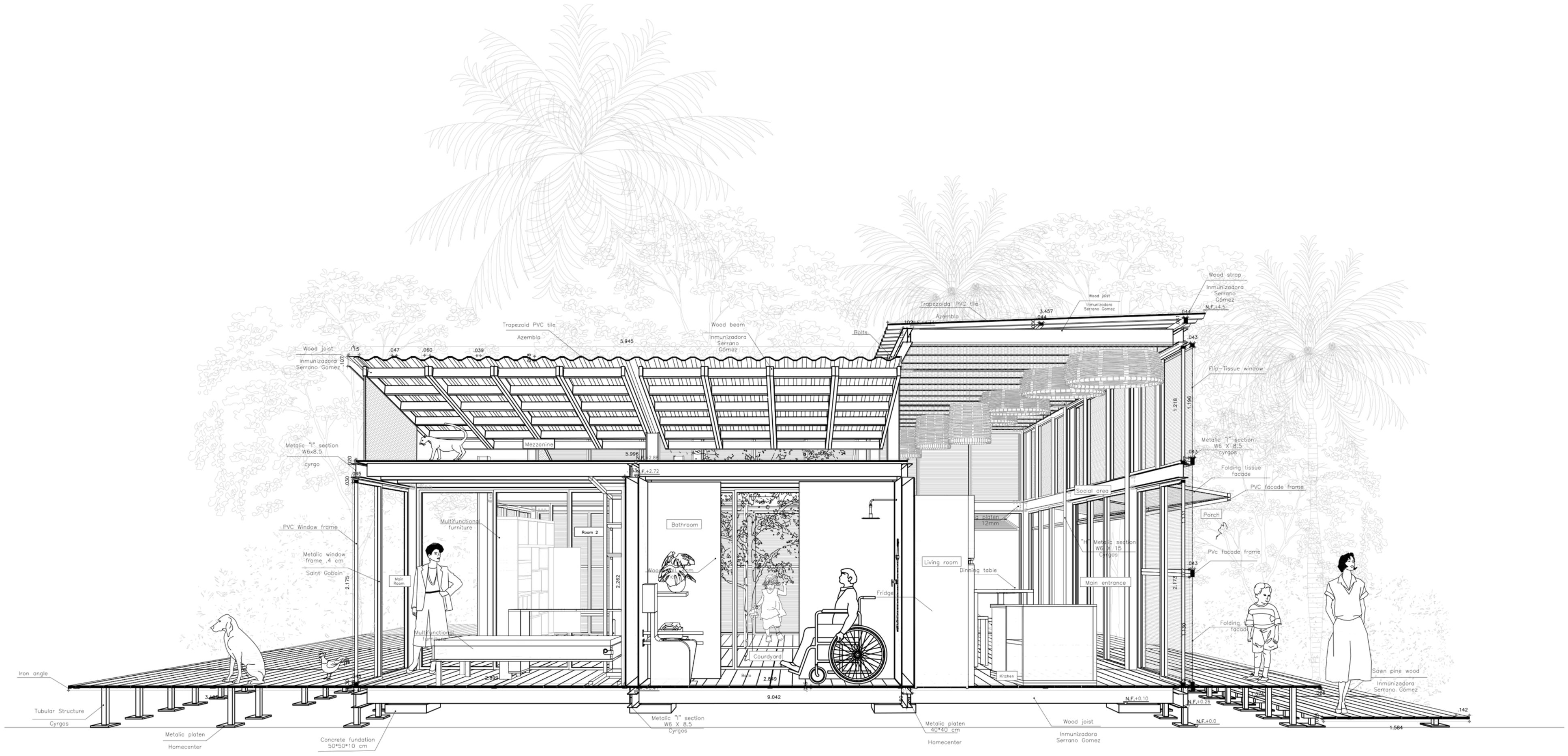
the drawings made by the students of the PEI team - extrapolated from the project drawings shared between the students who compose the Solar Decathlon team.





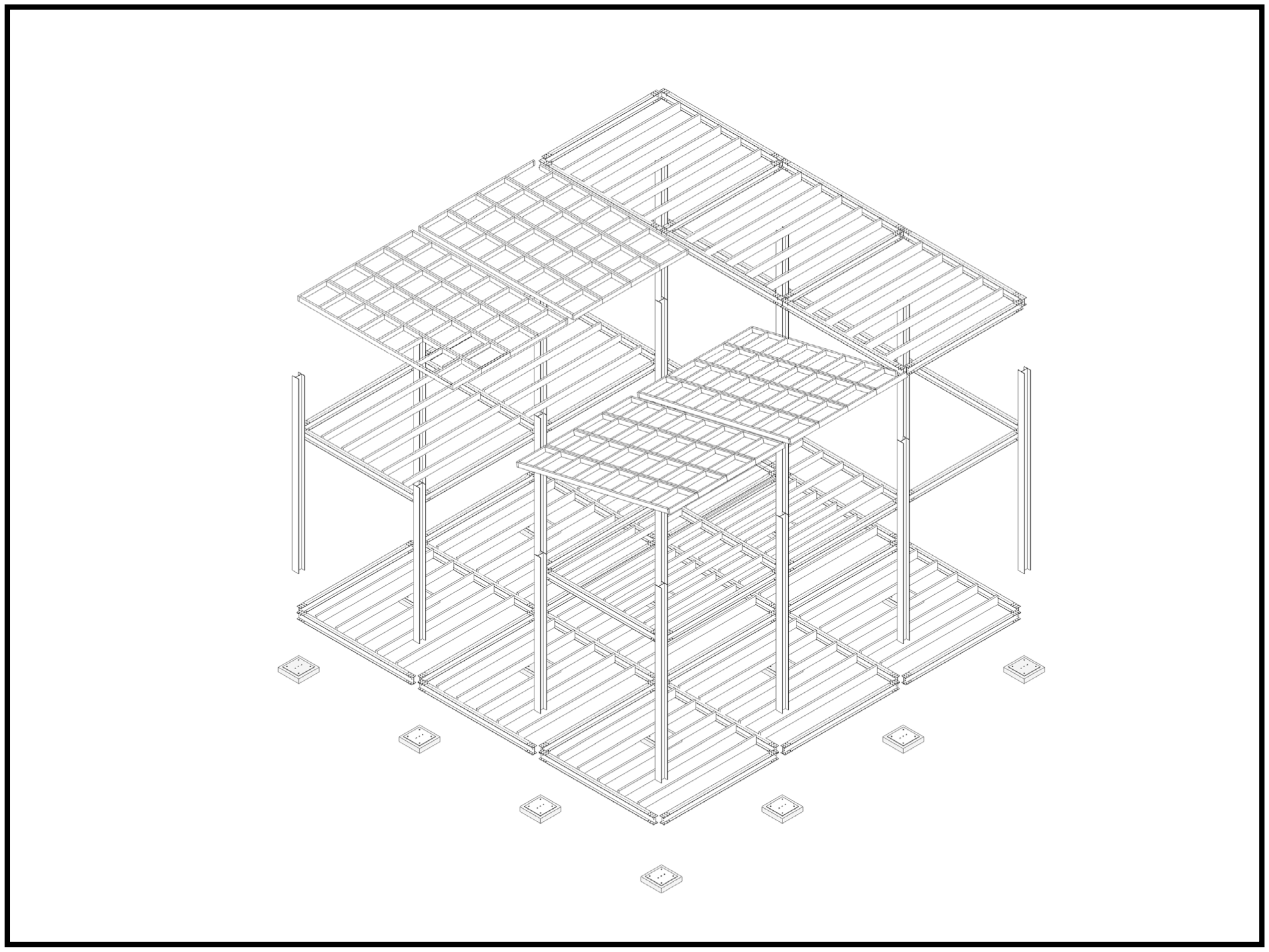
Perspective Sections.
Scale 1:100

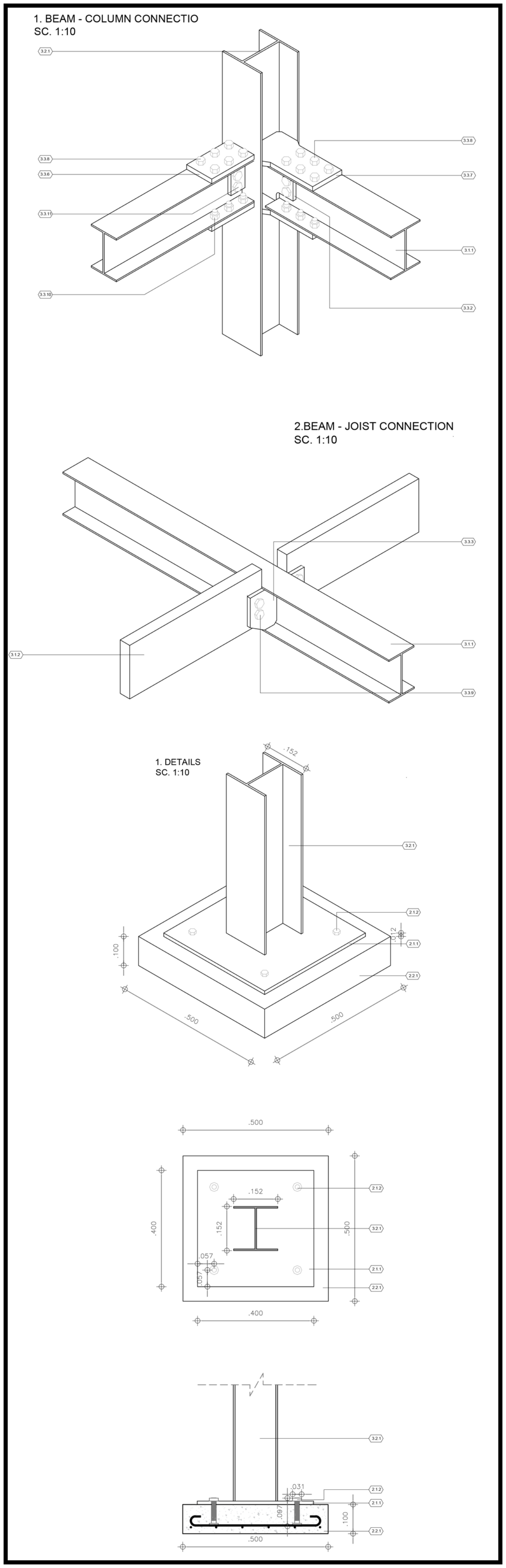




Details of all structural joints.
Scale 1:20
Structural Exploded View.

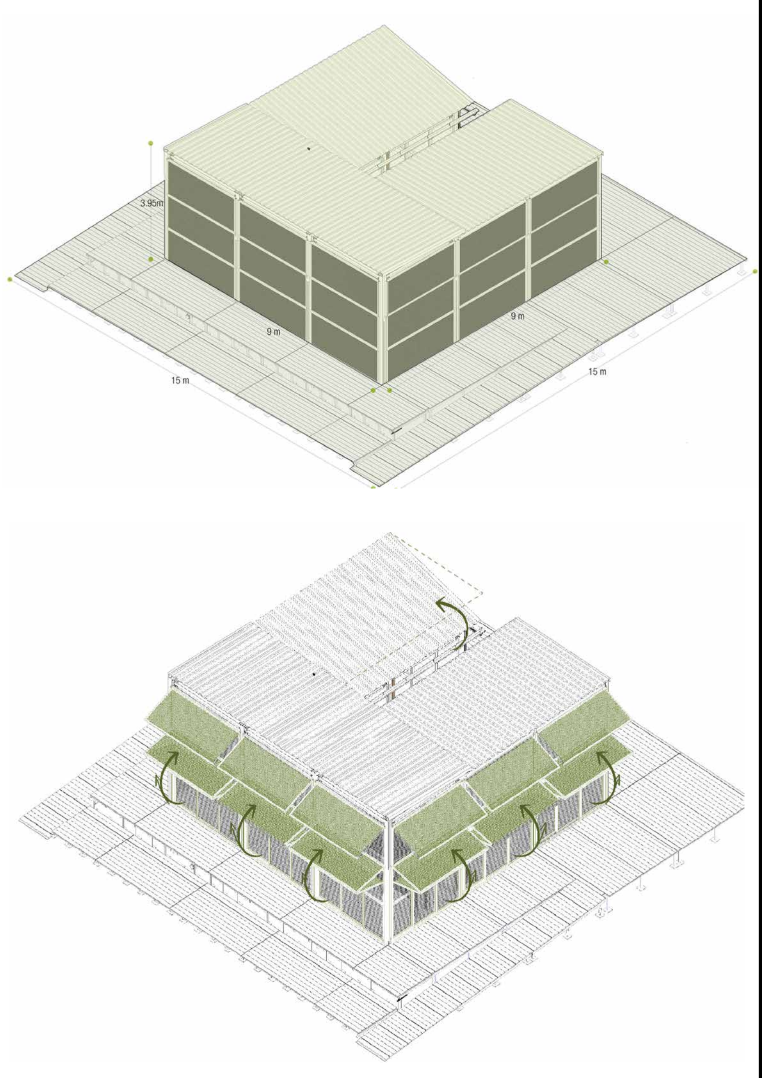
The project consists of a modular grid in which the chosen profiles allow to lower the weight of the structure and, at the same time, to increase the light between the pillars (reaching a distance of 2.95 meters).
The structure is supported by 16 surface foundation slabs (0.5*0.5 m), anchored to the columns by four ¾" bolts. The project foresees two types of metal profiles (W6*8.5 and W6*16) corresponding to a square column of about 0.15 m side. The joints are established at the moment of cutting and bending to adjust the beams and columns. The joists are made of wood (0.15*0.10 metres), adjusted in bending moment to the beams. The housing of the secondary structure is divided into three horizontal parts, determined by the variation in height.
The first corresponds to the elevation of the house (the deck is 0.5 meters above the ground). The second height is the housing of the mezzanine beams and the third is the roof structure. On the ceiling, there are two different systems: a mobile one, in the two side wings where the mezzanine is provided. This makes it possible to increase the volumes of the mezzanine as needed. The second, above the social space, as a per manent double height system.

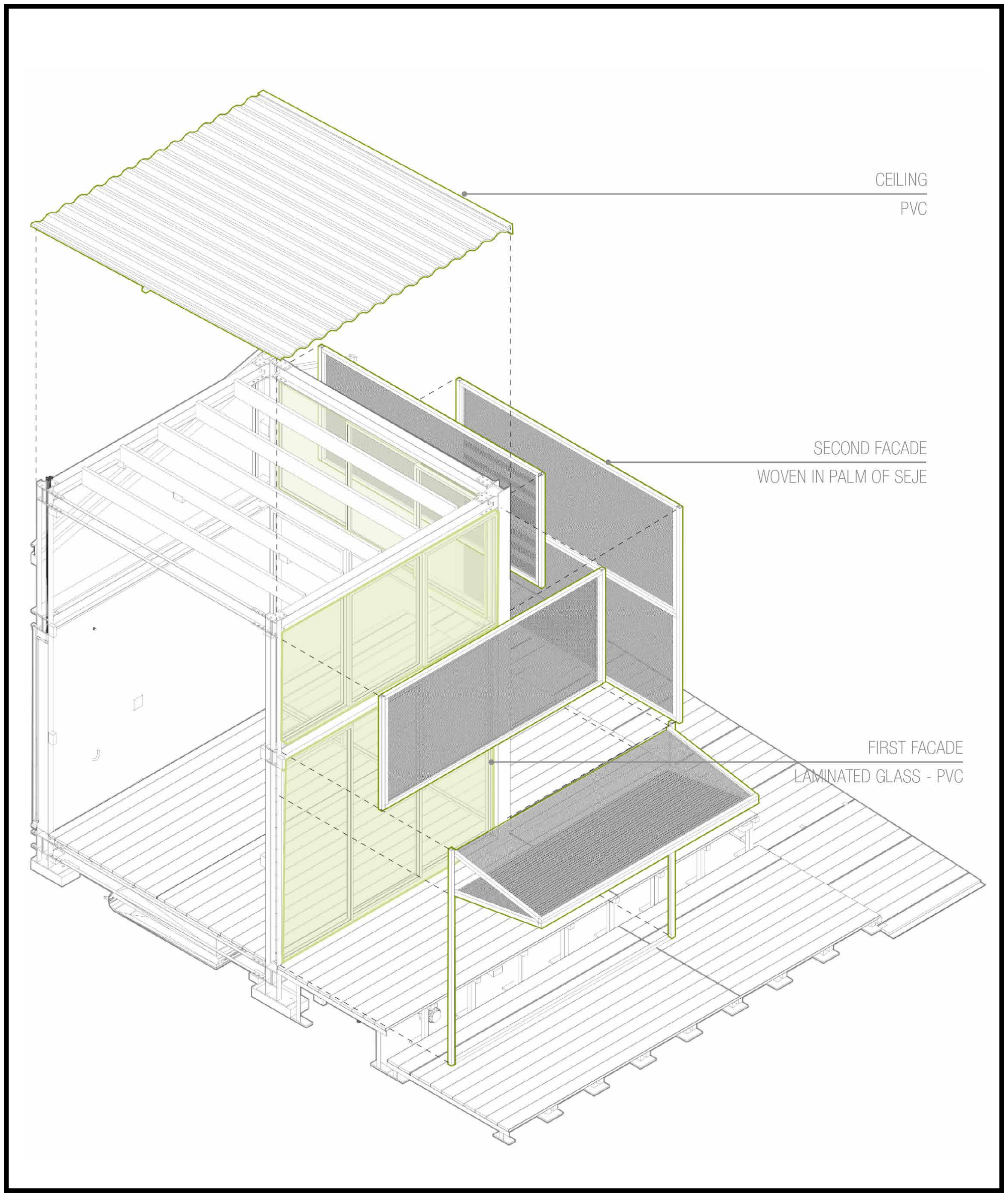




Axonometric explosion of the facade. Off-scale

The facades of the prototype of the Vivienda are covered internally with sliding windows and externally protected by shutters. These shutters are divided into three modules that determine the frame and have the size between the pillars. The lower part of the house has the first two frames connected with welded hinges in the central position. The upper part of the house is covered with a single rectangular module hinged to the structure in the upper part. To these frames are attached mats made of a fabric typical of the Caribbean region, the *Palma de Seje*. The composition of these textiles requires a great deal of labour. In this way, an attempt is made to combine industrial production with traditional handicrafts, generating a visible social value for the façades. The opening of these vertical parts allows the patio to expand, mixing the exterior with the interior.





the drawings made by the students of the PEI team - extrapolated from the project drawings shared between the students who compose the Solar Decathlon team.

The sanitary project

Preliminary approach through EDGE software for the Vivienda water consumption

For Maquina Verde, the question of saving resources was fundamental. One of the main objectives of the project was to save and reuse water inside the house.

The international EDGE (Excellence in Design for Greater Efficiencies) certification was examined in order to understand the consumption limits necessary to achieve a consistent result with respect to the self-imposed objectives of the project idea. EDGE is an innovation of IFC, a member of the World Bank Group, is a green building certification system that aims to make buildings more resource efficient. This enables developers and builders to quickly identify the most cost-effective ways to reduce energy consumption, water consumption and embodied energy of materials. EDGE requires that a building achieves a minimum expected reduction of 20% in energy and water use, and that the embodied energy of the materials is reported compared to a standard building, in order to evaluate the savings in the use of the building's materials. The EDGE software application provides a quick way to determine the optimal combination of building design strategies. Particularly the software has been useful to choose the bathroom equipment and to evaluate their efficiency in the technical data sheets. All the accessories used for the bathroom have been selected trying to follow these general directives of the project.

The main supplier was CORONA, as it offered the best products on the Colombian market, meeting the budget availability and the required efficiencies. The project[7] includes products aimed at a resposible use of water such as dry water closet and faucets with flow regulators, improved by aerators to reduce the use of water with the addition of air, that increases the water pressure at a given flow rate. Below are showed the values entered within the EDGE software used in the project compared with the efficiency standards to reach 20% of water savings:

- Low-flow Showerheads: 6,37 L/min

Saving is achieved because the base flow rate is 7,3 L/min

- Low-flow Faucets for Kitchen Sinks: 5,7 L/min

Saving is achieved because the base flow rate is 5,7 L/min

- Low-flow Faucets in All Bathroom: 4,5 L/min

Saving is achieved because the base flow rate is 5,7 L/min

- Single Flush for Water Closets: 0 L/flush

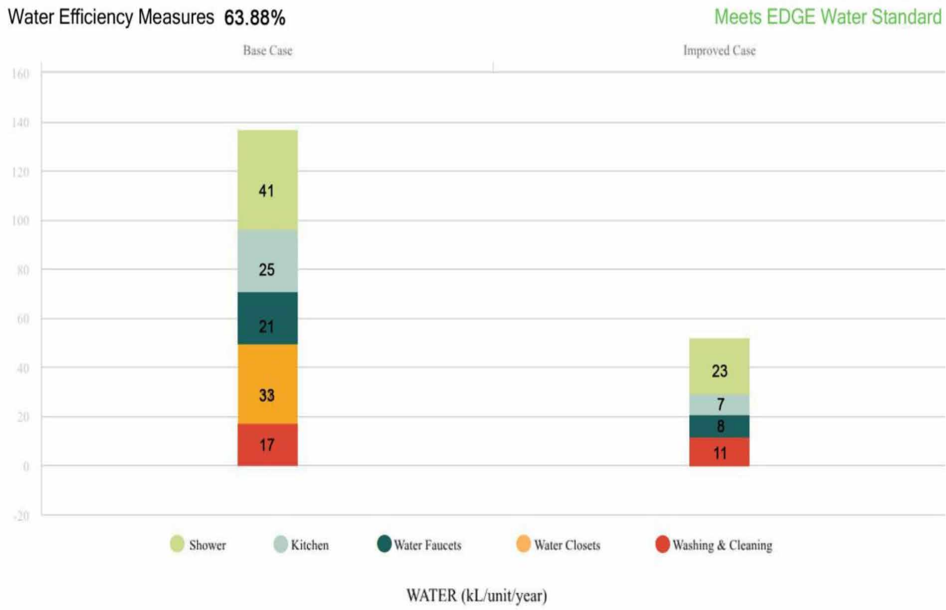
Saving is achieved because the base flush rate is 3,8 L/flush

- Rainwater harvesting System: 62,01%

Saving is achieved because the base percentage is 50%.

These technologies meet EDGE water standards with a 63,88% (FIG.2). The final water use is 4,10 kL/Month/unit and a saving of 87,10 m^3/year in ensured.

Water savings



[7] The plumbing project of the house shows our full collaboration with the hydraulic team of the *Pontificia Universidad Javeriana* of Bogota composed by the students: Ana Calle, Lina Sanabria and Andrés Pérez.

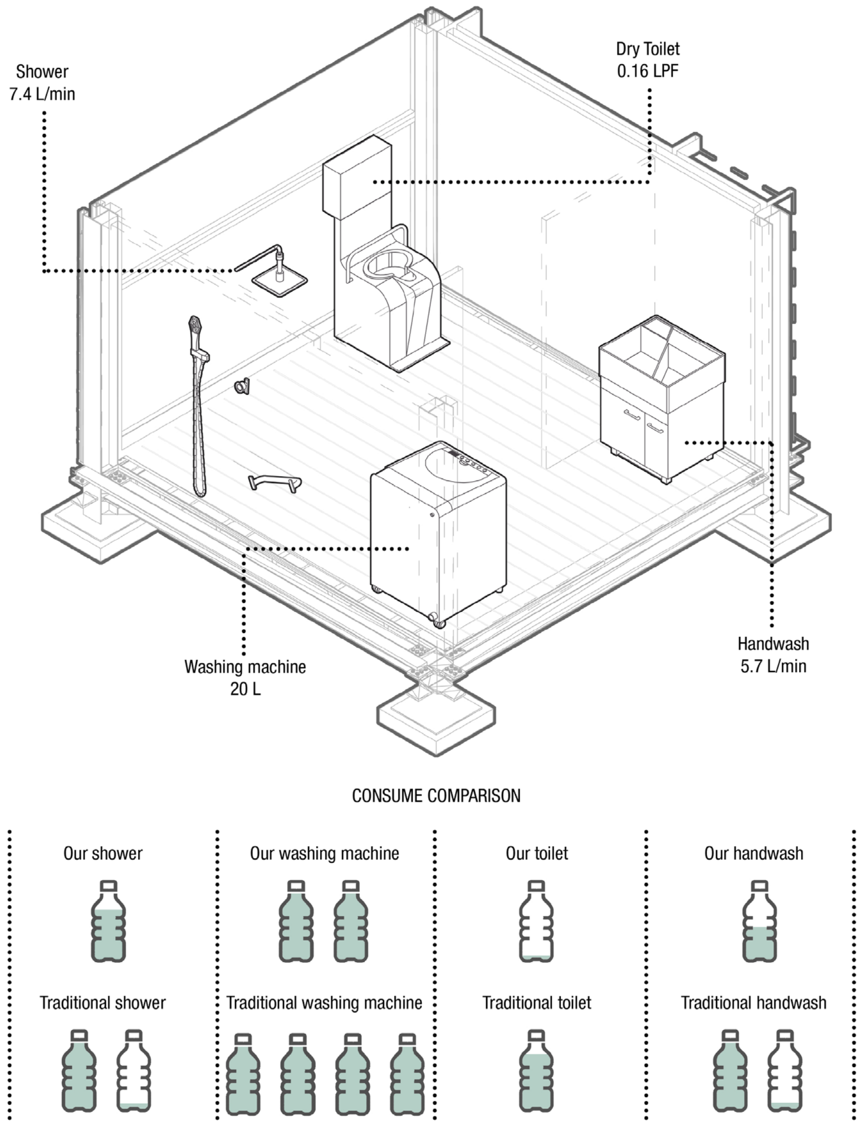
[8]Vivienda's hydraulic system was supported by specialists in the field of hydraulic engineering who were responsible for verifying the correct functioning of the network.
[9]The tanks were produced tailor-made for *Maquina Verde* by Colman. They consist of inflatable tanks with a nominal size of 0.3x0.6x2.5 m, with a volumetric capacity of 250 litres.
[10]The company S2R provided technical support and took care of the capacity of the system, recommended the type and model of electric pump to be used according to the characteristics of the network (electric pump 1/2 Hp 110 V, by the company Pedrollo).

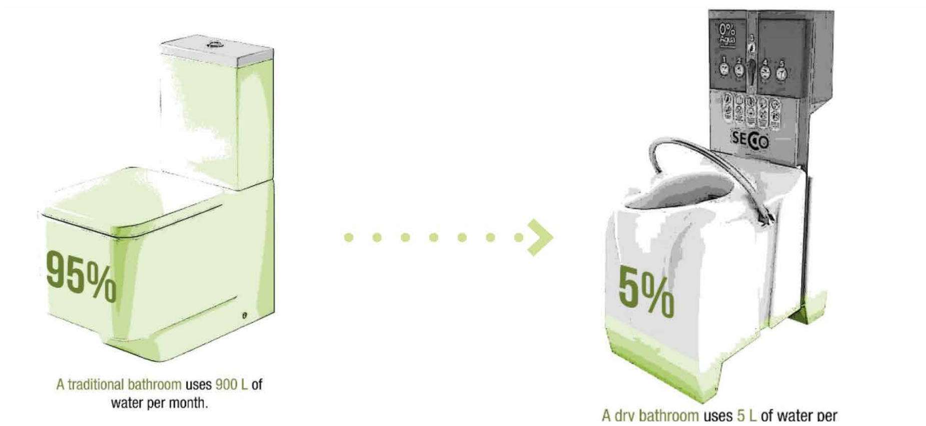
The Plumbing System

The main objective of the plumbing system design is the reuse of water through strategies that reduce consumption and allow a more efficient storage. The correct[8] design in the hydric sector is fundamental to develop a project that is focused on the sustainability and economy of resources. This is not only to gain an advantage from the resources available, but also to reduce the use of the non-renewable ones in an approach more concerned with the planet. The two main sources of the system are potable and rain water. The first was supplied from the aqueduct of Cali to the lot and used for the kitchen sink, the basin, the washing machine and the showerhead. According to the competition rules, there is an emergency potable water tank[9] in case of a problem with the main water supplier. This tank will be placed in the bathroom area beneath the wooden deck so that it does not obstruct any common area and that it is not visible due to aesthetic issues. A bladder tank with specific measures, which ensure the needed capacity, was chosen to minimize the intervention on the ground. The same model of tank is used for the recollection of the gray and rain water. The use of these tanks is supported by two low consumption pumps[10]. The nature of the project allows the proper functioning of even small pumps without compromising the efficiency in terms of pressure and flow rate to be guaranteed in the piping system for proper functioning of the elements installed in the bathroom and outside the house. The first pump connected to the potable water tank serves the bathroom elements and the valve installed to fill the small tank in the kitchen, and also pushes the water up to the rooftop where the water heating system is located. The second one is connected to the grey water tank to pump water to a tap outside the house. The piping system is supplied by the company PAVCO and is made of PVC. This choice was considered for the simplicity during the design phase and the simplicity during the installation on site because of the low weight and the possibility to vary during the work. Each function within the system provides a different diameter of pipe strictly related to the pressure to be maintained during the path. The water is supplied by the project site with a pressure of 10 meters of water column with a pipe section of 1/2". The pump selected to maintain this pressure has a 1" inlet and outlet.

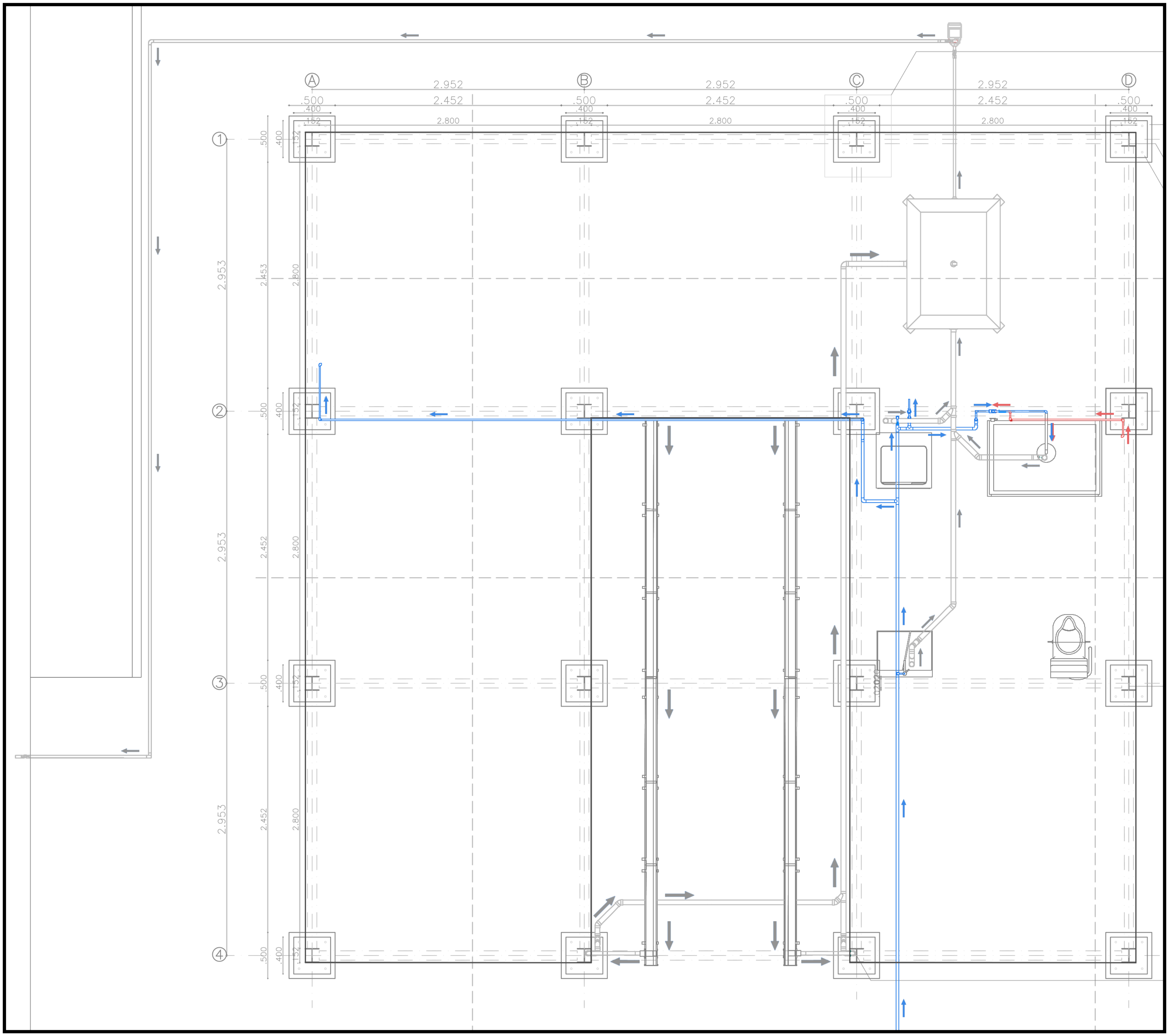
Therefore, the main pipes of the drinking water system maintain this section in the distribution and are halved once they reach the final elements. The waste water system that starts from the bathroom elements such as the sink, the shower and the washing machine have pipes with a diameter of 2" and include siphons to prevent the return of water. At these points, the selected siphons are equipped with a cap to ensure the purging of collected solid elements. The gray water cycle includes the water from the shower, the washing machine and the bathroom basin to storage it for the garden irrigation and to clean the house. The kitchen system is indipendent to be able to be moved in different point of the house and it is composed by two small tank that storage the potable water and recollect the residual gray water. Initially for the residual water was designed a system that included filters to be able to purify it and reuse it. Subsequently, however, it was decided to use ecological soaps in the house in order to be able to directly recycle the water for irrigation without the need to filter it. For this reason the tank receives both residual water and rainwater. Rainwater harvesting is a fundamental practice that could increase the water recollected amount that can be used for the plants irrigation and an eventual conventional toilet. Most of the roof's run-off surface is inclined so that the water is optimally directed to the collection systems. Due to the mobile system roof, it was necessary to think of a particular system of gutters for water recollection. It was chosen a product from the catalogue PAVCO: the gutter RAINGO. The roof displacement follows a three module order for each of the four section in which is divided and for this reason the gutter modules are of the same size of the secondary wooden structure in order to follow the progressive displacement of each roof module. A rubber seal is placed within each modules to prevent water form filtering into the interstices. In addition, to allow the movement of the roof, a flexible pipe has been designed to connect the gutters to the downpipes.

By using a dry bath[11], instead of a traditional one, it is possible to reduce the water consumption from 900 liters per person per month, to 5 liters. Furthermore it offers the possibilty to implement in the project a composting cycle, where the residual matter can be used as a fertilizer for the garden. Specifically, the toilet developed by the company SECCO offers the possibility of discharges which do not involve the use of water at all, allowing a 100% savings for the treatment of solid waste. The discharges in this system are made of medium grain size land so that the feces are surrounded by soil to facilitate their decomposition and avoid odors. However, a system of dilution of urine in water could be adapted to the pre-existing system and this would be a way in which the use of gray water can be involved in the discharge process of the toilet. Another incentive point for the choice of the dry bath is the alternative use of the solid waste generated. By excluding water in the process we try not to pollute it to the point that it cannot be reused, thus creating an alternative output to this resource. In the same way solid waste is treated: trying to provide an additional function to the residue trying to make it a resource.
The solid matter from the dry bath becomes a source of minerals that feed the garden, because when mixed with fertilizers they can decompose and turn into composting to feed the plants. Similarly, urine also has two processes that could be beneficial for green areas on site: dissolution in water and then direct irrigation or the fermentation process that neutralizes the biological risk and therefore the best predisposition to be mixed with fertilizers due to the higher mineral load and amount of nutrients compared to solid matter. This vision is a complete alternative to the traditional and linear approach of considering these wastes as useless and therefore dispersed in environments without a precise purpose. The alternative that the project provides instead is more circular than linear, in which attention is paid to conservation rather than disposal, closing the natural circle of life.





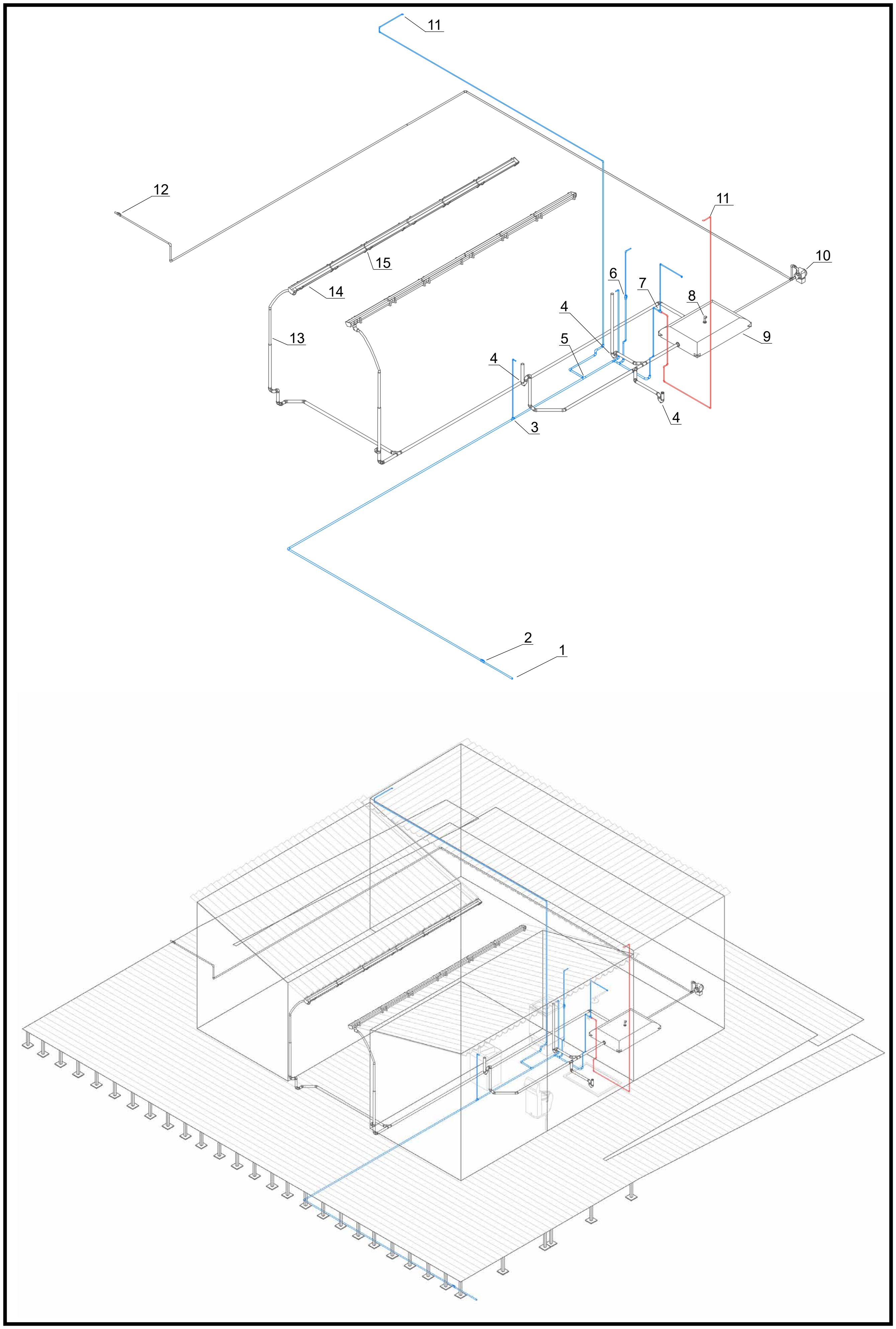
Plumbing System plant.
Scale 1:50



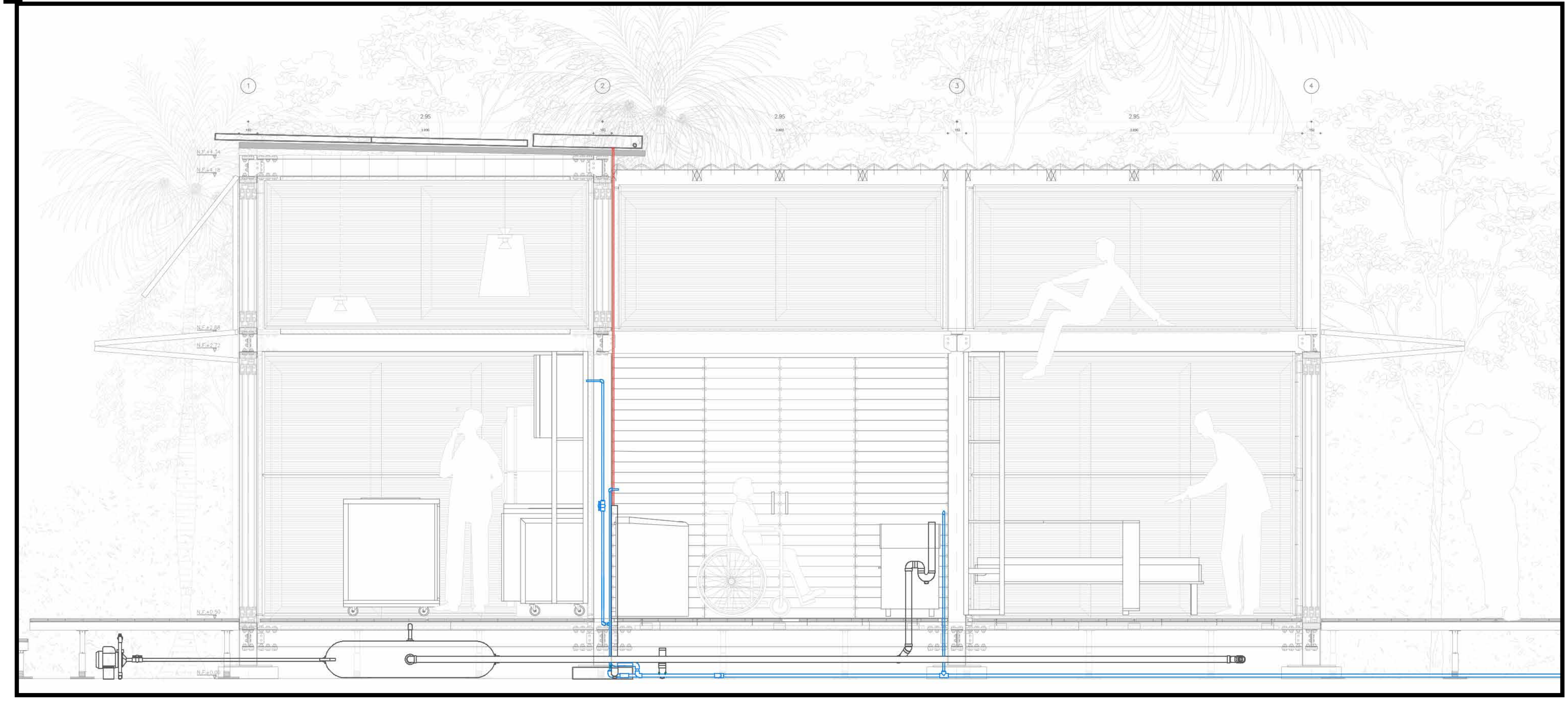
Plumbing System axonometry. Off-scale

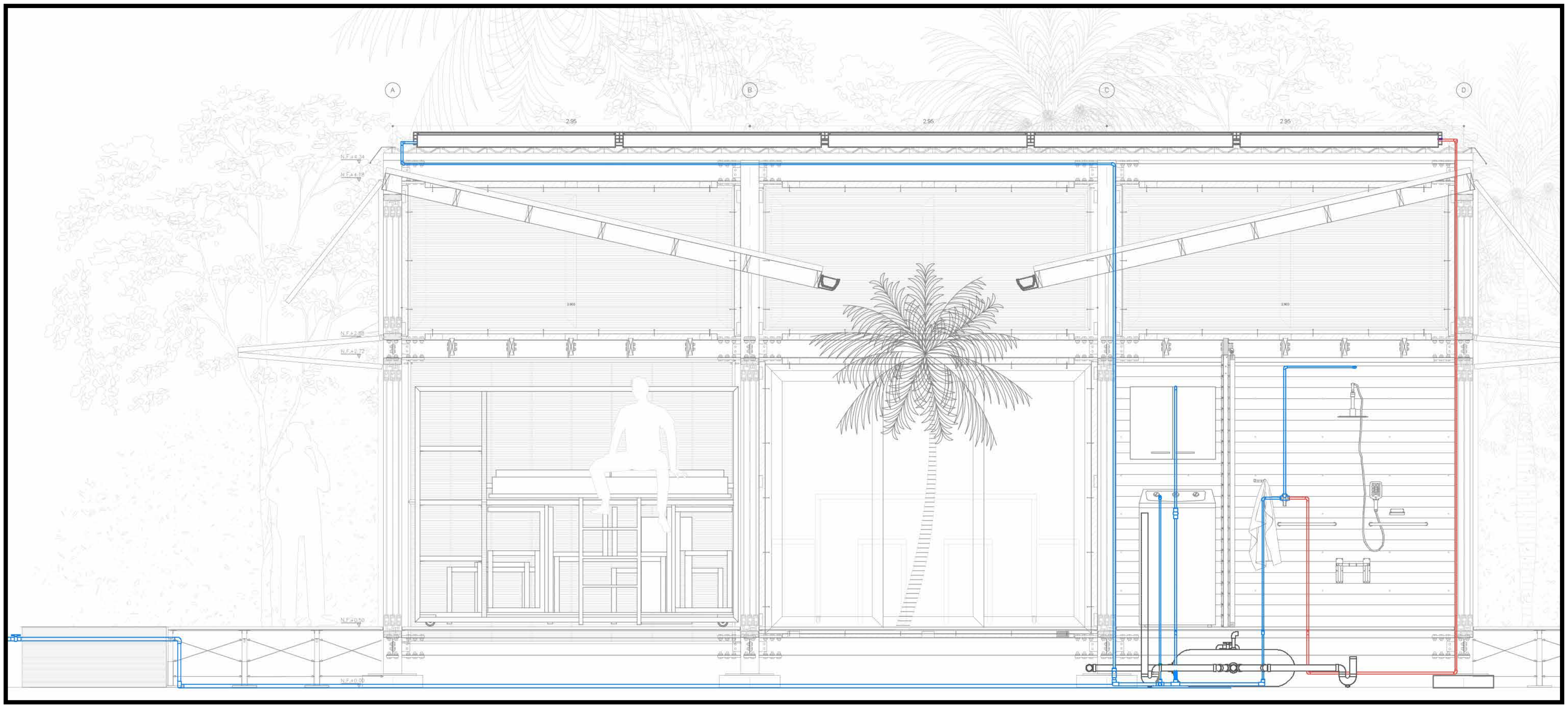
In the design of the hydraulic system:

1. connection to the central hydraulic network of the competition;
2. non-return valve;
3. PAVCO adapter 1” - 1/2” (this adapter is present for the sink, washing machine, kitchen and shower);
4. siphons for residual water (this is present in the sink, washing machine and shower);
5. T-union divides the potable water for the internal equipment of the house and that which serves the solar collectors on the roof;
6. kitchen valve;
7. hot water - cold water mixer;
8. grey water tank breather;
9. grey water tank;
10. electric water pump;
11. water inlet and outlet from the solar collector circuit;
12. grey water outlet valve;
13. telescopic downpipe;
14. mobile gutter;
15. joint between the water infiltration gutter;

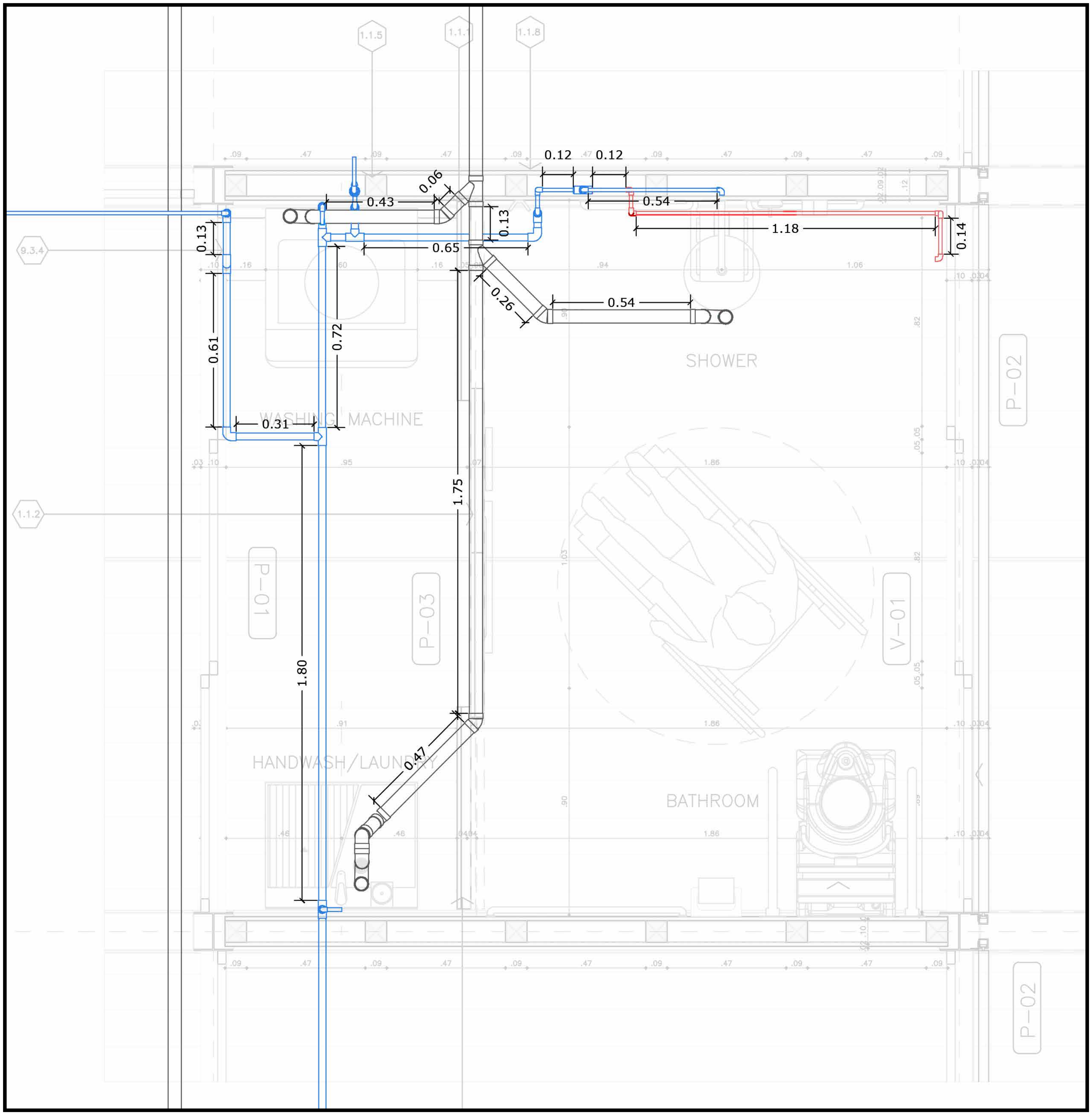


Plumbing System sections. Scale 1:50



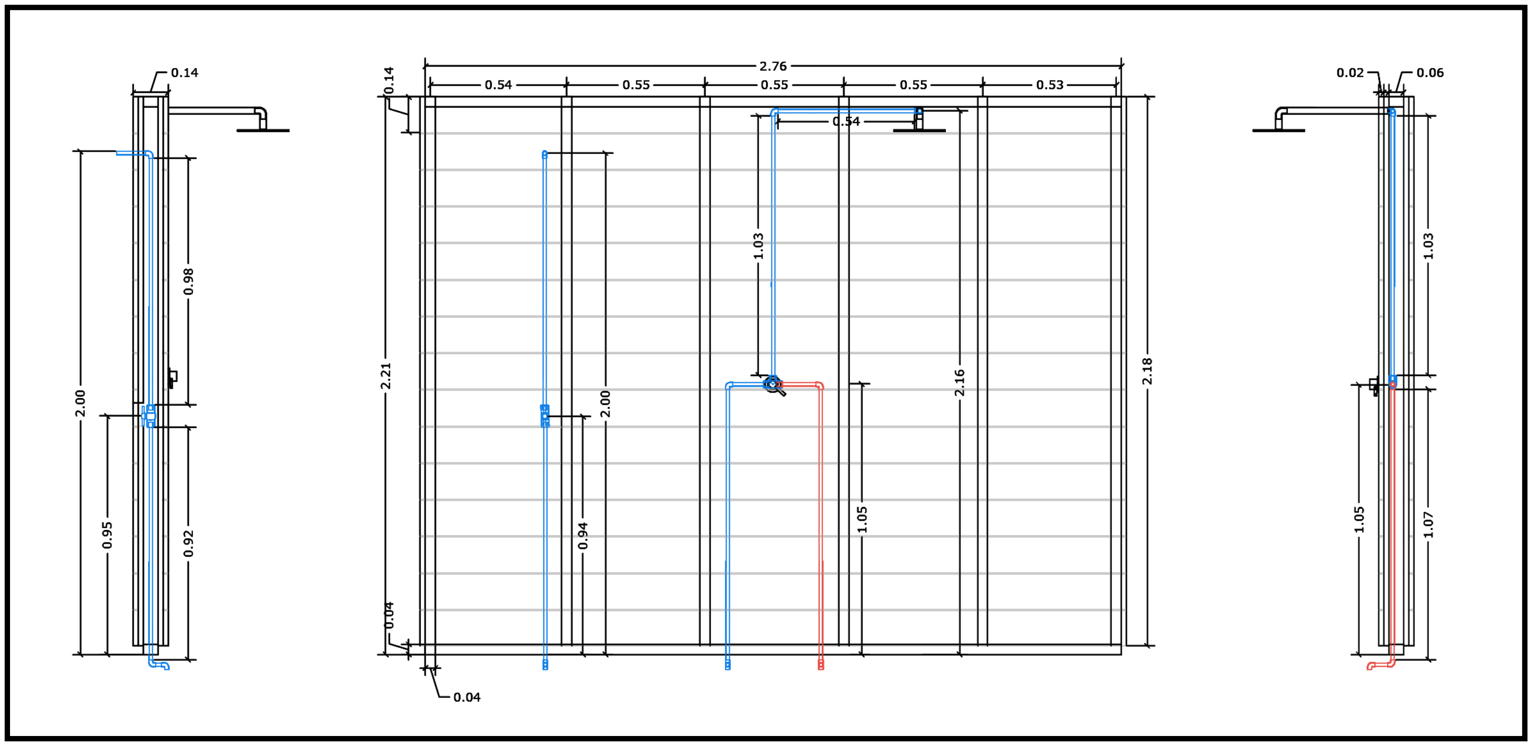


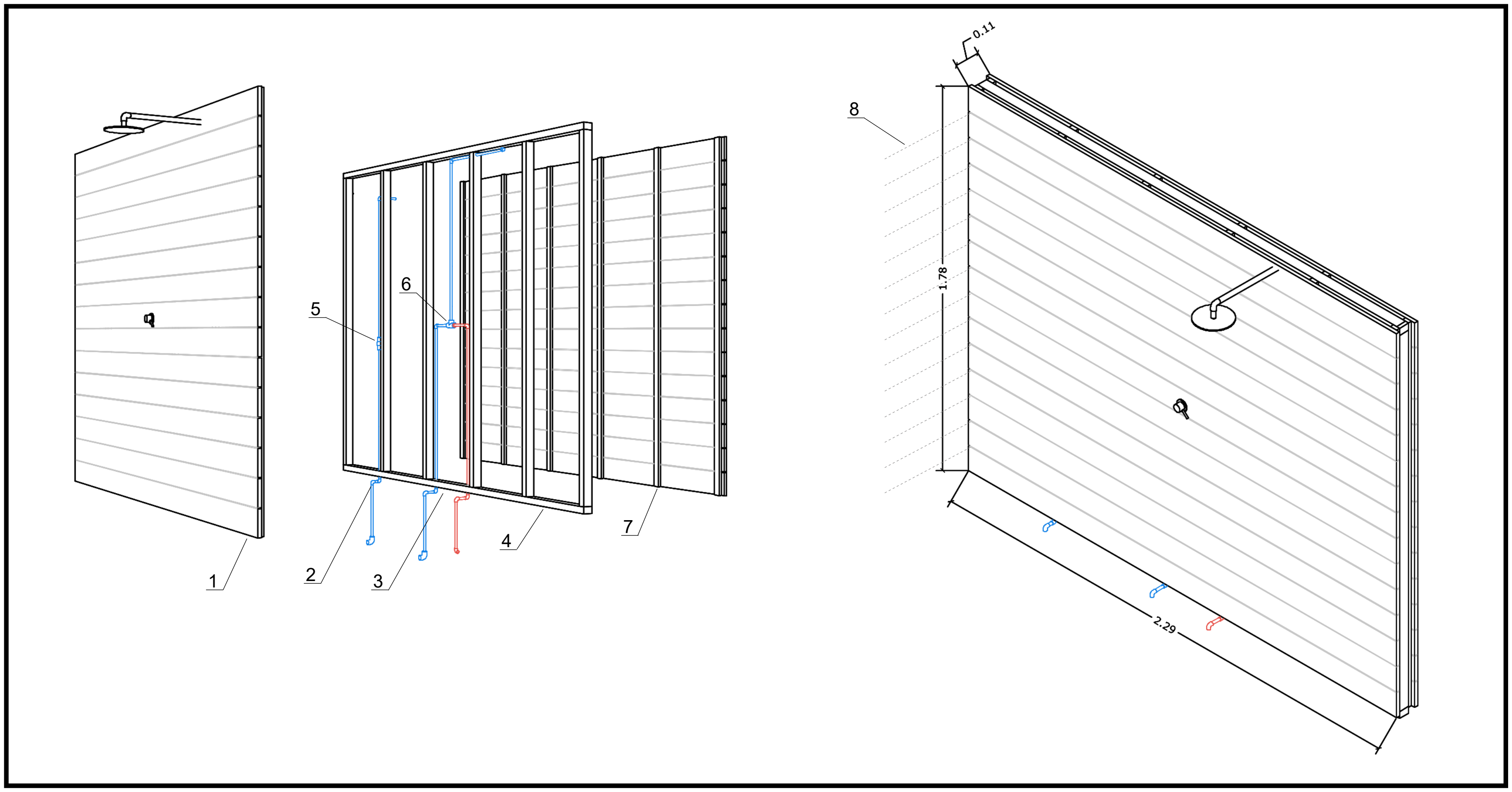
Bathroom Hydraulic plant.
Scale 1:20



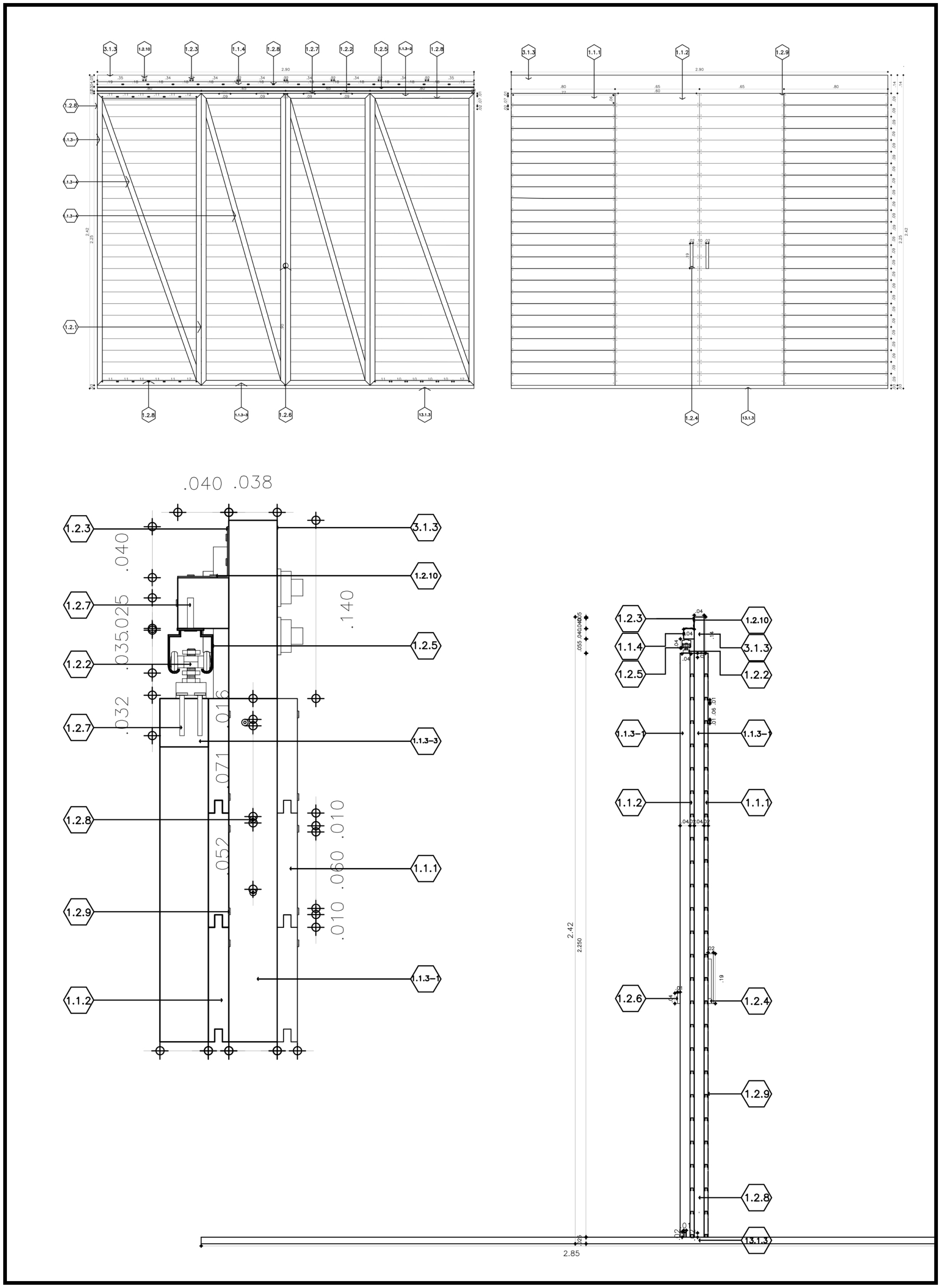
Technical details of the bathroom wall. Scale 1:30

1. wooden panels finishing, internal part of the bathroom (panel size 2x2x14 cm);
2. lower part of the structure hole for kitchen tube passage (1/2”);
3. holes for cold / hot water pipes for the shower (1/2”);
4. internal wall structure;
5. kitchen valve;
6. shower mixer;
7. support structure for wall finishing;
8. fixing with screw of the finish to the structure.





Technical details of the bathroom wall, 1:20 scale



the drawings of this wall were made by the students of the PEI team - extrapolated from the project drawings shared between the students who compose the Solar Decathlon team.

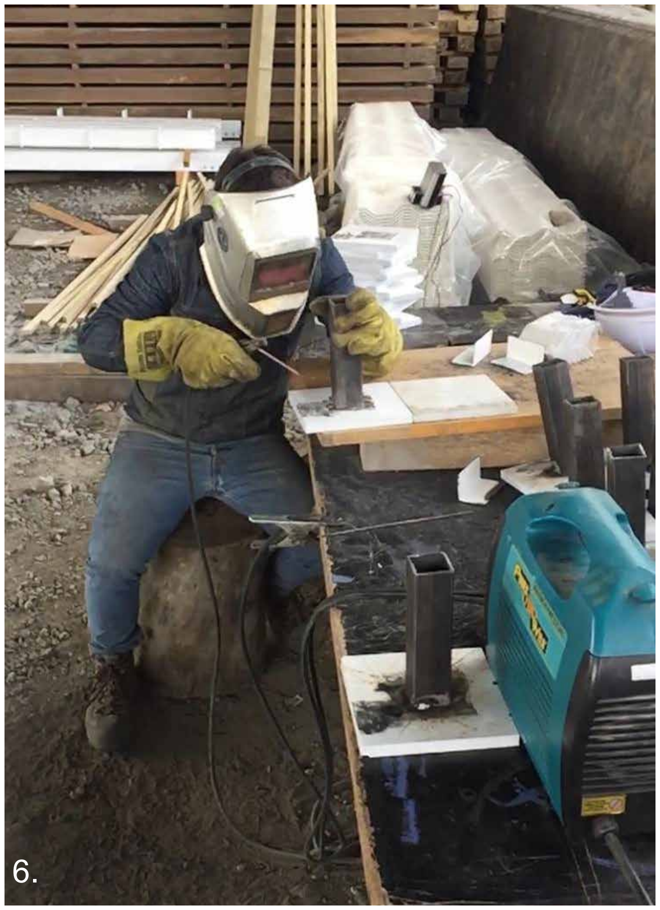
The construction phase: *Colombia e Italia tejen la Maquina Verde*

Phase one: arrival of the construction materials and pre-assembly in Bogotà

The construction phase of the Vivienda of social interest *Maquina Verde* began one month before the start of the international competition of the Solar Decathlon - Latin America and Caribbean 2019 in Santiago de Cali. The arrival of all building materials was scheduled in Bogotà, where the house should have been built and dismantled for a general test before proposing it for the competition. As a place for the pre-assembly, the sponsor company SERRANO GOMEZ had provided a space in their lots where testing could be done. This company also supplied all the wood used for the beams of the secondary structure, the structure of the external pile paving and the panelling of the external and internal deck. This construction element, once cut according to the project dimensions, was immunized with a mixture of Chromium, Copper and Arsenic, a technique used to make the wood more suitable for the construction, avoiding the aggression of insects or wood parasites. The first elements to be ready for testing were the pillars and the steel beams of the main structure, made by ESTHAL. Once the welding work on the plates for anchoring the windows and the painting in white was finished, the structure was ready. A team of volunteers bolted the main structure into two pieces in just one week. Some measures had to be taken on the structure for the anchorage holes of the counterframes and a check on the actual dimensions with respect to the project. At the same time, at the engineering headquarters of the Pontifical University of Javeriana in Bogota, the reinforced concrete plinths for the foundation structure were being formed. The first thing to do was to assemble the plywood formwork and the internal steel grid which was to be electrowelded. The engineering team provided the percentages by weight of the components to form the concrete to be inserted in the formworks. The 16 plinths had to spend at least two weeks drying. The work after the assembly of the structure concerns the pre-assembly of the wooden deck modules, the sanding and the painting layer. In addition, the 12 modules of the wooden deck structure of the mobile roofs and the stairs for the access to the mezzanine were built. At the same time the 180 feet of the outer deck structure were welded; cutting square steel profiles, grinding the square bases and then electrically welding the two parts. These feet had to contain the wooden battens of the deck, it was too difficult a job to do under the heat of the Cali sun, so it was preferred to pre-assemble them. Another element pre-assembled in Bogotà was all the windows and doors - arrived separated by the glass - which was too delicate, as it needed more space than the Cali site envisaged. This phase of verification took two weeks, in the following week it was planned to disassemble the various parts built. Finally, one week before the start of the competition, all the materials of the house were placed on two containers, heading towards Santiago of Cali.

1. first foundation plinth freed from the formwork ready for hardening;
2. preparation of foundation plinths from raw material to forming. Once the parts were mixed to form the concrete in the concrete mixer, it was placed inside the formworks and then through vibrations the mixture was made uniform.
3. first part of the supporting structure mounted by the group of volunteers in the Serrano Gomez immunizer in Bogotà.
4. second portion of structure mounted.
5. two volunteers from Serrano Gomez's company showing how to form the deck finishing modules.

6. the project manager of the Maquina Verde, who is working on the electrowelding of the steel feet of the deck's external structure.
7. positioning of the secondary wooden structure.
8. positioning of the counterframe of the internal windows and the structure of the bathroom-kitchen wall.
9. Once the deck finish modules were ready, they were all sanded and painted with the selected coat.
10. assembly of windows and glass frames.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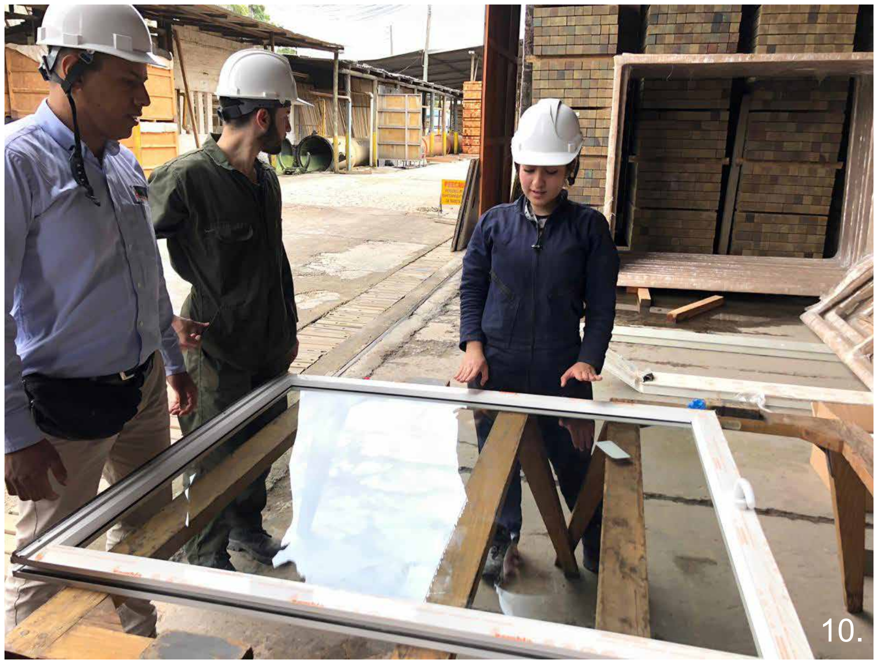
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Phase two: construction of the *Vivienda Solar* in *Santiago de Cali*

The construction phase during the Solar Decathlon - Latin America and Caribbean competition lasted a total of two weeks. During this time the team was divided into three groups of 12 people and worked on the construction site alternating so as never to stop the construction phase. The teams were uniform, guaranteeing at least one component per project theme. The project themes were the teams into which the students were divided during the design phase: communication, furniture, structure, energy, windows, sanitary, roof and floors, architectural design, sustainability and site management. All the members of the different groups were specialised in their own theme and guaranteed its correct development, but in the implementation phase everyone was in charge of what the building site programme envisaged.

The first thing to do was to unload the elements of the house from the container into the residual space of the lot that the competition had allocated to each team. In addition, each team had the availability of a sheltered environment for the more delicate elements that could not resist the weather such as the electrical equipment installed for last. The main structure was completely dry and pre-built, making it quick to set up and avoiding the use of cranes on site. Once the structure was built, the units started working on several fronts in parallel. The energy group immediately started working on the electrical system, one of the most difficult and time-consuming tasks on this site as it was necessary to weld the metal boxes of the lighting system, anchor the pipes containing the electrical wires to the secondary beams, before positioning the flooring. On the other side of the worksite, the wooden external structure of the deck was being constructed, which during the construction site had some changes from the project, when the timing was reduced for the work that the *Piso Techo* group initially proposed with the "L" section metal profiles. Used successively for the handrail. The hydraulic project during the construction phase received the support of some external figures, for the correct installation of the different pipes and for the positioning of the electric pumps and tanks. Initially, the project involved two tanks, one for drinking water and one for wastewater and rainwater. These tanks were an innovative prototype, consisting of an inflatable tank. This was chosen because of its size, as it could be installed under the wooden beam structure, eliminating the need to dig or place it in sight. During the construction site, however, the drinking water tank exploded. Therefore, during the central phase of the construction site, it was essential to modify the hydraulic network by overcoming the collection of drinking water by sending water to the bathroom equipment directly from the central network. So the drinking water tank and the electric pump that served it were eliminated. Once the plastic sheets of the roof were finished, the rainwater collection system was positioned. This element designed on site included a telescopic downpipe consisting of two pipes of different diameters (2" and 1.5"). The smaller of the two was connected with a hose directly attached to the end of the mobile downpipe. The purpose of this system is to guarantee the collection of rainwater in the different positions that the two mobile roofs assume. Placed the interior floor of the house, were built the bathroom walls and the installation of various bathroom, kitchen and bedroom furniture.The building site experience was difficult, but with the correct organization had by the team the house was completed in the expected time. The Maquina Verde housing module received 7 of the 10 prizes up for grabs during the competition: 2 first prizes in the "Engineering & Construction" and "Urban Design & Affordability" categories, 4 second prizes in the "Architecture", "Innovation", "Energy efficiency", "Energy consumption" categories and a third prize in "Communication, marketing and social awareness". In addition, the team was awarded the second overall prize in the Solar Decathlon - Latin America and Caribbean 2019.

11. *Maquina Verde* team. The team of 40 students from the Pontifica *Universidad Javeriana* in Bogota was led by professor Carlos Correa Hernandez, supported by professors Juan Carlos Cuberos and Bucheli Agualimpia and the project manager Sebastian Rojas.
12. the support team of the *Politecnico di Torino* that helped the Colombian team to complete the project. The team was led by professors Roberto Giordano and Lorenzo Savio, supported by doctoral student Monica Alexandra Munoz Veloza and students Juliana Jimenez Camacho, Andrés Cruz, Maria Caterina Dadati, Marco D'Amico, Federica Gallina and Benedetta Quaglio.

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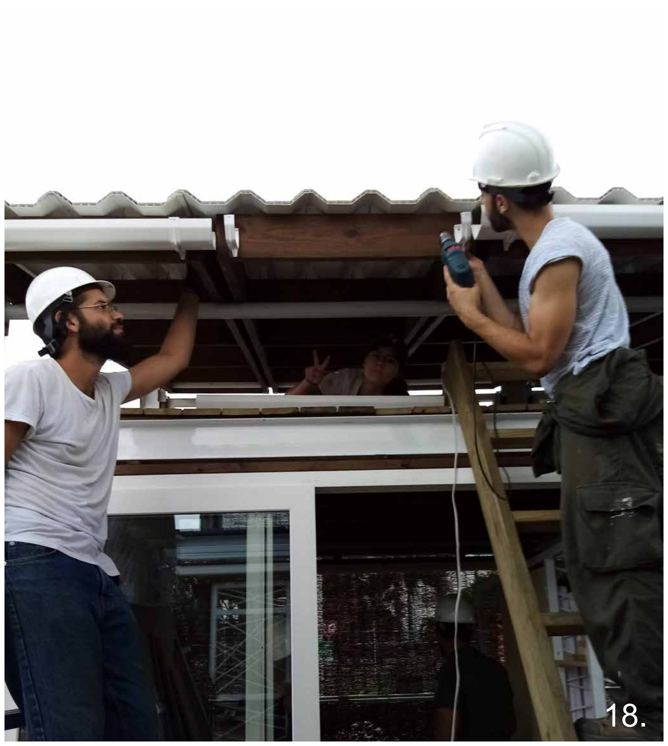
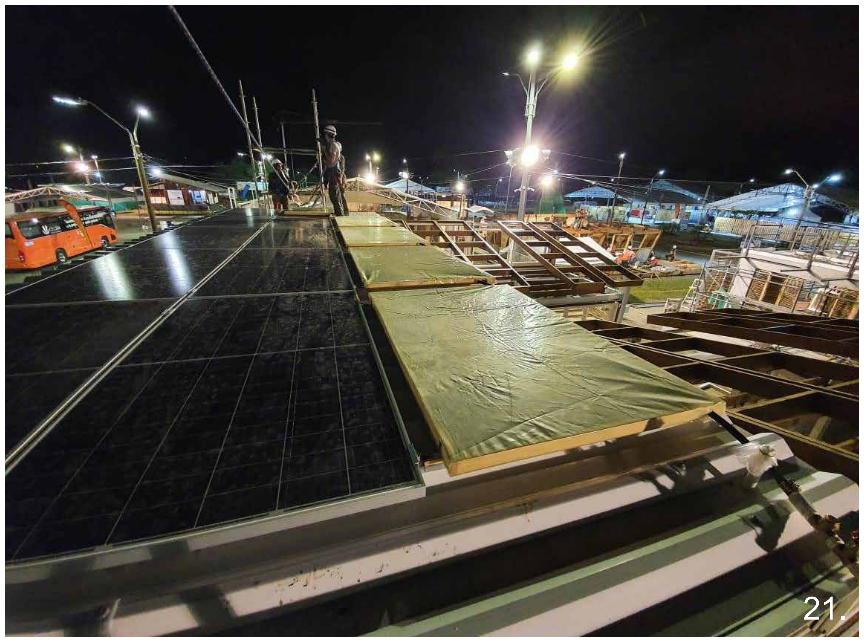

18.

13. union of foundation structure between plinth and pillar and between pillar and beam.
14. works on the upper main structure, hooking the beams.
15. evening work on the positioning of the secondary foundation structure and the positioning of the wooden structure of the outer deck.
16. shifting the internal painted surface of the bathroom.
17. positioning of the wooden support structure of the mobile roof.
18. anchoring the module supports of the gutter modules to the mobile roof structure.

19. adaptation by sawing of the deck to the main structure.
20. assembly of the first window frame in Palma of Seje and function test.
21. positioning of photovoltaic panels and prototypes of solar collectors on the roof of the *Vivienda* social area.
22. the sanitation team during the net placement.
23. first mounted bathroom wall.



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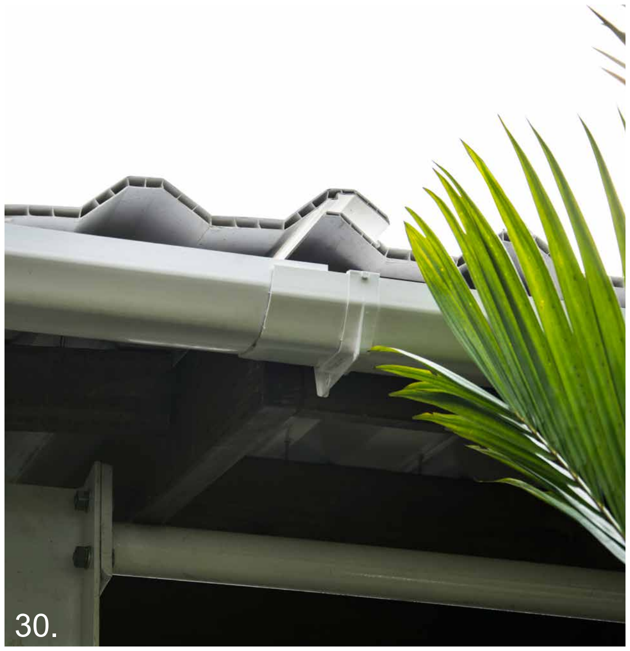
24. the double height of the social area of the house.
25. wall and ceiling lighting in the common area.
26. living area.
27. bedroom furniture.
28. interior dimensions without furniture in the house.

29. particular technologist of the roof system.
30. detail of the joining point of the modules on the rear movable roof.
31. mobile rainwater harvesting system.
32. structure to raise the roof and add volume to the mezzanine.
33. Mezzanine view.

29.



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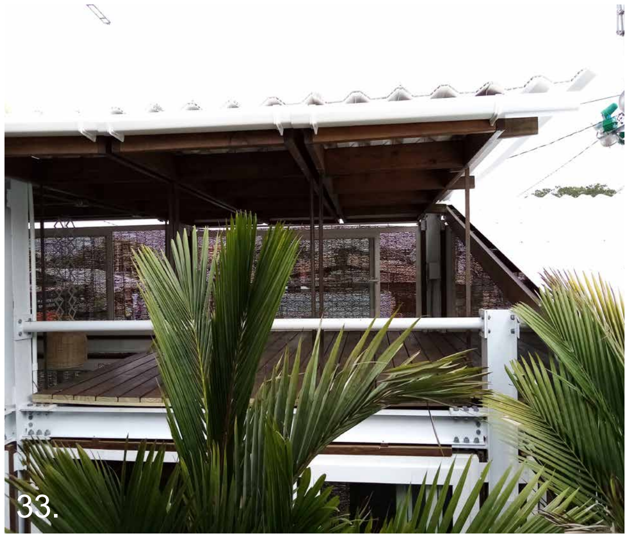

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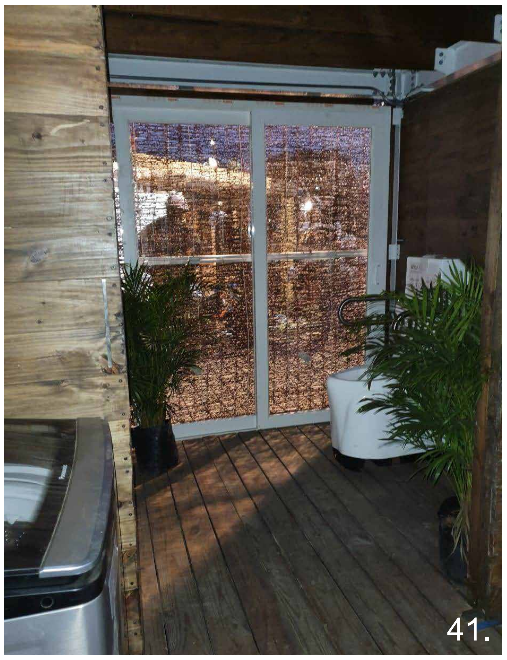
34. the side elevation of the *Vivienda* from the garden.
35. back of the house
36. from a bird's-eye view on the patio.
37. fully enclosed and fully open shutter system.
38. the Palma of Seje.
39. particular about the mezzanine shading system.

40. detail bathroom furniture: the sink.
41. access to the bathroom
42. the water closet SECCO.
43. the shower.

40.



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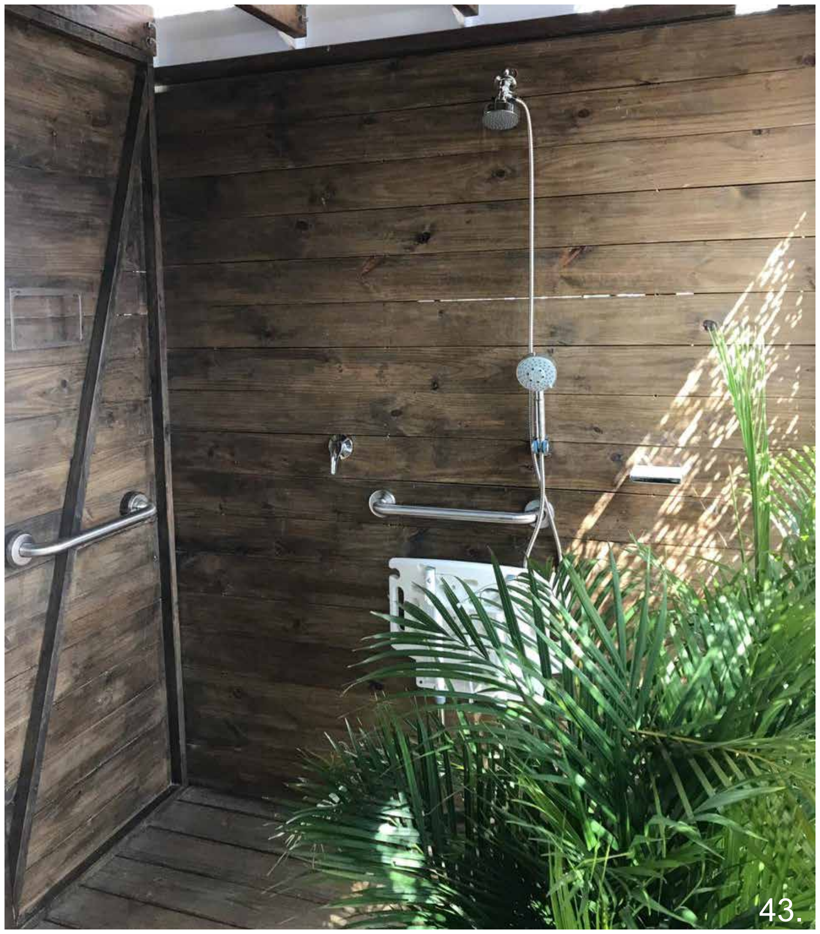

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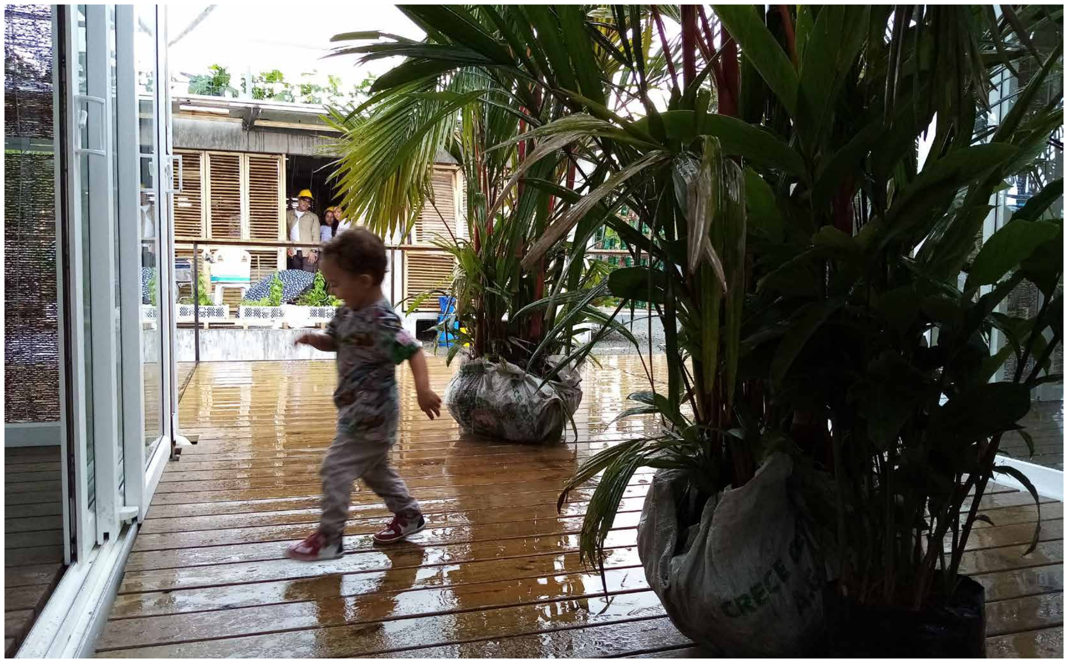
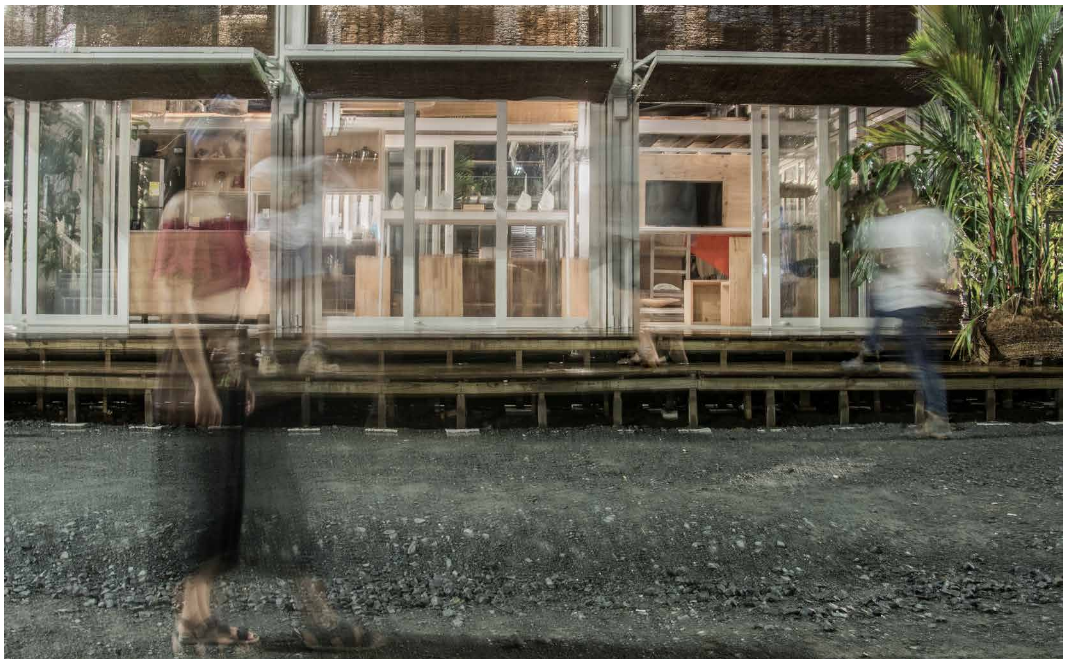




Chapter four:
la Vivienda azul-verde

***Maquina Verde*, a laboratory of practices for sustainability**

This chapter, one of the most important for the thesis work, has as its starting point the Solar Decathlon experience and the project's attempt to manage the water cycle, focusing on the research of additional and/or alternative solutions consistent with the nature of the Vivienda and its context, the barrio El Pozon in Cartagena de Indias. As it was said before, the concept of water and therefore the importance of its management in the everyday life is fundamental, given the ancestral link that this neighborhood has with the Cienaga de La Virgen. The fundamental point is to transform a threat into a resource, trying to provide practical and affordable solutions that could be added to the project at any later stages of construction. This possibility is even more concrete thanks to the work of the architect Carlos Hernandez Correa and the entire PEI team in all of the post-competition phases; in fact, participatory workshops and other activities focused on the Vivienda are planned and will be described later in the chapter.[1]

All the changes here suggested for the project are based on researches concerning a specific technology, a blue green roof module, that could contribute to the process of depavimentation and could increase the rainwater collection surface area. For this reason, starting from the information collected in previous chapters and in researches on similar technologies, a catalogue has been created in order to slist and study all the elements of which these different modules are composed. This catalogue is necessary to design and build a specific prototype of the blue green module for the Vivienda representing the starting point of the subsequent additions and modifications applied to the project. Thus leds inevitably to a reverse process to the one commonly used in architectural practice: starting from the particular to get to the general, the module being the particular, which, through processes of scaling and adaptation, produces the general.

[1]All the practical activities are currently pending due to the COVID-19 current situation, however will be described as previously planned.

Catalogue of a blue green roof module elements

The need for this kind of technology

Among all the naure based technologies there are those concerning the increase of permeable surfaces, through the use of green areas with special stratigraphy and methods of operation. What is a green roof, what are the advantages and how it is composed has already been explained previously in the elaboration, now the focus is on this technology as a starting point for the new technology to be presented in this research. Considering the topic examined in this research, the focus is on green roofs in the form of modular elements, in order to create a blue-green roof module. For this reason, the analysis of green roof modules on the market was focused on modular technologies and later integrated with other models encountered on Google Patent. At the end of the chapter are attached the sheets of the different models and patents examined (own elaboration based on data provided by producers and creators).

The choice to directly consider a modular technology, and therefore to analyze only this type on the market, was dictated by some specific considerations. Considering first of all the reasons that led to the choice of a modular system, there is the ease of construction, assembly and maintenance that characterizes this particular technique. The aim is to identify a technology that can be universally feasible, regardless of the resources and manpower available. In the same way, this module is not linked to any particular size other than the basic one and therefore can be easily adapted to any roofing and repeated as many times as necessary, without resulting in an exaggerated system complexity. In addition, the subdivision into modules allows to grow different species more easily and maintain them according to the needs of the individual.

One of the main reasons, however, concerns the decision to implement a water collection system through these modules, which completes the usual rainwater collection system (gutters and canals); in fact, the realization in modules makes the possible water collection system, and consequently also its maintenance, more controllable.

What has already been done: the sample

Below a general list of the examples considered with a brief description and their respective references. First are listed the models encountered on the market, then those resulting from searches on Google Patent.

• Modular Green Roof Tray BZ1050 and Modular Green Roof Tray BZ2050.
Dimension: 50x50 cm. Height: 10-20 cm.
Company: Baozhen Technology co. - located in Xiamen City, Fujian (China).
The trays are produced by modular design and are made of High Density Polyethylene (HDPE) that presents high impact resistance, strong mechanical properties and toughness.[2]

• Modular Green Roof Planted-In-Place or Pre-Grown tray.
Dimension: 60x60 cm. Height: 10-20 cm.
Company: Columbia Green Technologies , located in Portland, Oregon (U.S.A.).
The trays design maximizes stormwater retention and present interlocking edges, so that excess media can be placed over the top of the tray for invisible tray edges when planted-in-place.[3]

• EcoGrid EcoSedum Pack.
Dimension: 40x60 cm. Height: 7,5 cm.
Company: Ecogrid, located in Liverpool, U.K.
The trays are made from MDPE and feature a reservoir within to facilitate ease of irrigation.[4]

• Automated Green Roof Modular Tray System GF508, GF512, GF520.
Dimension: 50x50 cm. Height: 8-12-20 cm.
Company: GS-Tanks Underground Stormwater Management Solutions, located in Xiamen (China).
All the different typologies of trays guarantee strong, full and rapid drainage and water storage functions with an effective response to continuous heavy rainfall.[5]

• Hydropack.
Dimension: 60x40. Height: 10 cm.
Company: Vegetal i.D. Green innovation for smart cities located in BATAVIA, NY, USA
The tray comes complete with all green roof components: mineral drainage, filter cloth, growing media, and vegetation. It has been designed with water reservoirs and an interlocking system that maximizes stormwater retention.[6]

• Hydroventiv
Dimension: 40x60 cm
Company: Vegetal i.D. Green innovation for smart cities located in BATAVIA, NY, USA
The tray is made of an recycled HDPE. It's a versatile and low-cost stormwater detention system because water flow control can be set to whatever the flow needs to be for the project, thanks to sensors installed in the roofs and to its sub-irrigation possibilities.[7]

While the models on the market have very specific physical characteristics, patents focus primarily on innovation in the context of the material. In this section, therefore, data on specific dimensions, performance, etc. are missing.[8]

• Patent No.: US 7,596,906 B2
This patent provides the classic stratigraphy of a green roof and focuses on the use of recycled carpets for the containment box.

• Patent No.: US 8,429,851 B2
This patent provides the classic stratigraphy of a green roof and focuses on the use of corrugated cardboard, preferably pre-molded egg carton, for the reservoirs.

• Patent No.: US 8,479,443 B2
This patent provides the classic stratigraphy of a green roof and focuses on the use of corrugated cardboard for the containment box.

• Patent No.: US 9,095,097 B2
This patent provides the classic stratigraphy of a green roof and focuses on the use of high strength plastic, high density polypropylene and recycled rubber for the hole module.

• Pub. No.: US 2002/0007591 A1
This patent provides the classic stratigraphy of a green roof and focuses on the use of high strength plastic, high density polypropylene and recycled rubber for the hole module.

• Pub. No.: US 2013/0031833 A1
This patent provides the classic stratigraphy of a green roof and focuses on the use of recycled cardboard containment boxes that can facilitate transportation and installation.

• Pub. No.: US 2013/0239476A1
This patent provides the classic stratigraphy of a green roof and focuses on the use of aluminium for the containment box.

[2] www.greeningclub.com
[3] www.columbia-green.com
[4] www.ecogrid.co.uk
[5] www.gs-tanks.com
[6] www.vegetalid.us
[7] www.vegetalid.us
[8] All of the patents can be found on Google Patent (www.google.com/?tbm=pts) using the reference number.

• Patent No.: US 6,606,823 B1

This patent provides the classic stratigraphy of a green roof and focuses on the possibility to crate a module that can support solar panels.

Following the decision to adopt a modular system, there was reasoning about the possibility of using these modules also to increasing the rainwater recovery capacity. This was mainly due to the climatic characteristics of *Cartagena de Indias*, which is subject to long periods of drought and long periods of rain. The possibility of implementing a water recollection system is suggested and supported by one of the most advanced models encountered on the market: Hydroventiv, a versatile and low-cost stormwater detention system. If, in fact, all the modules provide for the storage of only a part of the water, the one necessary to meet the needs of the plants, with the consequent outflow from the module of the excess water, Hydroventiv provides an additional inferior tank, in which the excess water is storaged. In the case of this prototype, the water is then recirculated to provide nutrition to the plants when the first quantity of water evaporates completely. The main idea drawn from this example is to implement, through the addition of the same tank placed on the lower level, a system of piping that can recollect the excess water and send it to the rainwater tank. The development of this secondary collection piping system will be explained later in chapter five, because it is designed and adapted only to the module developed for the *Vivienda*.

The need for this catalogue

This catalogue is intended to be a manual of the different elements for the construction of a blue-green modular technological system that can be applied on the roof. Providing not only guidance on the functions of each element, but also a detailed list of the different options that can be adopted, based on chemical and physical characteristics, the catalogue wants to be a basic guide for those who want to build a similar module. The catalogue presents basic elements, the assembly of which creates a basic blue-green modular technological system that can be applied on the roof. In the fifth chapter the composition of the module created for the research case study will be analyzed and will present all the elements indicated here. However, some changes will be made, concerning some different aspect:

• the use of alternative materials to those listed, the choice of which is based on analyses of chemical and physical properties and availability of resources;

• the possibility to collect water through a more evolved conception of the containment box and of the drainage layer;

• the use of soil and plants specific to the climatic and geographical area of the case study.

Other possible changes are envisaged, depending on the research objective.

There are two main bases used to draw up this list: information about green roofs, green roof modules encountered on the market and green roof modules patents encountered on Google Patent. Each of the information encountered is adapted to the purpose of the research. Some data sheets from which information has been taken are attached at the end of the chapter.
There are six principal elements that form the module in examination and for each of these elements is given a brief explanation and a series of examples. Below is an introductory description of the individual elements.

• Waterproof material: the waterproofing layer is used to cover the surfaces of an architectural object to prevent the circulation of water inside materials or elements that are unable to counteract the deterioration.

• Drainage: drainage layer principal functions are drainage of rainwater or excessive irrigation, storage reservoir of water for vegetation and aeration of the rootsystem.

• Geotextile material: geotextile materials indicate some types of drainage membranes of different nature and composition. Usually they are used in contact with earth, rocks, gravel and sand or other construction materials to carry out geotechnical and hydraulic engineering works.

• Containment box: the box that contains all the components that constitute the module under examination.

• Growing medium: the growing medium is the material used in a container to grow a plant and it guarantees plant establishment and stability in order to maintain the physical, chemical, and biological conditions for the correct vegetative development.

• Vegetation: the upper layer provides the essential presence of vegetation.

It should be noted that the descriptions of these elements are homogeneous within the individual categories, but present different fields of analysis, depending on the different aspects on which the research is focused. In particular, for some categories the analysis of the material and physical characteristics is important, the function for others and the morphological composition for still others. Furthermore the research was carried out following the main typology green roof modules, but leaving ample space for the variety of materials, construction techniques and types of assembly. The combination of the models already available on the market and the patents has made it possible to create a heterogeneous catalogue, in which there are both materials already used in the construction field and more unusual materials that can replace some specific components.

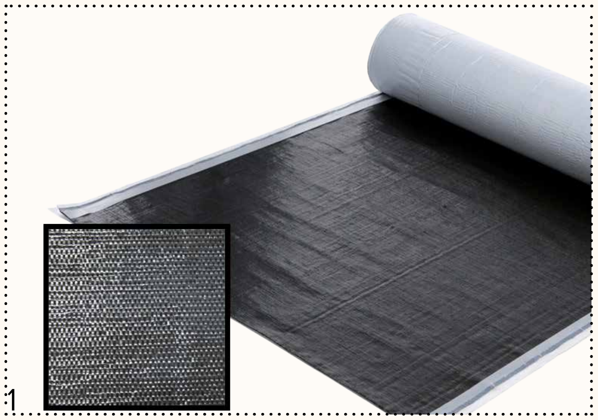
Waterproof Material

Waterproofing is the property of a material that does not enable the penetration of fluid elements through its pores, thanks to the low porosity, result of a more homogenous chemical composition. In construction, the waterproofing layer is used to cover the surfaces of an architectural object to prevent the circulation of water inside materials or elements that are unable to counteract the deterioration caused by chemical reactions that water could induce over time. The infiltration of water could occur by capillary ascent or gravity in those parts of the building structure that are most at risk: foundations; floor slabs; vertical closures of the basement floors; balconies; roofs. In addition to the water resistance property this layer should also have other characteristics in order to meet certain performance conditions, such as good mechanical properties and a rot-proof nature.
About 80% of building problems are related to the presence of water, so there are many reasons to use this waterproof element in buildings. The benefits of quality waterproofing include:
• Preserving structural integrity;
• Improve indoor air quality;
• Increased commercial value;
• Increased service life;

There is no waterproofing material that has the absolute best characteristics, but it is always necessary to analyse the starting conditions to understand the origin of the problem and the consequent applications to be adopted. In addition, to select the appropriate waterproofing, it is necessary to determine:
• the density of the water that must pass through the surface or the water flow rate on the surface of the material to be waterproofed;
• the climate of the region, in particular the change in the temperature range.

Considering the nature of the study of this thesis, the focus is placed a the blue-green modular technological system applied on the roof. Therefore are investigated only possible waterproofing products to be used in roofing, together with the related materials and the different applications. The roof is the part of the house in complete contact with atmospheric agents, so the waterproofing must guarantee maximum resistance to counterthrust, frost and thaw cycles, good behaviour to UV rays, and obviously to water and humidity in general. On the basis of the artefact analysis it will be possible to decide between the different actions of intervention:
• waterproofing overlapping the existing flooring;
• waterproofing after removal of the existing flooring;
• demolition of flooring and screed with total restoration.

The continuity of the waterproofing layer is the most important requirement when installing this layer on the roof, together with the welding to the joints. Continuity for the purpose of water tightness is a fundamental condition to be tested after installation by filling the roof with water and assessing the presence of seepage. The typologies of waterproofing layers are various and depend on the material and the state of the product.
A division can be hypothesized, according to some particular characteristics:
1_Natural - Bituminous Membranes;
2_Synthetic - Polymeric Membranes;
3_ Mixture - Polymer-Bitumen Membranes;
4_Liquid Coating.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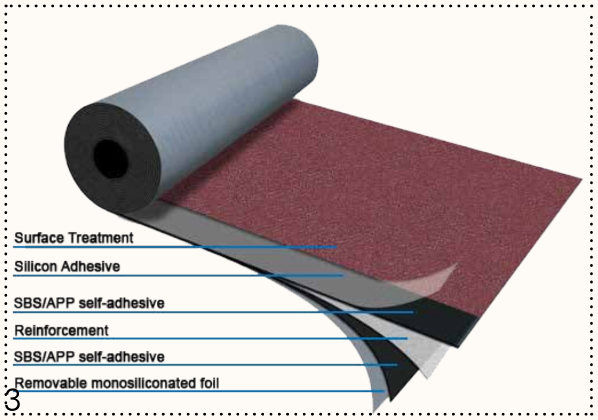

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4

Waterproof Material

Natural - Bituminous Membranes

The bituminous material is a natural hydrocarbon, or a combination, of natural origin. It is a thermoplastic resin, of colloidal nature, which does not contain volatile substances. The artificial bitumen, which is today more commonly used, is the product of petroleum distillation, a process that consists of the extraction of gasoline and some precious oils. There are several typologies of bituminous membranes and they differ according to the type of armature adopted: paper filter, felt glass, burlap and fiber glass.

Mechanical resistance	●●●○○
Elasticity	●●○○○
Chemical resistance	●●●○○
Durability	●●●●○
Adherence to support	●●●○○
Workability	●●●○○
Walkability	●●●●○

Synthetic - Polymeric Membranes

Polymeric materials are synthetic macromolecular substances that can be differentiated into plastomeric or elastomeric, according to their deformation under stress. The polymers called plastomers have a rigid behaviour, after a deformation they do not return to their original state, while elastomeric ones return to their original form. A polymeric synthetic membrane is a waterproof covering, generally prefabricated, in which bitumen is not present. There are different types of membrane depending on the nature of the polymer used, the most known are PVC, or polyvinyl chloride, PIB, or polyisobutylene and HDPE, or high density polyethylene. Plastomeric and elastomeric polymeric materials are produced by calendering, extrusion and coating.

Mechanical resistance	●●○○○
Elasticity	●●●○○
Chemical resistance	●○○○○
Durability	●●○○○
Adherence to support	●●●○○
Workability	●●●○○
Walkability	●●○○○

Mixture - Polymer-Bitumen Membranes

A bitumen-polymer membrane is a composite material containing a higher percentage of bitumen mixed with a considerably lower percentage of polymer. In these mixtures the polymer represents the minority ingredient. Mixed hot, at a temperature higher than the melting temperature of the polymer, a mixture called "phase reversal" is obtained where the majority ingredient, that is the substance dispersed inside the polymer, constitutes the continuous phase of the mixture. In this mixture it is the polymer that provides the features even if it is not the predominant portion. Bitumen-polymer membranes are classified into Plastomeric (APP) and Elastomeric (SBS).

Mechanical resistance	●●●○○
Elasticity	●●○○○
Chemical resistance	●●●○○
Durability	●●●●○
Adherence to support	●●●○○
Workability	●●●○○
Walkability	●●●●○

Liquid coating

Liquid waterproofing products are all those natural and synthetic waterproofing materials that are not prefabricated in the membrane version, but are applied directly on the surface. They are in a fluid state and require a drying time to ensure waterproofing performance. These types of waterproofing products have greater workability and excellent adhesion to the support structure that needs to be waterproofed, permit greater versatility as the application is more comfortable, because of the possibility to act on the entire surface, without leaving points uncovered. Liquid waterproofing membranes are applied like paint, once dried, they form an elastic membrane with an excellent waterproofing capacity.

Mechanical resistance	●●○○○
Elasticity	●●●○○
Chemical resistance	●○○○○
Durability	●●○○○
Adherence to support	●●●○○
Workability	●●●○○
Walkability	●●○○○

Image 5: Patent *Modular Interlocking pre-Vegetated Roof System*. patentimages.storage.googleapis.com/19/18/92/c3d83f9dd26751/US8429851.pdf

Image 6: Patent *Green Roof System with Biodegrabale Vegetation Tray*. patentimages.storage.googleapis.com/52/7a/14/ae371ae4b8b-2db/US8479443.pdf

Image 7: ECOGRID tray. ecogrid.co.uk/wp-content/uploads/2017/11/Ecosedum-pack.pdf

Image 8: HYDROPACK® tray. www.vegetalid.com/solutions/green-roofs/the-all-in-one-system-hydropack/features.html

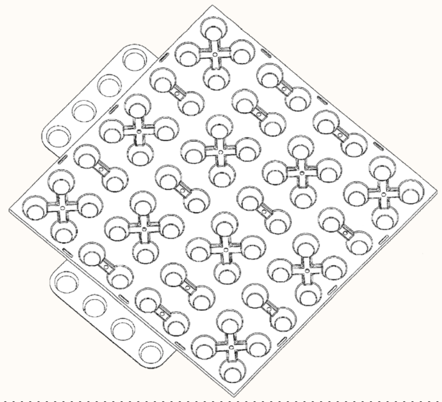
[9] The description of the drainage trays, the main advantages and the materials used are described in the introductory phase of all patents.

Drainage

The drainage layer is a fundamental element in the structure of a green roof. The principal functions of this element are:
• drainage of rainwater or excessive irrigation;
• storage and reservoir of water for vegetation;
• aeration of the root system;
• additional protection of the waterproofing layers.

Generally the drainage is a filter fabric characterized by ovoid cavities that have the function of collecting water, which then goes up by capillarity in the soil above with consequent nourishment of the vegetation. The layer is usually installed as a continuous film over the entire surface of the green roof and the different sheets should be overlapped to eliminate the possibility of gaps being created between sheets. Furthermore, other two main materials used for the drainage element are granular materials, such as clay and crashed bricks, and modular panels, that are usually made of plastic materials and presents the same ovoid structure of the fabrics. (Cascone, 2019)
Considering the nature of this thesis, the focus is placed on a blue-green modular technological system applied on the roof. Therefore, only a typology of drainage elements was investigated, seeming to be the most fitted for the composition of a modular green roof system: the drainage tray. In this cataloguing, the objective is placed on the different types of drainage trays that can be used for the composition of these modules, physical conformation and the material of which they are composed. Drainage trays represent an advanced configuration of drainage boards. In particular these trays are thicker than the usual technologies and present bigger cavities, allowing a fuller functioning of the element. In the common configuration of the drainage tray, the water is collected in the tray in dedicated molded reservoirs or slots. Excess water drains through a series of holes that are opened on the surface in differents positions, according to the tray structure. The water stored can move up into the upper layer using capillary movement, evaporation, or condensation. The reservoirs or slots are sometimes connected at an intermediate height so that the water is directed toward the drainage holes only when its level reaches a determinate height. This system provides for water retention in the tray, without saturation of water near the plant roots, which could otherwise cause rotting.
Depending on the specific case, the tray can have walls that are usually made of the same material of the bottom. The shape is usually rectangular and square in order to facilitate the assembly of different trays on the roof surface. In most of the examples encountered, anchoring mechanisms for joining the different modules are described and represented. The materials are generally polymers or other light-weight material capable of being molded and holding water.[9]

This catalogue contains seven examples that have different configurations and are divided by the three main materials:
1_molded pulp;
2-5_polypropylene or polyethilene;
6_reycled rubber.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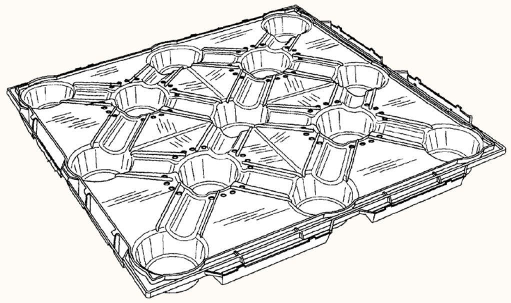
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Drainage trays

Example 1
The tray, made of mulded pulp, consists of:
• Reservoirs formed in cup-like features to store water.
• Channels between interconnected groupings of water reservoirs.
The channels between reservoirs can be an X shape, a straight line and a L-shape.
The channels are preferably opened-top.
• Drain holes at a central location in the channels.
The holes permit the flow of excess water and air circulation therethrough.
Dimension: 45x45x1,5 cm
Number of reservoirs: 64
Reservoir max diameter:4 cm
Reservoir min diameter:2 cm
Reservoir depth:1,5 cm
The tray can storage approximately 0,64 l before the process of overflow begins.

Example 2
The tray, made of polypropylene, consists of:
• Reservoirs formed in cup-like features to store water.
• Fluid channels interconnecting all the water reservoirs.
The channels between the pockets can be criss-crossed into an “X” shape.
• Drain holes at the bottom edge of the reservoirs. The holes permit the flow of excess water.
Dimension: 55x55x3 cm
Number of reservoirs: 12
Reservoir diameter:8 cm
Reservoir depth:8 cm
The tray can storage approximately 1,80 l before the process of overflow begins.

Example 3
The tray, made of recycled polypropylene, consists of:
• Side walls and a bottom wall.
• Reservoir formed in slots features to store water.
• Drain holes formed through the bottom of each slots.
• Drain holes formed through the top of each slots.
The holes permit the flow of excess water and constant water metering.
Dimension: 60x60x20 cm
Number of reservoirs: 10
Reservoirdimension: 60x2x1,5 cm
The tray can storage approximately 2 l before the process of overflow begins.

Example 4
The tray, made of recycled polypropylene, consists of:
• Side walls and a bottom wall.
• Reservoirs formed in hexagonal features to store water.
• Bumps extending from each corner of the hexagonals reservoirs.
• Drain slits on the bottom part of the bumps.
The slits permit the flow of excess water.
Dimension: 40x60x7,5 cm
Number of reservoirs: 10
Reservoir side dimension: 8 cm
Reservoir depth : 4 cm
The tray can storage approximately 8 l before the process of overflow begins.

Example 5
The tray, made of recycled high density polypropylene, consists of:
• Side walls and a bottom wall
• Resevoirs formed in a cross-shaped features from squared extrusions.
• Linear extrusions that connects the squared ones
• Drain holes formed through the top of the squared extrusions.
The holes permit the flows of excess water.
Dimension: 40x60x10 cm
Number of reservoirs: 16
Reservoir side dimension: 8 cm
Reservoir depth : 4 cm
The tray can storage approximately 1 l before the process of overflow begins.

Example 6
• The tray, made of recycled rubber, consists of:
• Side walls and a bottom wall
• Reservoir formed in slots features to store water.
• Drain holes formed through the top of the slots
The holes provide drainage of the soil mass or other contents of the tray.
• Drain holes formed in the sides of the panel.
The holes permit the flow of excess water.
Dimension: 60x120x8 cm
Number of reservoirs: 6
Reservoir dimension: 65x10x3,2 cm
The tray can storage approximately 8 l before the process of overflow begins.

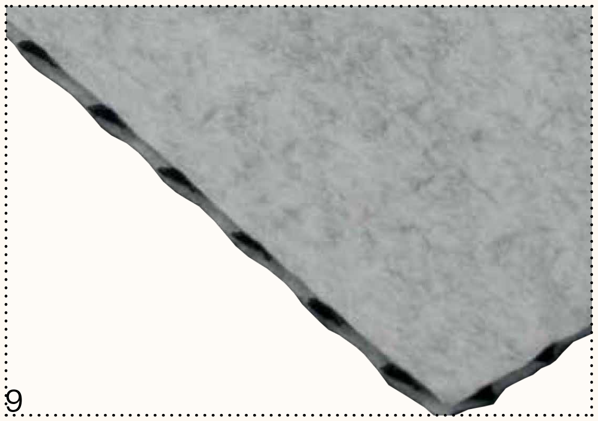
Geotextile Material

Geotextile materials indicate some types of drainage membranes of different nature and composition. Usually they are used in contact with earth, rocks, gravel and sand or other construction materials to carry out geotechnical and hydraulic engineering works. Furthermore, they are also used in many building applications such as green roofs. The mode of operation of a geotextile in every application is defined by six distinct functions: separation, filtering, drainage, reinforcement, sealing and protection. Depending on the application, the geotextile performs one or more of these functions simultaneously.
The membranes can be differentiated according to the internal structure, i.e. the arrangement of the internal filaments:
• ordered structure - Woven textile;
• random structure - No-woven textile.

Woven geotextiles are formed by weaving together threads or filaments in parallel, using techniques similar to weaving clothing materials. The thread running along the length is called warp, the transversal thread is called weft. The main function of geotextiles is to act as a separating and reinforcing material for the soil. Textiles have a high tensile strength, which is the resistance of a material to breakage when subject to one or more tensile forces.
This type of geotextile holds:
• excellent capacity as reinforcement layer for the soil;
• high tensile strength;
• high load capacity;
• low water permeability;
• low drainage capacity.
Non-woven textile are thicker than woven textiles and are formed by a continuous filaments or staple fibres. They are produced with the following joining techniques: needle punching; thermal bonding; chemical bonding.No-woven geotextiles are similar to felt and do not offer much in terms of compressive resistance, tensile strength or shear strength. Their main functions are related to filtration and drainage performance. They can also be used for erosion control.
This type of geotextile holds:
• limited capacity as reinforcement layer for the soil;
• low tensile strength;
• low load capacity;
• high water permeability;
• high drainage capacity.

Composite textiles are formed by a plastic mesh reinforcement that serves to form the static part of the system, enclosed by two non-woven geotextiles that act as protective filtering states. These materials are mainly indicated if consistent drainage is to be achieved

The typology of materials considered are only those that can constitute membranes suitable for the case study project of this thesis.
The main ones are materials of synthetic origin:
1_Polypropylene PP;
2_Polyester PET;
3_High density polyethilen HDPE.
These materials modify their performance depending on the geotextile formations. Below follows the characteristics of these materials according to the method of production.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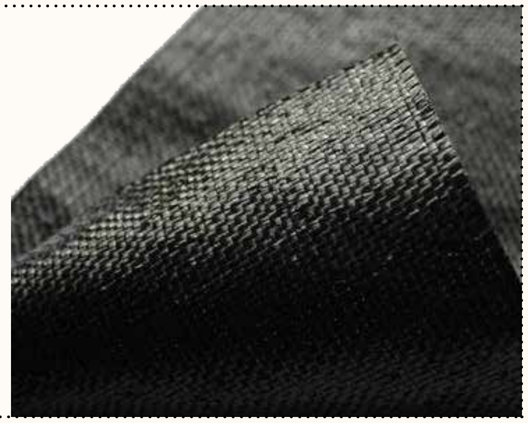
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Geotextile Material

Woven textiles

These membranes are weft and warp woven geotextiles, black in colour, made of polypropylene strips of constant width, intertwined regularly.

Polypropylne PP

Polymer:	Polypropylene
Process:	Weaving
Specific weight:	0,91 kg/dm3
Colour:	Black
Durability:	25 years

Polypropylene PET

Polymer:	Polyester
Process:	Weaving
Specific weight:	1,38 kg/dm3
Colour:	White
Durability:	25 years

Non-Woven geotextiles

These membranes are nonwoven geotextiles obtained by mechanical needling and calendering of synthetic fibres of polypropylene randomly disposed without a precise structure.

Polypropylne PP

Polymer:	Polypropylene
Process:	Needling and calendering
Specific weight:	0,91 kg/dm3
Colour:	Black, White
Durability:	5 years

Polypropylene PP high tenacity

Polymer:	Polypropylene
Process:	Needling and calendering
Specific weight:	1,38 kg/dm3
Colour:	White
Durability:	5 years

Polypropylne PP recycled

Polymer:	Polypropylene
Process:	Needling and calendering
Specific weight:	0,91 kg/dm3
Colour:	Multicolour
Durability:	5 years

Polyester PET

Polymer:	Polyester
Process:	Needling and calendering
Specific weight:	1,38 kg/dm3
Colour:	White
Durability:	5 years

Polyester PET recycled

Polymer:	Polypropylene
Process:	Needling and calendering
Specific weight:	1,38 kg/dm3
Colour:	Multicolour
Durability:	5 years

Geocomposite textiles

These membranes are geocomposites consisting of a high-density polyethylene tri-mensional geogrid with high compressive strenght combined with polypropylene nonwoven geotextiles on one or both sides.

Polypropylene PP - HDPE composite

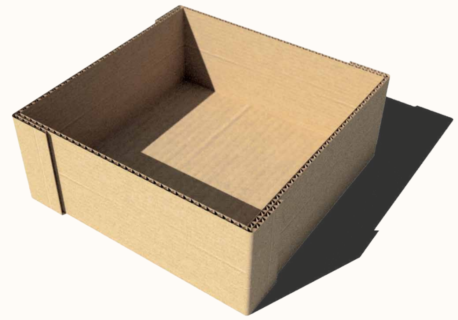
Polymer:	Composite
Process:	Structured
Colour:	Black and white
Durability:	25 years

Image 12: Possible configuration of a cardboard tray.
Image 13: Possible configuration of a recycled carpet tray.
Image 14: Possible configuration of a cwood tray.

Containment box

Considering the nature of this thesis, the focus is placed on a blue-green modular technological system applied on the roof. For this reason, it has to be considered an element that is generally not part of the stratigraphy of a green roof: the box that contains all the components that constitute the module under examination. This element will henceforth be referred to in this thesis by the term containment box. In this cataloguing, the objective is placed on the different types of materials that can be used for the composition of these boxes, mainly according to their physical and chemical characteristics. In addition to the traditional materials found in the literature, there are also some examples drawn from recent experiments in the construction of green roof modules.
The square box configuration was the one taken into account because it was considered as the one most recurrent and more advantageous for assembly. It has to be said, though, that this shape is not the only possible set up, but the methods of union are generally the same for the different possible forms. Furthermore, there is the possibility that the necessary configuration for the module is not that of a box, if not simply a defined number of side walls, as the drainage tray can replace the bottom of the containment box. Again, it is considered that the methods of union are generally the same whether for a box or a set of side walls, while the way these are glued to the tray depends on the material of which the last one is made. As a final consideration, the storage box may not contain the tray, but may rest on top of it, while preserving the bottom wall for mehanicall reasons. In this case the bottom wall present holes of defined dimension to allow water to pass through. Each containment box needs a waterproofing layer, described in section 1 of the catalogue.
As far as the containment box construction is concerned, there are different ways of assembling the material pieces. In particular two differents kind of joinings can be mentioned, depending on the material. The firts one is based on preparing separately all the different components of the box (lateral walls and base) and then joining them together by mechanical unions, glues or welding. The other one consists on folding along certain lines a single piece of the material in order to create a box with overlapping portions that are secured together.
It should also be noted that in the configuration chosen for this research, there is a water collection system that imagines a box configuration composed as follows: an upper box that contains the drainage, resting on the bottom wall of the box. The bottom wall of the box has holes, through which the water can flow to collect in a lower box, separated from the main one, so that the system can be more easily maintained. This aspect will be discussed in more detail in the next chapter, which deals with the composition of the module based on the cataloguing present here.

In particular five different configurations are considered, defined specifically by their materials, and their different bonding methods are analyzed.
These materials are:
1_aluminium (sheets);
2_cardboard (panels);
3_recycled carpet;
4_rigid PVC (sheets);
5_wood (boards).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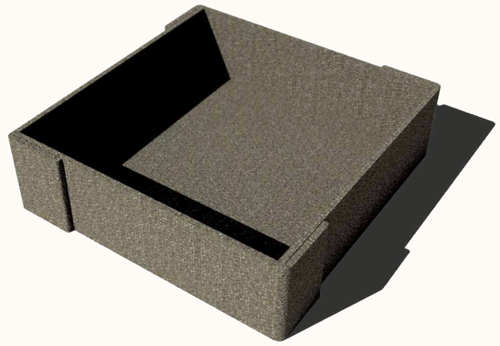
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Containment box

Aluminium (sheet)

Aluminium is present in nature in the form of minerals and gems: the most important and widespread mineral for the production of aluminium is bauxite. The raw material is crushed, cooked and ground and then transformed into alumina and subjected to electrolysis in a molten state in electrolytic cells. The molten mass is arranged in lingot shapes and then subjected to thermal processes. Annealing is necessary after the subsequent hot and cold milling and rolling phases. Due to its ductile nature, aluminium is used in alloy with other elements, as manganese, magnesium, magnesium-silicon, depending on the characteristics and functions required. Precisely because of its natural resistance to oxidation and corrosion, aluminium has a natural capacity for endurance that lasts unaltered over time. For this reason aluminium is a first choice when the first options are durability and minimal maintenance. In order to further improve corrosion resistance characteristics, aluminium can be subjected to anodization processes and coating processes.
Thickness: 0,5-1,5 mm
Weight: 2,7 Kg/m2
Density: 2700 Kg/m3
Specific Heat: 0,89 kJ/kgK
Thermal conductivity: 220 W/mK

Corrugated cardboard (panels)

Corrugated cardboard is made from the combinations of two sheets liners glued to a corrugated inner medium called the fluting. Pine trees provide the primary raw material to make corrugated cardboard. The harvested trunks are subjected to the kraft process, in which sulfate is used to break down wood chips into fibrous pulp. After pulping and other processing, the fibers are sent directly to the paper machine where they are formed, pressed, dried, and rolled into the wide, heavy rolls of kraft paper sent to corrugating plants to be made into cardboard.[10] The idea of this type of containment box is that it will eventually disintegrate completely, because of its biodergadable nature, to obtain a continuous green mantle.
Thickness: 4 mm
Weight: Kg/m2
Density: 1050 Kg/m3

Recycled carpet

Taking into account the recycled nature of the material, the carpet can be artificial, therefore made of a polyamide fabric, or natural, made of natural fibers that can be animal-based or plant-based. In terms of overall performance characteristics, polyamide fiber is the most versatile, providing flexibility, duration and resistance to stains and molds.
Thickness: 5-10 mm
Weight: 1,12-2,24 Kg/m2
Density: 223 Kg/m3
Specific Heat: 1,46 kJ/kgK
Thermal conductivity: 0,30 W/mK

Rigid PVC (sheets)

Polyvinichloride is the polymer of vinyl chloride, a gas obtained by synthesis from acetylene and hydrochloric acid. Before PVC can be made into products, it has to be combined with a range of special additives, that can influence or determine a number of the products properties. This process is called compounding and the functional additives used in all PVC materials include heat stabilisers, necessary in all PVC formulations to prevent the decomposition of the by heat and shear during processing, and lubricants, used to reduce friction during processing.[11] The structure and composition of PVC lends itself to being mechanically recycled, with reasonable ease, to produce good quality recycling material.
Thickness: 4 mm
Weight: 7,8 Kg/m2
Density: 1400 Kg/m3
Specific Heat: 1,17 kJ/kgK
Water vapour permeability: 1 Kg/smPa
Thermal conductivity: 0,16 W/mK

Wood (boards)

The wood, once the tree has been felled, is debarked and processed to obtain round and square timber. It is then cut to obtain a block which is then treated with preservatives.Planed wood boards are naturally processed solid wood products ready to be used for different types of applications. The boards are made from solid wood, the central part of the tree, the oldest and most valuable, but also the most resistant. The planing process of the boards is used to process the wood and give it different shapes and sizes. Outdoor wood is continuously subjected to various phenomena. Among the main causes of deterioration are: direct exposure to ultraviolet rays and bad weather, continuous changes in temperature and humidity, attack by fungi, mold and parasites. For this reason the wood boards require treatments with impregnating oils and water-based paints, or, when the when maintenance is difficult, immunization processes.
Thickness: 20-30 mm
Weight: 10 Kg/m2
Density: 350-750 Kg/m3
Specific Heat: 1,38 kJ/kgK
Water vapour permeability: 4,5 Kg/smPa
Thermal conductivity: 0,12 W/mK

Image 15: Commercial soilles mix.
Image 16: Sharp sand.

[10]The complete manifacture process can be consulted on *Corrugated Cardboard.* www.madehow.com/Volume-1/Corrugated-Cardboard.html

[11]*Lifecycle of a plastic product.* plastics.americanchemistry.com/Lifecycle-of-a-Plastic-Product/

[12]Informations on the best soil composition can be found on *Soil structure for green roof media.* https://www.denbow.com/soil-structure-green-roof-media/
[13]*Green Roof Plants.* www.growinggreenguide.org/technical-guide/design-and-planning/plant-selection/green-roofs/
[14] The different typologies and its advantages can be foud on *Soil for containers* extension.umd.edu/hgic/topics/soil-containers

Growing Medium

The term growing medium is used to describe the material used in a container to grow a plant. Considering the nature of this thesis, the focus is placed on a blue-green modular technological system applied on the roof. For this reason, it has to be considered the growing medium element, typical of a green roof stratigraphy. The growing medium is a fundamental element that present some pricipal functions:

• guarantee plant establishment and stability in order to maintain the physical, chemical, and biological conditions for the correct vegetative development;
• ensure the improvement of water quality and reduce the impact of rainfall peaks;
• provide noise and thermal insulation.

The typical substrate in green roofs, that usually differs from traditional garden soil, as traditional soils are mainly composed of organic materials such as compost. Green roof substrates are mainly composed of mineral materials, with a variation of 50% to 90% of the substrate volume. (Cascone, 2019) This class of materials makes it possible to obtain a soil characterised by low density, high porosity and good drainage capacity under saturation conditions. The inorganic materials can include scoria, ash, pumice, sand, coir, pine bark, porous and chemically inertfoams. Recycled materials like crushed bricks and roof tiles can even be included to reduce the embodied energy of the green roof. "In particular, the particle size should have a high percentage of granules with a diameter between 2–4 mm" (Cascone, 2019, p.10). Organic materials should make up a maximum of 20% of the soil composition, most of all because they have a tendency to degrade over time and collapse. They can also become water resistant, hydrophobic, and can be difficult to get wet again once they have dried. However, they are necessary because they are nutrients for plants and have a high moisture retention capacity. Summarising, the best composition of the growing medium is: lightweight volcanic aggregate, organic matter and sand, required to balance organic matter and assist in soil structure.[11] The thickness of the substrate is a function of the type of expected vegetation, but for the calculation it also has to be taken into account the resistance of the structures, calculable considering the vegetal earth density.
The minimum thicknesses of the earth depending on the type of vegetation is:
• 0,300 mm for herbs and climbing shrubs with a height of less than 0.6 metres;
• 0,400 mm for flowers, perennials, roses and shrubes;
• 0,600 mm for trees;
• 1,000 mm for big trees.[13]

Each type of plant will require different growing medium, maintenance and local conditions to sustainable growth. The most common types of growing medium suitable for vegetated containers are:
• Commercial Soilles Mix_ These mixes are lightweight, capable of holding water and nutrients and generally free of weeds, insects, and diseases. Their most common ingredients are: sphagnum peat moss, perlite, vermiculite, composted bark, compost, and coconut coir. Other ingredients, such as lime and fertilizer, can be added to the mixture in limited amounts. Calcined, expanded or other lightweight clay products also improve stability, and can be added not exceeding 30% of the volume of the growing medium. The pH is usually around 6,2.
• Sharp Sand_ Builder sand is the best option that can increase porosity because of the large particles. Furthermore it is relatively inexpensive and heavy.
• Compost_ It contains all the nutrients that plants need for growing, at the same time guaranteeing the recycling of the nutrients from gardens. However many composts have a pH over 7.0, whilst vegetable plants generally grow best when soil pH is 5.5-7.0.[14]

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Vegetation

Within a technological bioretention system the upper layer provides the essential presence of vegetation. The plants constitute the main layer of these systems. In nature there are a variety of families and species (more than 260,000) with peculiar characteristics and identifying a specific species of vegetation that can be planted in every climatic condition all over the world is difficult. The fundamental rule is to consider local varieties and species in order to avoid altering the ecosystem and to facilitate the correct growth of species suitable in native habitats. This scenario considers not only plants, but also the organisms connected to them such as animals and parasites with which they interact. Native plants are basically in harmony with the environment, so they will respond better to climatic variations, parasite attacks and pest weed, being, in essence more resilient. In addition, understanding the resistance and sensitivity of the plants to the action of contaminants is essential when they are to be placed in urban areas. The polluted metabolism of cities influences vegetation which, for instance, may be sensitive to some pollutants or have growth disturbed by overheating caused by urban material radiations. The influence factors of the area of action determine the conditions for the selection of plants. The main ones are the weather conditions, such as the humidity and intensity of precipitations, and the type of exposure. In addition, the substrate mix also selects the plant species that can be installed in a given soil type, mainly in terms of pH, salinity and nutrients.
The correct performance of a green system depends mainly by the health of the plants, while the several benefits mainly on the selection of the plant species. The correct installation of the right species in a specific place might favour the common benefits that they bring both to the artefact and to the surrounding environment, for example improve air quality and purify the water from pollutants.
The fundamental characteristics that these plants must have in order to guarantee a correct operation of the bioretention system are:
• good soil cover
• short and soft roots
• capacity to survive in extreme climatic conditions
• capacity to survive under minimal nutrient conditions
• limited maintenance
• rapid growth.

Initially, the combination of various species of plants was correlated to a simple and major aesthetic value. Instead later it was determined that the synergies resulting from different species might produce significant improvements in the system. In order to combine species, it is necessary to consider that the plant groups must be characterised by the same pH and soil humidity requirements. Increasing biodiversity in the greening process potentially improves the resilience and long-term performance of the systems. In addition, it may improve substrate cooling, prevent the growth of pests and preserve water.

The plants are divided into three categories:
1_Sedum;
2_Poaceae o Graminacae;
3_Aromatic herbs.


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Vegetation

Sedum

The plants of the genus Sedum belong to the family of the Crassulaceae, rustic or semi-rustic 'xerophytic' plants which adapt without problems to difficult climate and substratum conditions. All are perennial plants and can live for more than two years. The family is divided into 400-500 different species and includes thousands of varieties. These plants are native to Central Africa, North and Central America, widespread in hot and cold climate areas and typical of the boreal countries, to the north of the equator. Sedum is a succulent leafy plant characterized by a great abundance of aquiferous tissues and a low number of stomata (to minimize the evaporation of liquids) and a thick foliar cuticle. In this way it consumes less water and optimizes the consumption. The internal tissues act as reserve organs in which a large amount of water can be stored and reused at the driest periods of the year.

All species have a bushy habit and a poorly developed root system, never more than 20 cm below the surface. The roots are soft and short, but very dense. Often the plant forms a large carpet (or bearing) because the stems can also be directly rooted. The major surface in contact with the soil guarantees a better supply of water and nutrients. The soil must have good drainage power and the composition of the substrate must contain a percentage of coarse and porous sand (in relation to the soil at least 7:1) or rich in stones. Its ideal location is rocky soil or even on walls made of porous materials, in order to avoid rotting roots.

Graminacae

The Poaceae, also commonly known as Gramineae, are a family of monocotyledonous angiosperm plants belonging to the order Cyperales. They constitute a large group of plants (about 10,000 species). These include those very common plants that form grass carpets, as well as some very important plants for humans such as rice, corn and wheat. On the other hand, the ornamental Gramineae species produce very beautiful flowers and colours all year to decorate gardens. Graminaceous plants are planted in well worked holes with the addition of draining material on the bottom. The planting distance depends on the size of the plant, from 40 to 80 cm.

Generally these typologies of plants prefer the outdoors and need full sun, therefore an exposition to the south, south-east. Only a few species prosper in shady areas, such as Luzula, Carex plantaginea, Muscanthus purpurescens and Chasmanthium.

Usually they fit perfectly in dry soils, but the substrate density must be well compact and must also ensure excellent drainage, in order to permit the roots develop to overcome periods of water scarcity. For this reason a layer of 3 or 4 cm of expanded clay or pebbles must be placed under the plant in order to drain the water easily.

Aromatich herbs

Aromatic herbs are a category of rustic plants, very rarely affected by insects or moulds, thanks to the active ingredients with pest repellent power present in their plant tissues. In effect, with the aromatic term, these plants produce aromatic odours pleasant to humans, but repellent to parasites and moulds. However some species (Rosemary, oregano, sage and basil) can be infected by pests, especially in rainy and cool springs or when there is too much nitrogen in the soil. Moreover, these typologies of plants are fundamental for the human organism because they contain essential oils with different biological functions.
The aromatic herbs present advantageous features, common to all species in this category:

- adaptability to very small spaces;
- resistant to adverse conditions;
- easy to cultivate;
- harvest all year.

The recommended exposure for aromatic plants is sunny: the environment must be bright, dry and warm. Avoid exposure to wind, cold areas and shade.
However, some species (rocket, mint, lemon balm and wild celery) can survive in partial shade, as well as wet places.
Cultivating them in a place rather sheltered from the winds, sunny or in shady areas created by tall trees.

The aromatic plants present a distinctive feature of being adaptable with good results to all types of soft, well-drained soil. They suffer considerably the radical rot caused by water stagnation. The ideal soil for aromatic herbs is loose, well aerated in the first 30-40 cm and containing the right amount of nutrients. Species such as wild fennel, thyme, rue and cumin can also grow in a sandy or semi-arid and not very fertile soil. Instead, species usually accustomed to water and swamps, such as lemon balm, rocket, mint and chives, need a heavy and clayey soil.

What will happen to *Maquina Verde* after the Solar Decathlon?

The design and construction phase of the *Vivienda* and the final stages of the competition have been extensively described in the previous chapter. It is important to point out that there have been variations between the initial design and the built one, mainly due to time constraints, changings in the competition rules and the availability of materials. In addition, some modifications were made following an initial inspection of the house, carried out at the end of construction and following some unforeseen malfunctions during the evaluation phase. In the weeks following the completion of the house, a monitoring activity was carried out to assess the overall performance and then contributed to the final ranking of the competition. These data, which are available to the participants[15], made it possible to identify some critical points of the project and in particular the energy and water consumption of the house. Especially this last point concerns this thesis work, which aims to focus on how to implement and improve the water system.

As pointed out previously, the house is designed from the beginning to continue its life even after the competition. For this reason too, it was designed with a structure that is easy to assemble and dismantle and adaptable to different climates, given the great biodiversity that characterizes Colombia. However, the two main sites for which it is designed are *Cartagena de Indias* and Cali. Initially, in fact, it was planned to move the house to *El Pozon*, the original place for which it was designed, immediately after the end of the Latin American Solar Decathlon. However, it was announced that all the houses would remain in the *Villa Solar* until the end of December, as an exhibition included in the program of the feria de Cali, a famous Christmas festival of the city. Subsequently, a workshop was organized for March 2020, again at the Villa Solar, with the aim of observing the effects of time on the house and to make some improvements in all those aspects on which it was not possible to work for the competition, especially for lack of time. This workshop would have presented an opportunity to experiment with new ideas that could be further developed in subsequent competitions, such as the next Solar Decathlon, scheduled, at least for the time being, for 2020, and for other possible competitions focusing on the theme of the *vivienda social*.[16] Precisely because the house will continue to be an object of study, some changes have been thought that, depending on the degree of intervention of the various activities that will be carried out, could be implemented and applied to the project.

In addition to the changes which mainly concern a part of the hydraulic system built during the competition phase and that will be described following in the chapter, a main problem was identified: the presence of a large amount of impermeable surfaces. This issue mainly concerns two specific areas of the *Vivienda*: the roof and the deck. The roof is divided into two movable and one fixed pitches. For the two mobile pitches there is a water collection system, while the fixed one, on which are placed the solar panels and the water heating, does not have its own system, but it is estimated that much of the water that falls on its surface is then diverted to the lower pitches.

As far as the deck is concerned, the outdoor area measures approximately 70 m^2 and it's designed so that the space can be experienced exactly like the indoor one, also by moving the furniture of the social area and the kitchen. The deck is not an impermeable surface, as the wooden battens are designed with a space for water flow. However, there is no water collection system, letting rainwater flowing freely under the raised surface. This leads directly to another fundamental issue that concerns water: the need to increase the capturing surface area. The main purpose is to raise, by means of specific technologies, the amount of rainwater collected in order to limit the use of water from the potable system. This matter, although important in the global context, takes on a specific relevance in *El Pozón*, where not only access to drinking water is not guaranteed for all sectors, but the inhabitants are already used to the collection and reuse of rainwater[17]. Therefore the aim was to technicalize this habit, using a not too articulate process that can lead to a solution that takes into account the scarcity of materials. The following two paragraphs describe two different solutions adopted for the roof and the deck, both based on previous research work and on the attempt to use blue green technologies.

[15] The data were collected through sensors in each house and through electricity and water counts during the competition. The reports were available to each team through the Microsoft Power Bi platform at https://solardecathlonlac.com/.

[16] All the practical activities are currently pending due to the COVID-19 current situation, however will be described as previously planned.

[17] This information was collected during interviews with citizens during the different visits

The phots shows the fixed roof pitch and the deck surface as they are now.

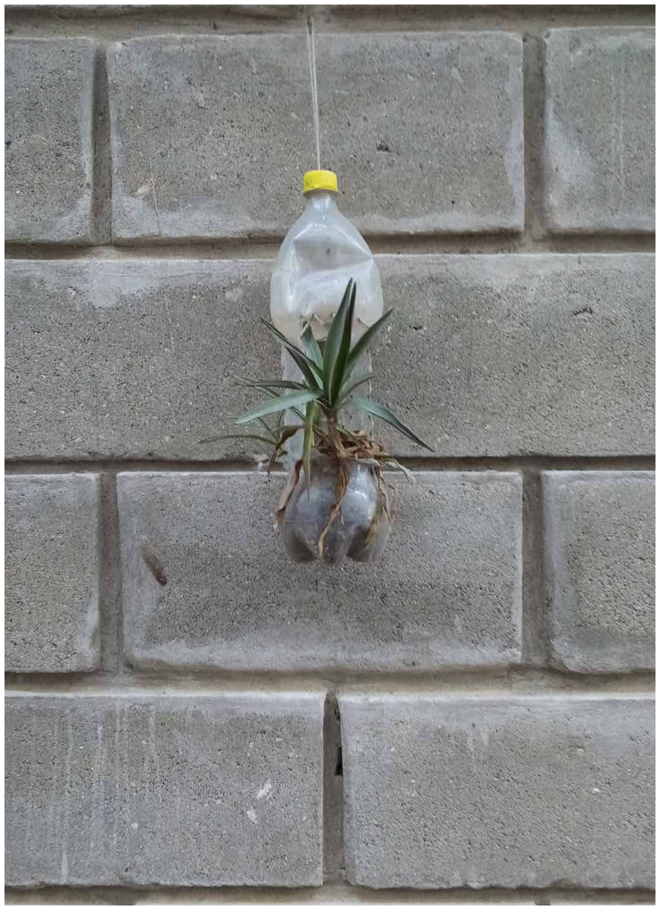
The creation process of a DO IT YOURSELF technology: the blue-green roof module

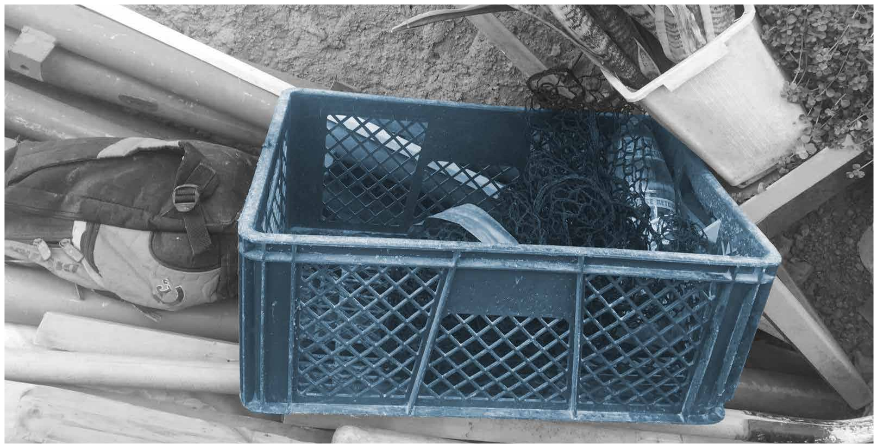
As far as the roof is concerned, the main intention is to convert it into a green roof. In addition to the main objective, i.e. to increase the capturing surface of the roof, the placement of an extra layer ensures a better indoor environmental condition, as it contributes to the insulation capacity. A further advantage is linked to an aspect of economic and social sustainability, which is also linked to the choice to use modular technology. Once the ideal solution was identified and the existing typologies were studied, the next step was to contextualize it within the *El Pozón* in order to design a module that can fit perfectly into the Solar Decathlon *Vivienda*. For this reason, in addition to implementing the territorial analyses already made for the competition, several inspections were carried out in the site project, which gave rise to some fundamental considerations for the composition of the module particularly as far as the materials are concerned. In particular, as it was explained in the previous chapter, differet inspections were carried out between January and February 2020, thanks to the collaboration of various social cooperatives active in the area. It must be underlined how the process of knowledge of the territory has been facilitated by the great sense of conscience of the *leader sociales* of the various corporations and by their operations to spread these issues in the comunity. In particular, the accompanying activity was carried out mainly by Mirian Correa, *leader social* of the *Corporacion para el Medio Ambiente*, who organized the various inspections and interviews with citizens. In general, the first visit was dedicated to a cognitive inspection of the area and the main activities in the neighborhood, thanks to which a macro division into two areas was identified. There is in fact a big difference in the degree of development between the *Isla de León* sector and the remaining sectors. During the second visit it was also possible to carry out inspections and interviews in the *Isla de León* sector thanks to Merlys, the social leader of the community, who introduced us to inhabitants and accompanied us during the process of interviews. A total of ten people were interviewed, representatives of as many households, who showed interest in the proposed topics, and were very willing and open to dialogue. The main question that was asked concerned the theme of water collection, i.e. whether the subject collected rainwater and if so by what method. At the time of the inspections, a precise configuration of the green module had not yet been defined, so examples and suggestions on how this collection could take place were shown.[18] It is interesting to note how the inhabitants themselves suggested possible problems and possible solutions, showing interest in the topic and in a possible collaboration, in the interest of a participatory research. During the last two visits, also dedicated to interviews, but in the remaining sectors and under the supervision of Mirian, following an increased awareness of the final objective of the investigation process, an attempt has been made to understand which materials are most used in the households and their disposal process. In this case it has been possible to document which are the materials that are used for building works, for vegetable gardens and gardens and which waste materials are generally stored for possible reuse.[19] In particular, the last inspection was dedicated to the visit of the *terraplen*, one of the two banks of the main channel that delimits the North West border of *El Pozón*, which houses a large amount of waste. Thanks to the catalogue of the blue green roof module elements it has been possible to carry out a more focused scouting and to identify a range of materials ad elements that are similar in composition or function to those required for the construction of the module. Among these were then chosen those more easily available or more suitable for the context for the realization of a technologically constructed module, but which can be realized in self-construction and with resources easily available in *El Pozón*. The complete process is explained in its entirety in chapter two, precisely because of the value it has assumed in the process of getting to know the neighborhood. In the following pages there is a photographic reportage that helps to understand the scouting process, considered as one of the main steps for the realization of the module.

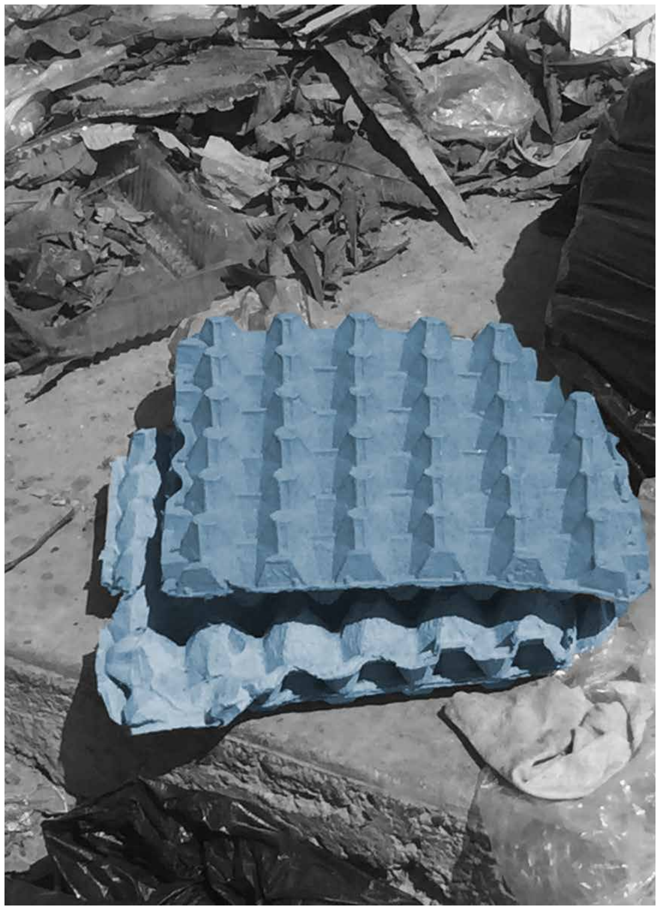
[18] Some examples of basic technologies for water collection, easily achievable in self-construction, have been shown and are explained in the second chapter.

[19] One must bear in mind the culture of self-construction that characterizes the neighborhood. The majority of the houses, in fact, were built by the families themselves and for this reason the inhabitants have helped a lot in the process of cataloguing the most used materials.

From the very start, it was clear the sentiment of awareness of the need to care for the environment and to address the issue through different activities present in the community. The *Corporacion para el Medio Ambiente*, in fact, has rented a space in the college and, together with the students, tranformed it into a *vivarium* where annual workshops on environmental conservation are held. One of the main activities concerns the cultivation of plants which are then planted in the different sectors of the neighbourhood to contribute to the urban regeneration of some of the most difficult zones. In particular the following species are cultivated: fruit plants such as *mango*, *torombolo*, *papaya*, medicinal plants and oak, *cedro* and *corales*.



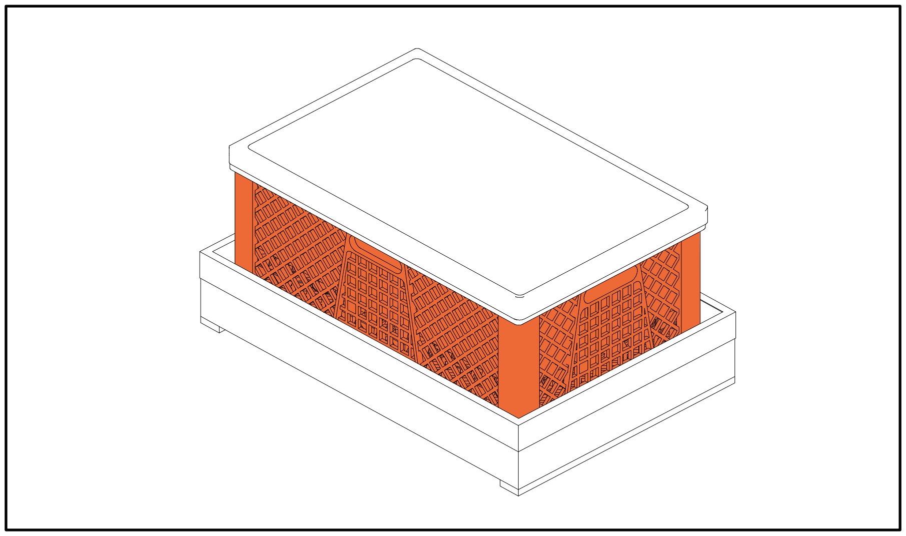


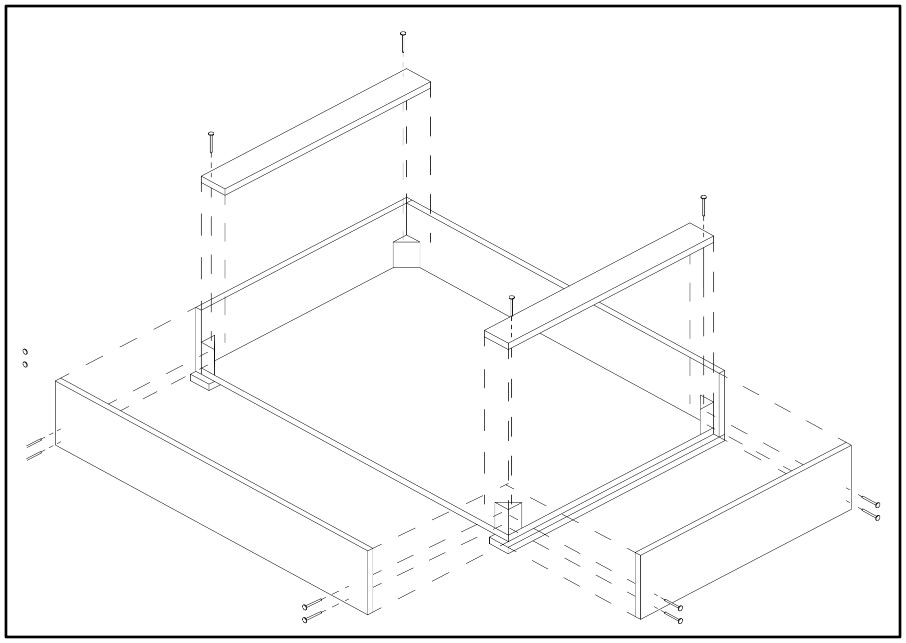


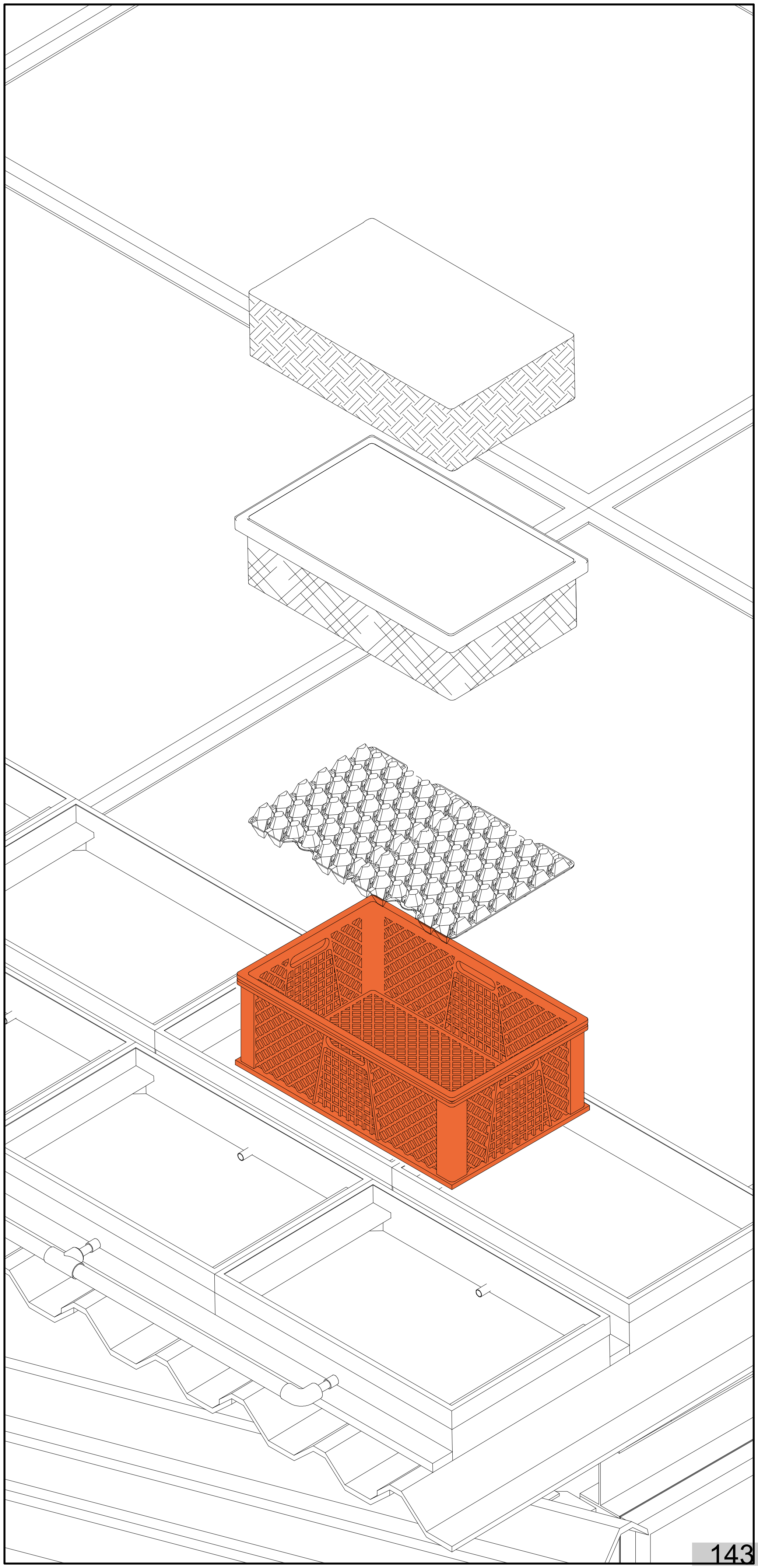
The scouting phase led to a photographic report illustrating the materials and elements chosen for the realization of the module. There are waste materials, some reused, such as the tarpaulin of the truck that serves as a billboard, while others thrown away, such as the egg container, and at the same time building materials, such as the plywood panel, used to create the counter of a kitchen. It must be taken into account how this phase provided for the need to enter the houses and to photograph what caught the attention, It was therefore necessary the collaboration of the inhabitants, who made this research possible.

Blue-Green Roof Module exploded view. Scale 1:10

The cataloguing and schematization of the examples found and the materials identified in the scouting phase led to the development of the module for the Solar Decathlon Vivienda. In particular, the module is divided into two parts, a fixed part and a movable part. The first part consists of the lower tank in which the overflow water is collected that is composed as follow: a box made of plywood panels (1 cm), covered with a truck tarpaulin (0,3 cm) that acts as the waterproofing. The box, which allows the entire module to be anchored to the roof, measures 1x1x1. On the lower tank rests the fruit box (1x1x1), which holds all the elements of the green roof stratigraphy: the egg container, the cooconut fiber and the growing medium. The egg container (30x25x25 cm) works as a drainage tray, allowing the water to collect in the egg pockets, whilst the coocnut fiber (0,3 cm) holds the growing medium in position. A solliess modified mix, made for the 50% of sand, for the 30% of clay and for the 20% of compost is the most is the most suitable choice for the module.

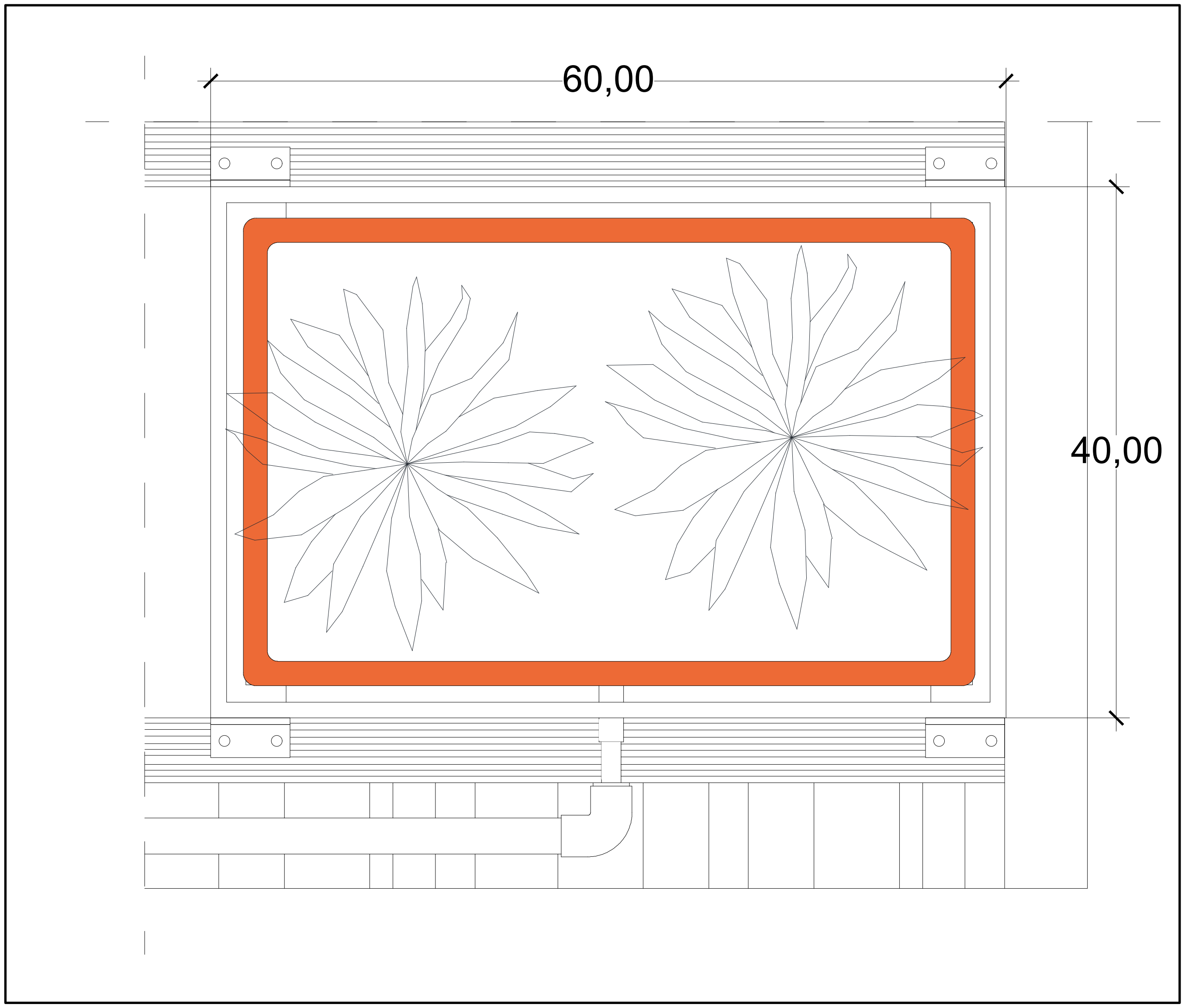


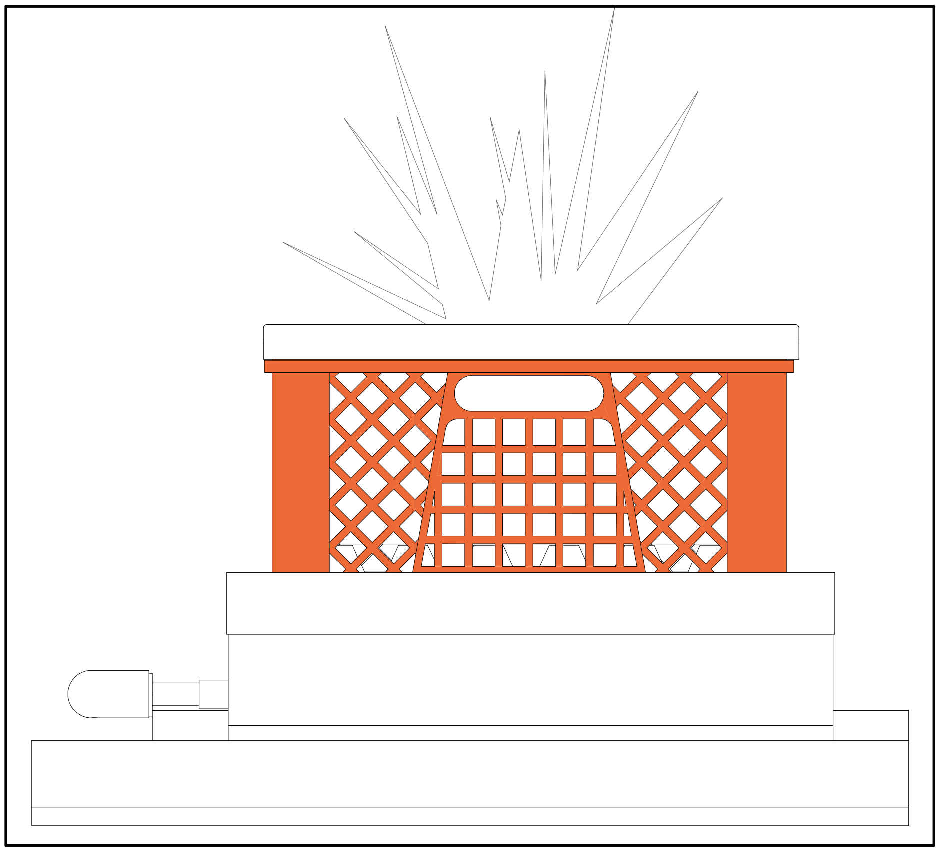


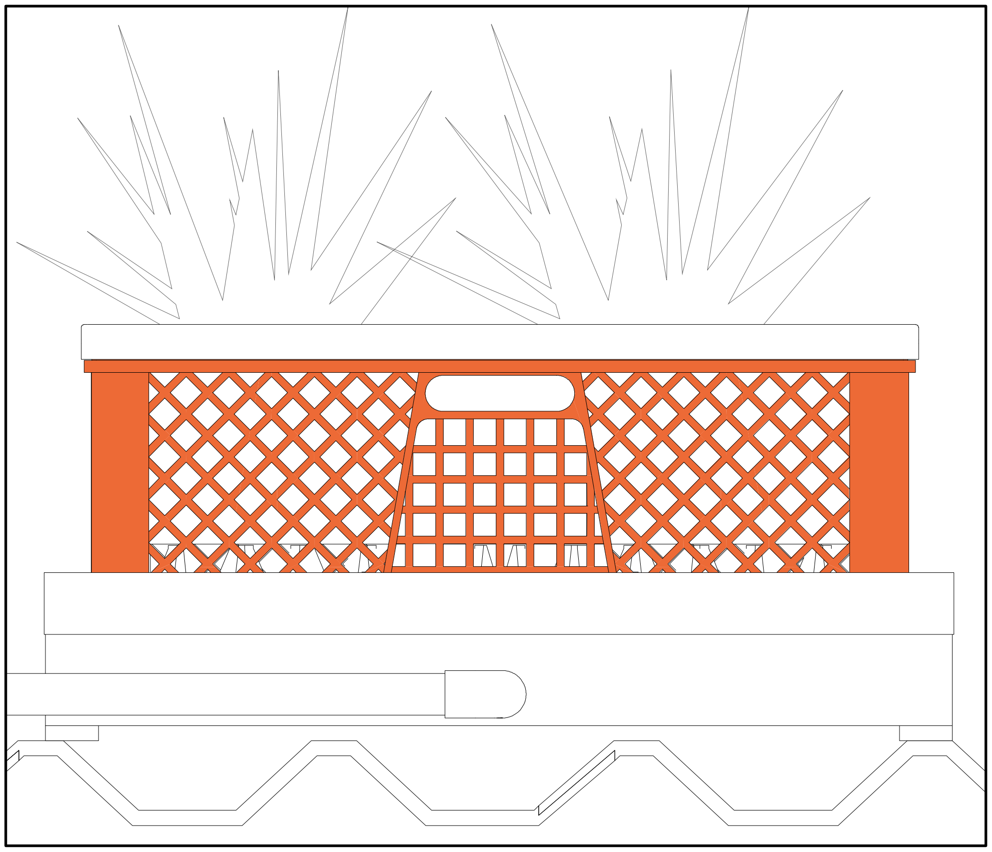


Blue-Green Roof Module plan and elevations. Scale 1:5

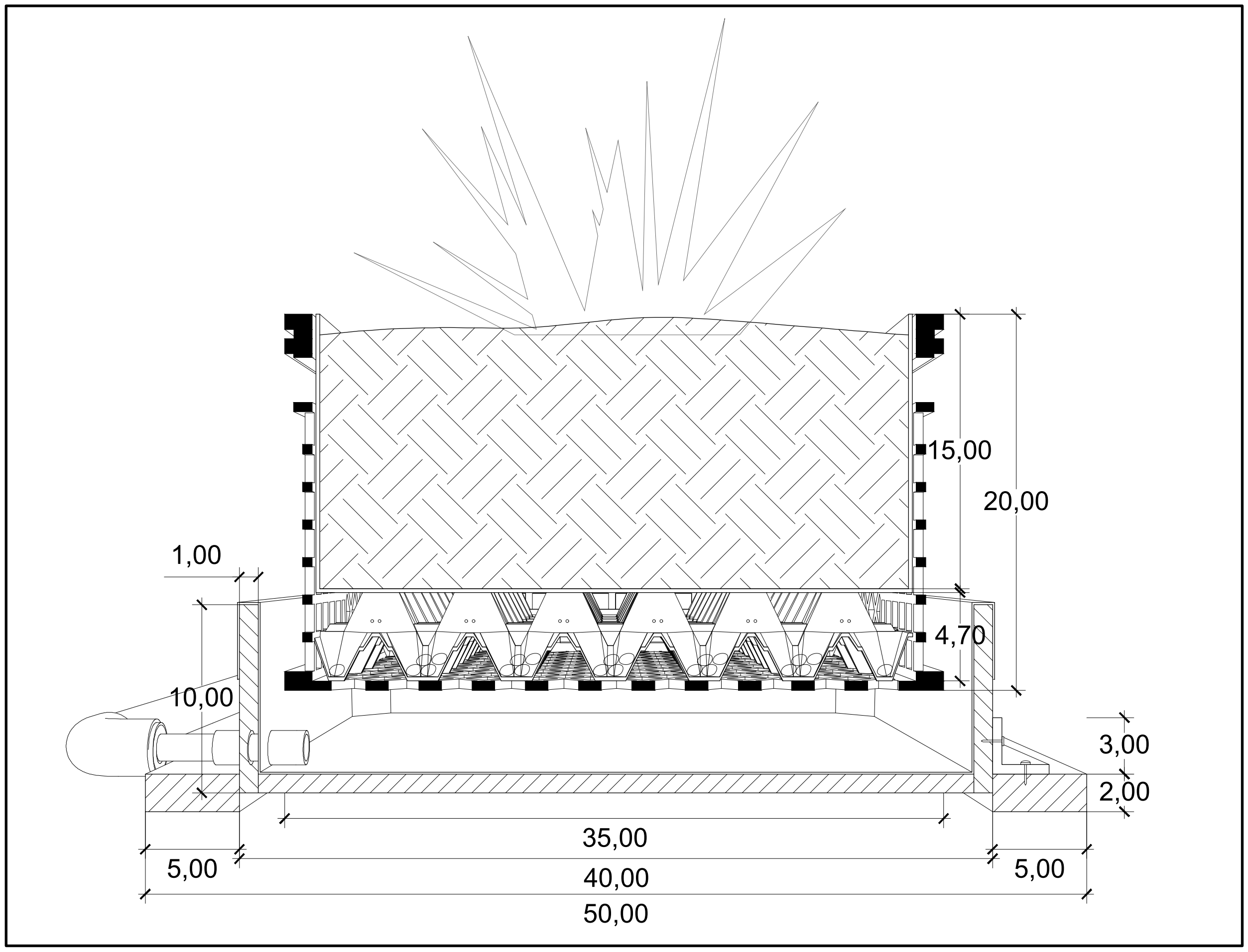
Particular attention is paid to the anchoring methods, because the module is designed to be easily assembed ad disassemled, given the need for maintenance. For this reason the technology of the anchoring methods follow the two parts division. The lower tank has to be inserted in a structure that guarantees its fixing: in this case the structure is a wooden frame, to which the module is attached with screws. Instead, the upper part must be easier to remove as it requires more constant maintenance. For this reason the fruit box is placed on two horizontal supports inside the short sides of the lower tank and anchored to it with adjustable clamps.
In the case study the wooden structure also serves as a support for the water collection system that will be illustrated later, but it has to be noted that according to surface to which the module has to be anchored the system can variate. For example, if there is the possibility to fix the module directly to the surface, screws can be inserted into the base of the plywood tank, being careful to position the insulating sheet afterwards.

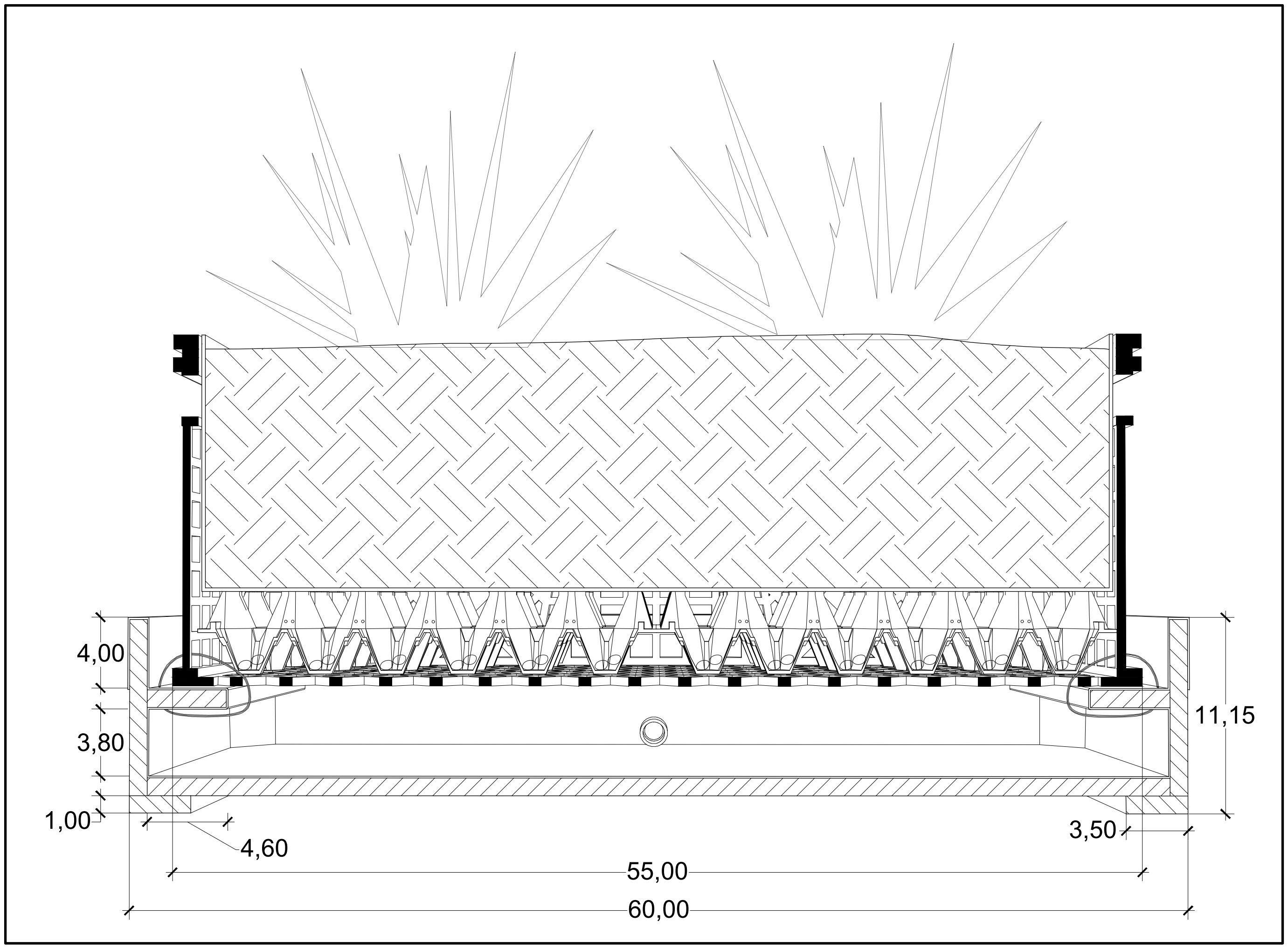






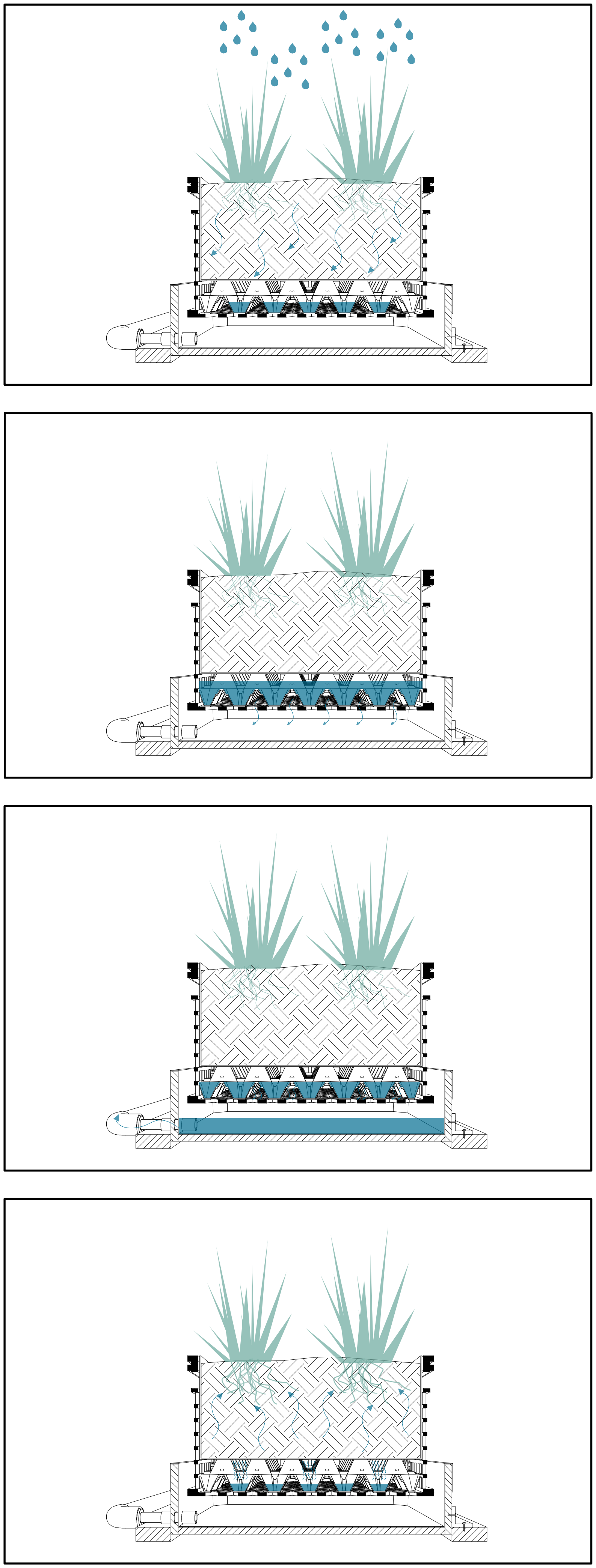
Blue-Green Roof Module sections. Scale 1:4





Blue-Green Roof Module functioning.

The operation of the module replicates exactly that of a green roof stratigraphy. When it rains, the water filters into the ground and fills the ovoid cavities that have the function of collecting water, which then goes up by capillarity in the soil above, with consequent nourishment of the vegetation. When all the ovoid slots are filled, the overflow process begins, so that water flows out of the tray. As the cavities are connected and the holes are 3 cm higher than the edge, for the process to begin all cavities must be filled evenly and the water must reach a certain level throughout the tray. In the examples encountered, water escapes from the module and flows over the roof surface whilst, in the module presented here, the wood tank collects the excess water and, slowing down the precipitation pressure further, sends it to the main rainwater tank. In the case study, the pitch for which the module is designed is not equipped, for reasons of architectural choice, with a water collection system. It has to be noted that, according to the typology of the roof, the upper part of the module can work and therefore can be used independently. The configuration of the module causes the overflow process to start at a capacity of 6,8 l/m2. While the amount of water that is stored in the tanks is of 50 l/m2.



Blue-Green Roof Module prototype.

The rain garden design: toward a better rainwater management

Once the roofing problem was solved, the same reasoning methodology was applied with regard to the deck area with the aim to use a technology similar to the one choosen for the roof, but adaptable to the paved surface of the deck. Based on the research carried out and the catalogue, the choice fell on the typology of the rainwater garden that presents the same functional layers as the roof module, but with a different conformation of the various elements. As a general explanation of the rainwater garden is given in the second chapter[20], from here on only specific information regarding the module designed for the Solar Decathlon *Vivienda* will be provided.

The rain garden sizing was the first step of the design process, involving the determination of the surface area necessary to contain rain loads during a storm. In order to determine this area, a number of characteristic variables were required regarding both the climatic aspects of *Cartagena de Indias* and the *Maquina Verde* project features. The precise computation steps are:

- Selecting and measuring of the catchment area surface (1);
- Estimating of precipitation during a storm event (2);
- Calculating of the volume of rainwater draining from the catchment area (3);
- Establishing the pooling depth (4).

In order to measuring the catchment area it was essential to understand how much water flows over the surfaces of the entire project and in order to do that an inventory of the waterproof surfaces, where the rain will fall and run off, was made. The sum of these areas surfaces represents the catchment area. In the *Maquina Verde* project only the roof was considered as a waterproof surface because the wooden deck includes cracks that permit water to flow below the pavement and into the ground. Furthermore only the two lateral pitches were considered for the calculation of the catchment area, because they are the only ones equipped with gutters and downspouts that allow the water to be directed in a specific direction. The value that has to be used in the measurement involves the use of the horizontal projection of the roof multiplied by a specific flow coefficient: the runoff coefficient that assumes some losses in the amount of water flowing off the roof, defining the actual catchment area. A typical range values is between 0,75 and 0,90 and the recommended one, which was used for the project, is 0,80 (step 1 in the formula).

Subsequently the volume of the precipitation during a strom event was estimated. In order to determine how much runoff volume the system interacts with - and consequently how large the rain garden should be - it was essential to understand how much rain falls during the biggest rain event through the precipitation value. The rainfall intensity is the amount of rain that falls in a given period of time during the most intense phase of a storm. Usually the heavy rainfall of a powerful storm (the peak intensity) is used in the calculations and the higher the design storm, the larger will be the basin. However it has to be noted that the choice of the right value is an inexact art and depends on several factors, i.e. the time that a raindrop requires to pass from the roof to the rain garden. To calculate this value data elaborated from the analysis of archived precipitations graphs and tables were used. The data were collected in the main meteorological station of *Cartagena de Indias*: *Rafael Nuñez*, located in the city airport. [21] The analysis includes a representative sample of the population of the rainfall data set and the period considered is 10 years, from 2010 to 2019. At first, the maximum peaks of each month within the sample period were taken into account to determine the precipitation value to be used in the calculations. The data have a high medium square deviation, which does not guarantee uniformity in the collection, risking to lower the estimate of the value to be taken into account. Subsequently it was decided to select the most significant event for each year and finally find the average of the 10 selected values, therefore the result is calculated as the average of the most intense precipitation of each year since 2010. All these data are represented in the graphs on the following pages (step 2 in the formula).

Then, in order to determine the volume that the rain garden needs to meet the set objectives, it was necessary to calculate the volume of water that it must be able to contain. The runoff volume is the amount of rain that flows from the catchment area to the infiltration surface during a heavy storm and it depends on the catchment area, a runoff coefficient and the intensity of precipitation. This value was calculated considering the

[20] Second chapter, paragraph 4.
[21] http://bart.ideam.gov.co/.

surface of the catchment area, determining the capacity of the house to capture and direct the water to the garden. Moreover - with reference to the peak value of the average precipitation seen previously - it has been assumed that this daily value can be divided by 24 hours in order to obtain an hourly average of precipitation. In the case of the *Vivienda social*, a collection area of 40 square meters and an average storm intensity of 5.88 mm/h has been calculated. This precipitation value was determined considering that the abundant rainfall in the area under examination is around 1 hour (step 3 in the formula).
The last step to determine the raingarden area was establishing vertical dimension of the technological system. Usually this dimension depends on the type of soil in contact with the raingarden and its drainage capacity. On the other hand, in the case of *Maquina Verde*, it was decided to place the garden in a waterproofed container in order to be able to collect rainwater and reuse it for secondary needs. The project requires this box to be the same height as the space under the deck. In this way the vegetated surface is about the same height as the deck and integrates perfectly with the pre-existence (step 4 in the formula). Finally, because volume is the product of area and depth, it is easy to calculate rain garden surface area once determined its volume and depth (step 5).

Catchment Area (1)

$$A_c = \text{length} \times \text{width} \times P_{rain} \times c_{runoff} =$$
$$= 5{,}93m \times 3{,}90m \times 1 \times 0{,}85 = 19{,}68\ m^2$$

Total Catchment Area (2)

$$A_{Ctot} = A_{C1} + A_{C2} = 19{,}68\ m^2 + 19{,}68\ m^2 =$$
$$= 39{,}36\ m^2 = 40\ m^2$$

P_{rain} = percentage of rain that ends up in the downpipe; the project provides only one downpiper por slope, so it is considered 1 (100%).
c_{runoff} = runoff coefficient.

Rainfall Volume (3)

$$V_{runoff} = A_{Ctot} \times [I_{mm}/(t \times (1\ m/1000\ mm))] \times t =$$
$$40\ m^2 \times [\ 5{,}88\ mm/(1\ h \times (1\ m/1000\ m))] \times 1\ h =$$
$$= 2{,}73\ m^3$$

I_{mm} = average peak precipitation in 24 hours.
t = time period considered for the duration of an event.
1m / 1000mm = conversion of the measurement units.

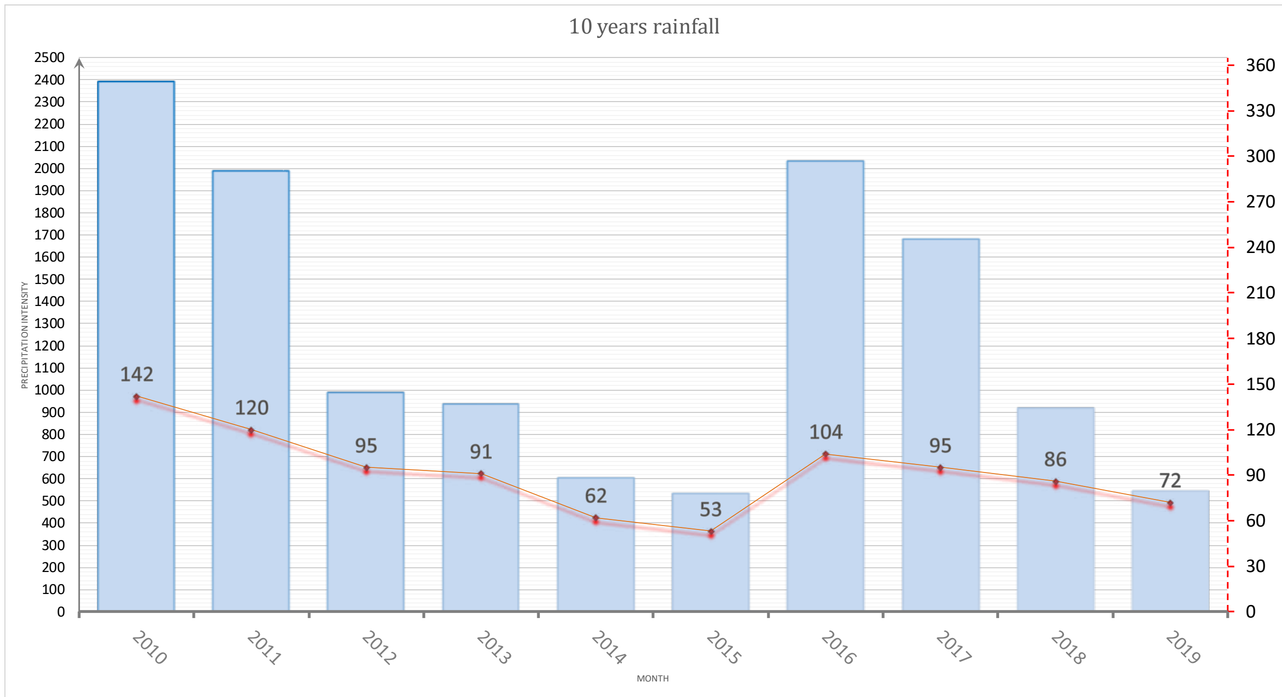
Pooling Depth (4)

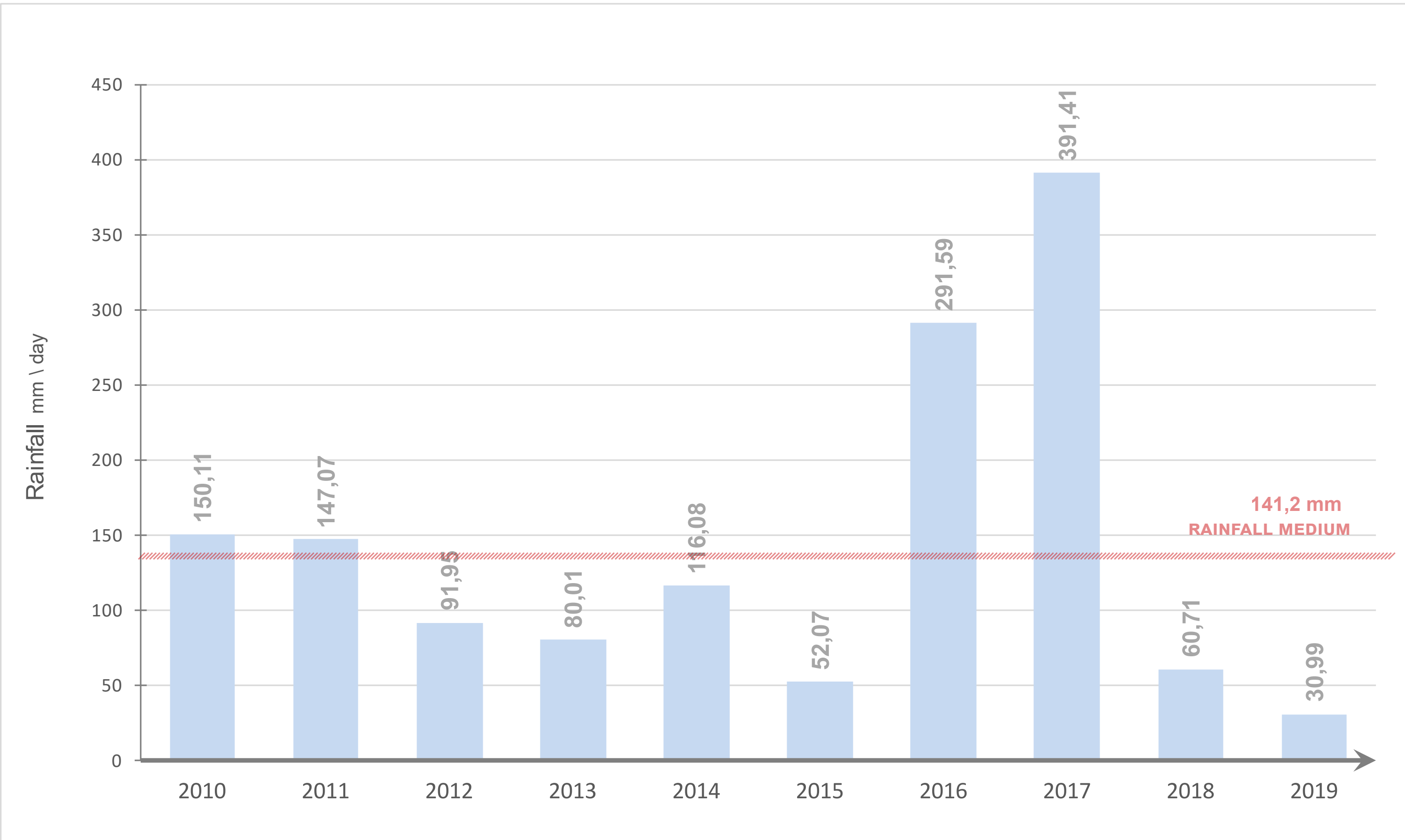
$$d = 500\ mm$$

The Area of the Raingarden (5)

$$A_{garden} = V_{runoff} / [d \times (1\ m/1000\ mm)] =$$
$$= 2{,}73\ m^3 / [500\ mm \times (1\ m/1000\ mm)] =$$
$$= 5{,}46\ m^2 = 6\ m^2$$

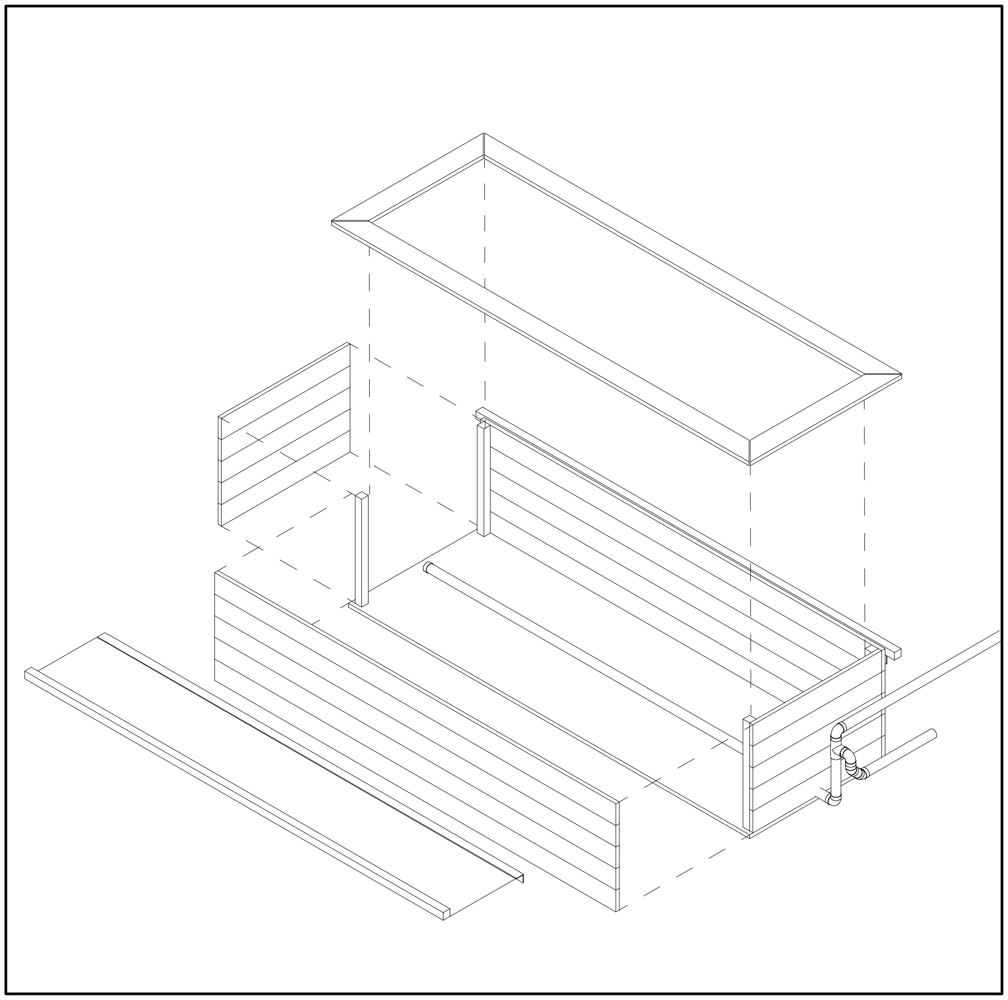
The graphs were elaborated by the authors based on the informations found on www.epacartagena.gov.co.

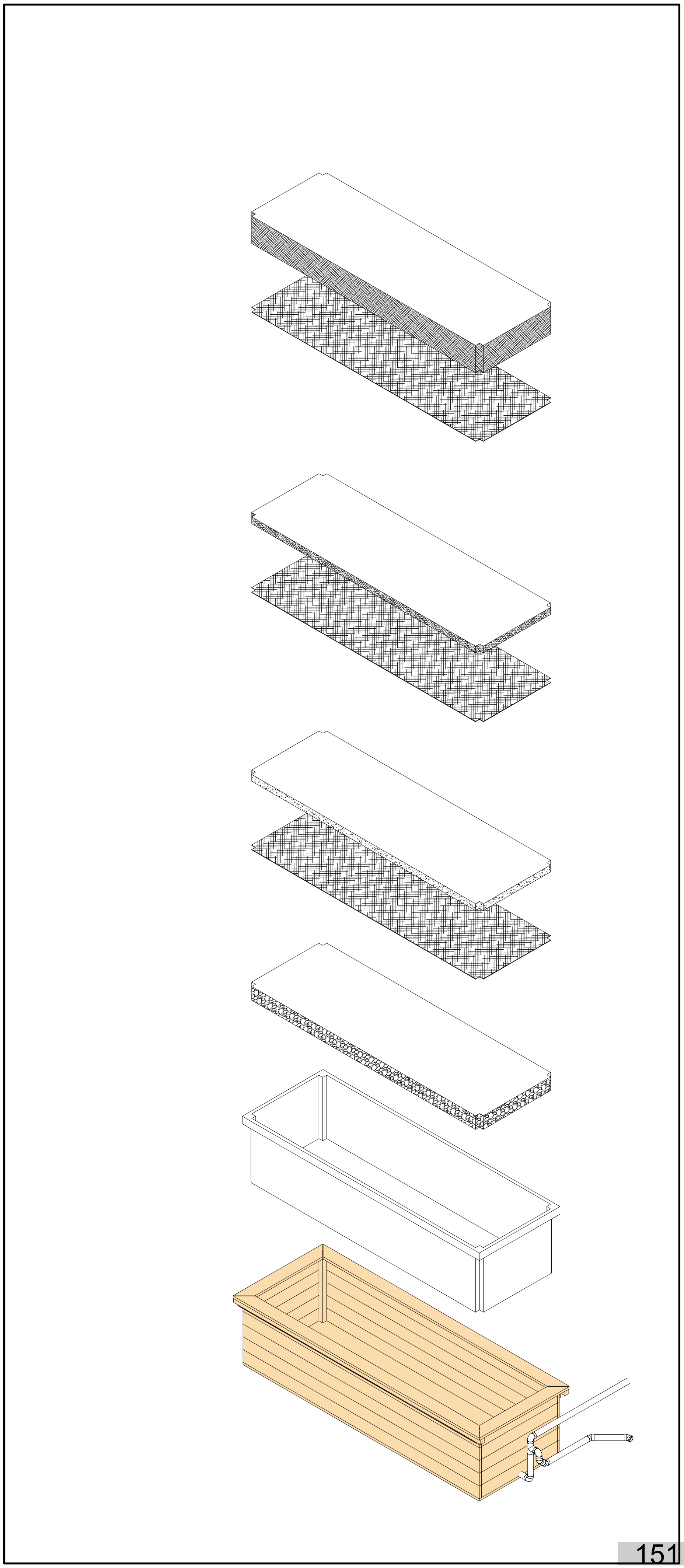




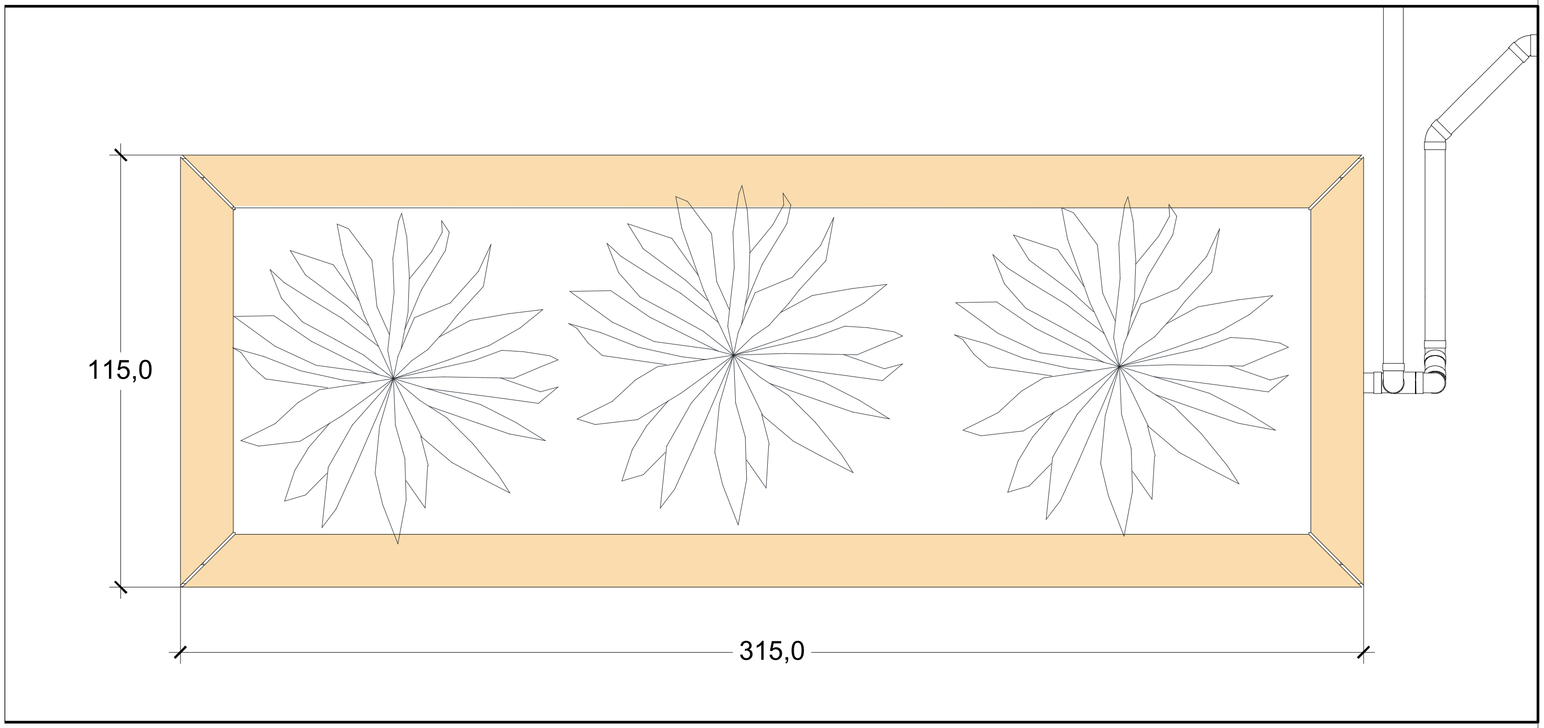
Rain Water Garden exploded view. Scale 1:50

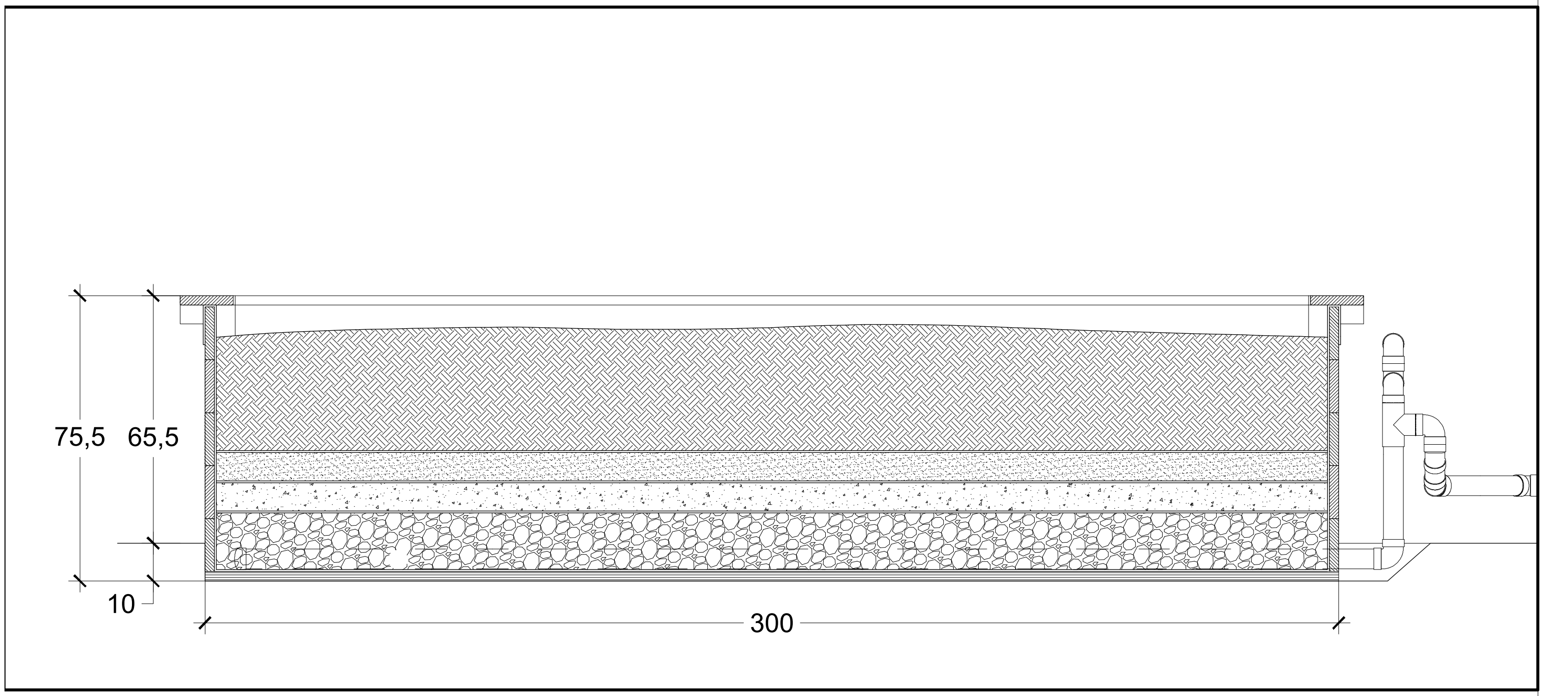
The module presents the classic stratigraphy of a rainwater garden. First of all the surface is covered in a waterproof layer, on which lays the stratigraphy, so composed: gravel, pea-gravel and a sub-base of sand. The topsoil is made of a mixture of 50% of sand, 25% of compost and 25% of loam. In the case study, the rain water garden is inserted into the paved surface of the deck in a container, which is made of the same planks that are removed from the surface to make room for the module. In this way it is not necessary to use additional material to that estimated for the construction of the prototype.

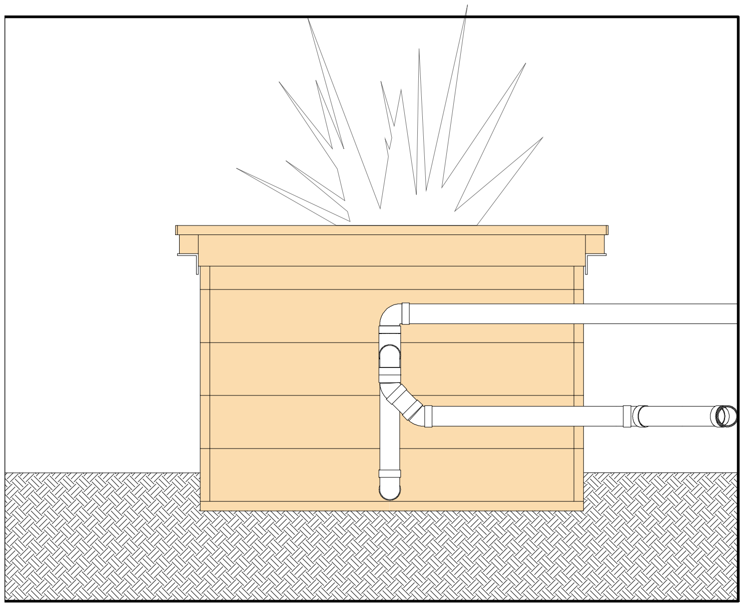


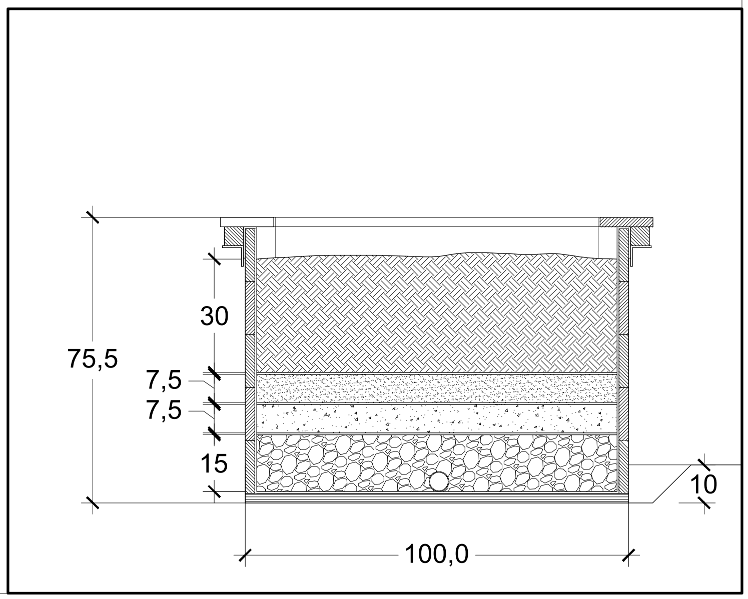


Rainwater Garden plan, sections and elevations. Scale 1:20



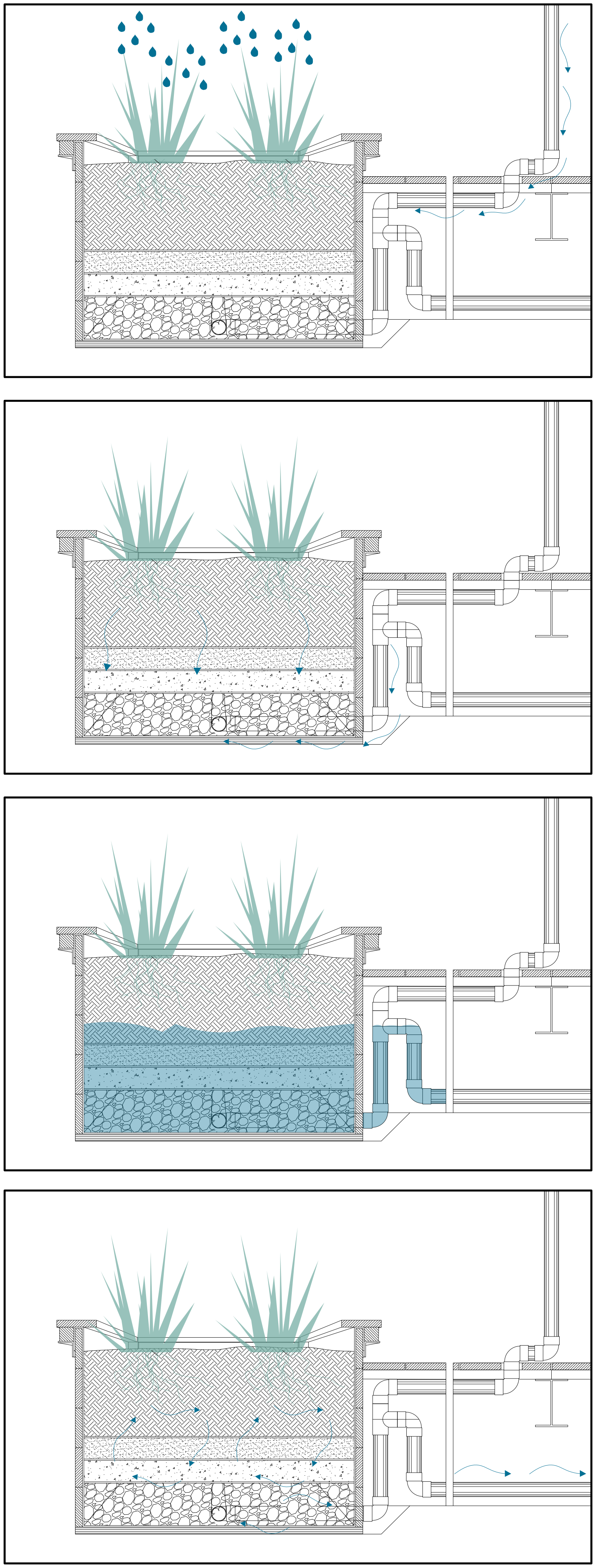






Rainwater Garden functioning.

The Rainwater Garden is connected to the traditional rainwater collection system through pipes that run in a pipette, so as to control the flow of water that reaches the module and also its speed. The water strats to fill the vegetated module, until it reaches the height of the pipette that connects all the system to the rainwater tank. In this case the amount of water is supplied not only by the gutters, but also by the water that falls directly on the module and on the paved surfaces on the sides, in order to collect as much water as possible. As soon as the water level reaches 90 degrees to the pipe, counting that a part of it will be absorbed by the ground, it starts to fill the connection pipes, leading to the main supply system. In this way, hyenas guarantee the amount of water needed to feed the plant species and the collection of excess water for other uses.



The overall system: from Maquina Verde to the Vivienda Azul-Verde

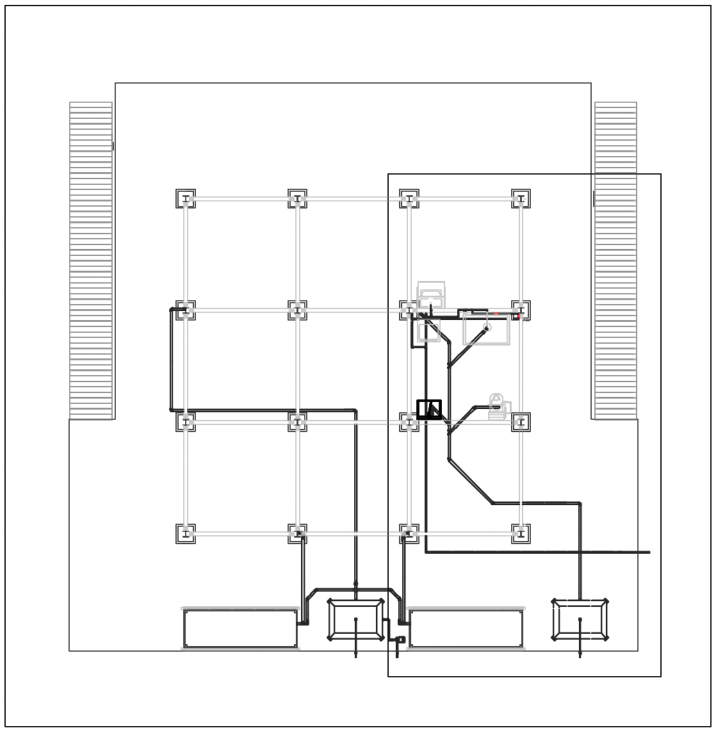
In the following pages the whole water system will be illustrated along with the changes assumed for the future of the *Vivienda*. The representation tries to follow the logical process acquired during the construction and installation of the hydrosanitary system: the drinking water, the grey water and the rainwater networks will be shown separately.

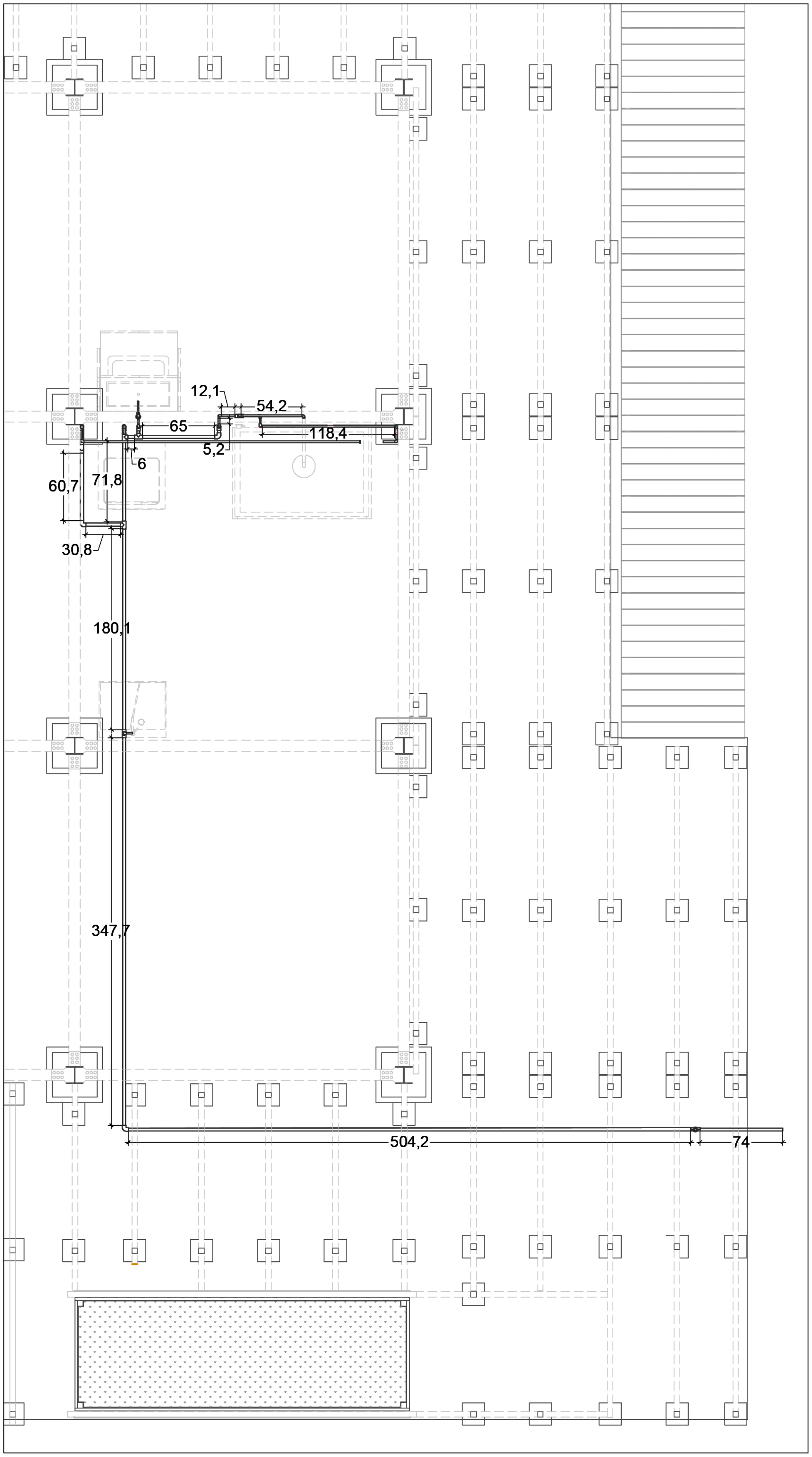
The drinking water system has not undergone any particular changes, except for the distribution of hot water. In the months following the end of the competition, in fact, there were maintenance problems regarding the water heating system, made with MDF panels and a garden hose, positioned on the fixed roof pitch. Specifically in case of rain, the panels were constantly filled with water that caused them to rot if someone did not proceed to empty them immediately after the rainy event. For this reason they have been removed and replaced by an electrical heating system, located on the mezzanine in correspondence with the wall between the bathroom and kitchen.

The grey water collection system has been separated from the rainwater one, as it is no longer considered to use only ecological soaps. A new grey water tank has been inserted, equipped with a control filter, which collects the waste water from the shower, washing machine and bathroom sink. In addition, the urine drain pipe of the dry bath, which has an integrated mineral filter, has been connected to the same tank via a control well to remove impurities.

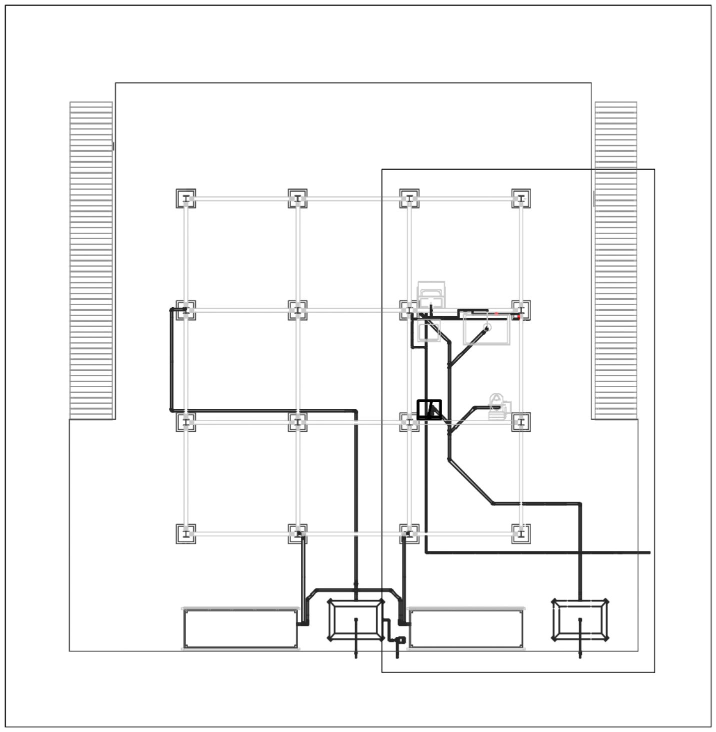
As far as rainwater collection is concerned, the green bue technologies inserted have substantially modified the system with regard to the amount of water recovered and the house itself in its external design. As far as the roof is concerned, the green modules are placed on the kitchen and social area fixed pitch, replacing the heating modules. There are 28 in total, arranged in two rows, and occupying a total of 7 m2, including the support structure and the water collection system that connects directly to the rainwater tank. As far as the gutters are concerned, on the other hand, two rainwater gardens have been added, which receive water through the pipe system described above. When the water reaches the height of the pipe, it is sent to the rainwater tank, where it is collected and from which it is then drawn for different uses. Although this water is not drinkable, it can still be considered clean and therefore it can be used for external surfaces, watering and other similar purposes. In addition, by contextualizing the project in *El Pozón*, it can also be imagined that water is used for more purposes, for example for the cleaning internal surfaces or washing the dishes. As it was said before, in fact, collecting rainwater and reusing it for different purposes, especially in case of lack of drinking water, is a common custom for the inhabitants of the neighborhood.

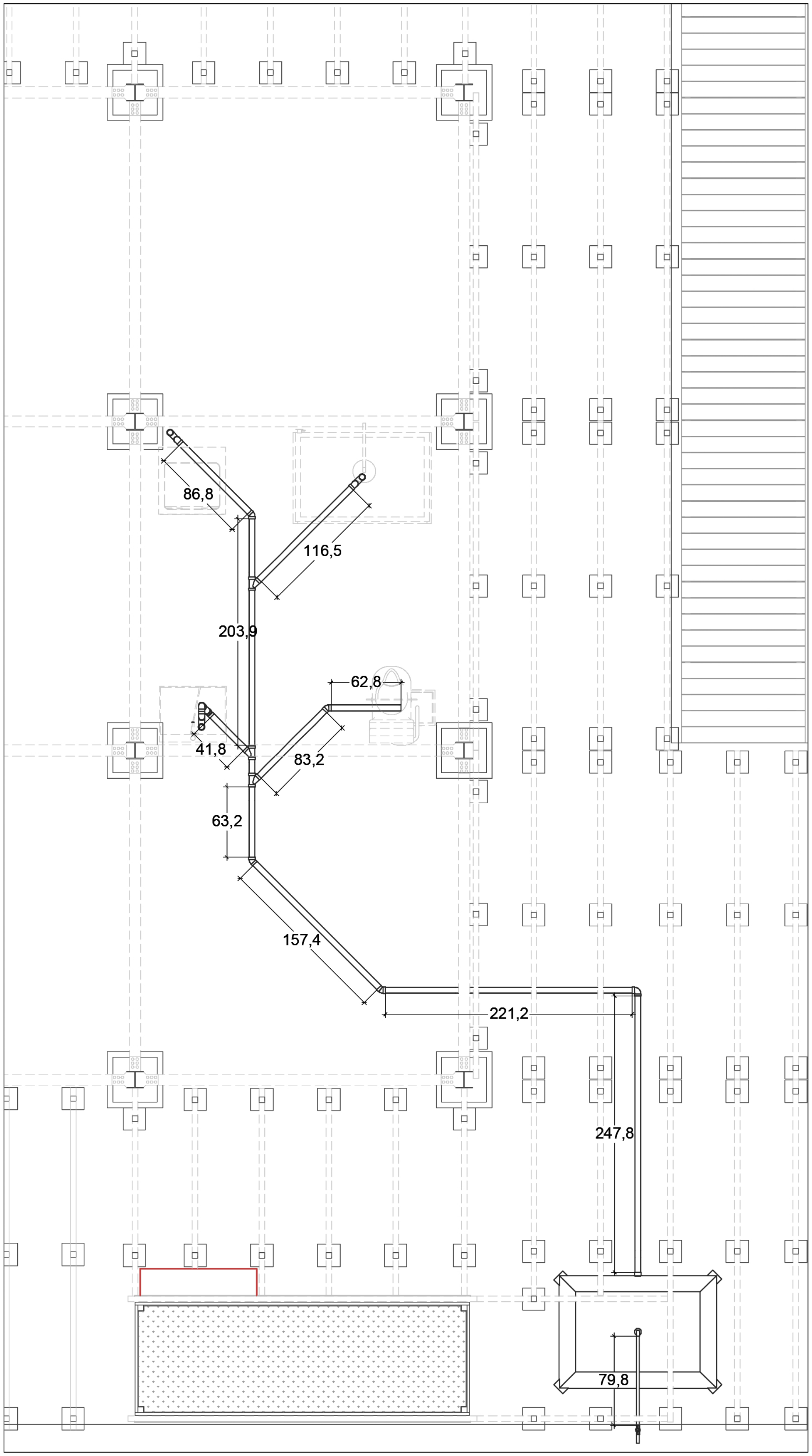
Drinking Water system plan. Scale 1:50



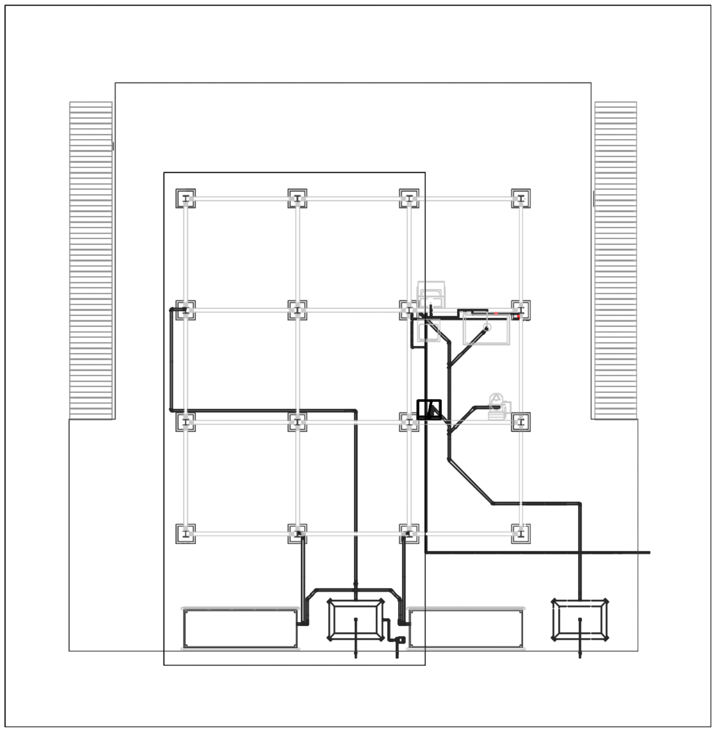


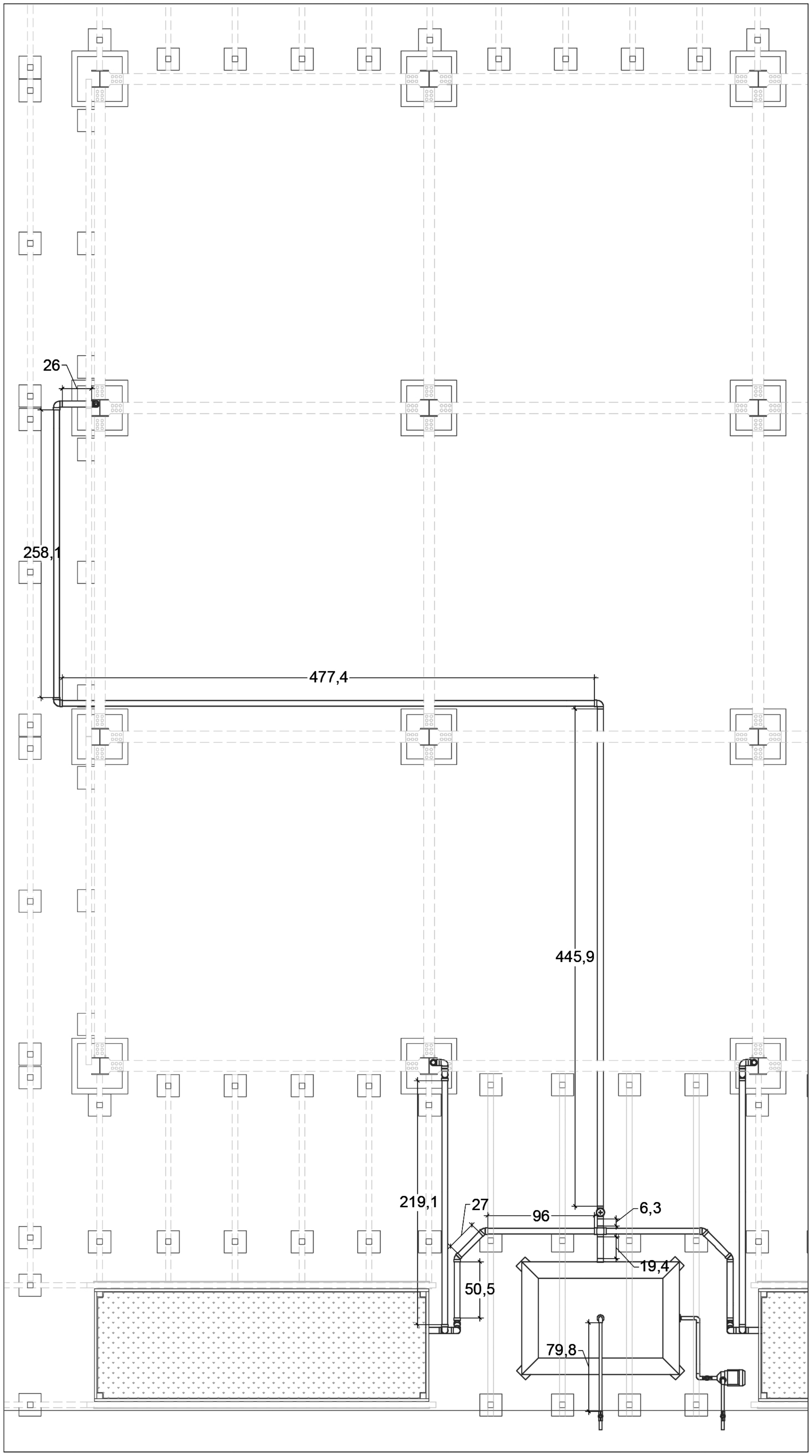
Grey Water system plan Scale 1:50



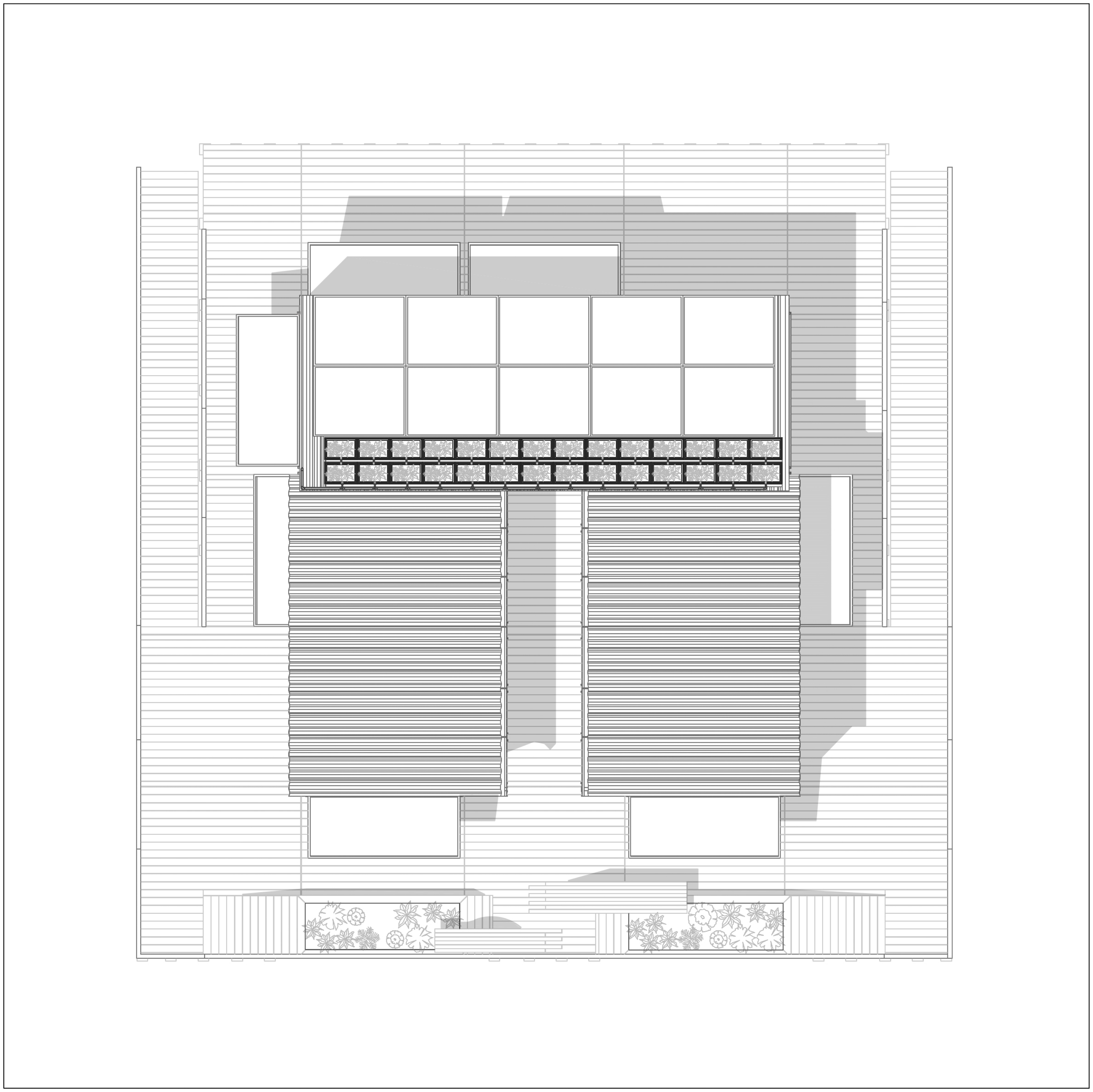


Rain Water system plan. Scale 1:50

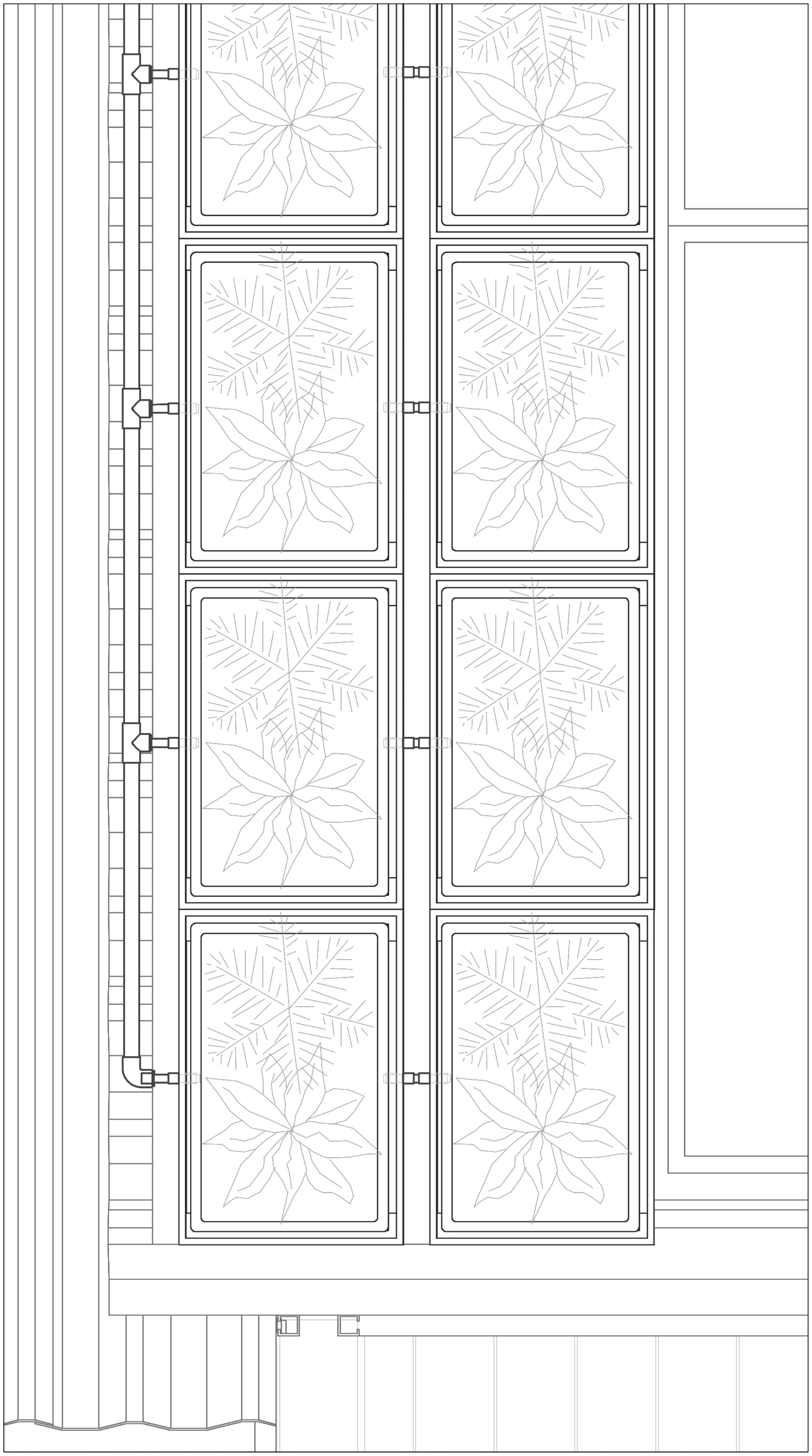




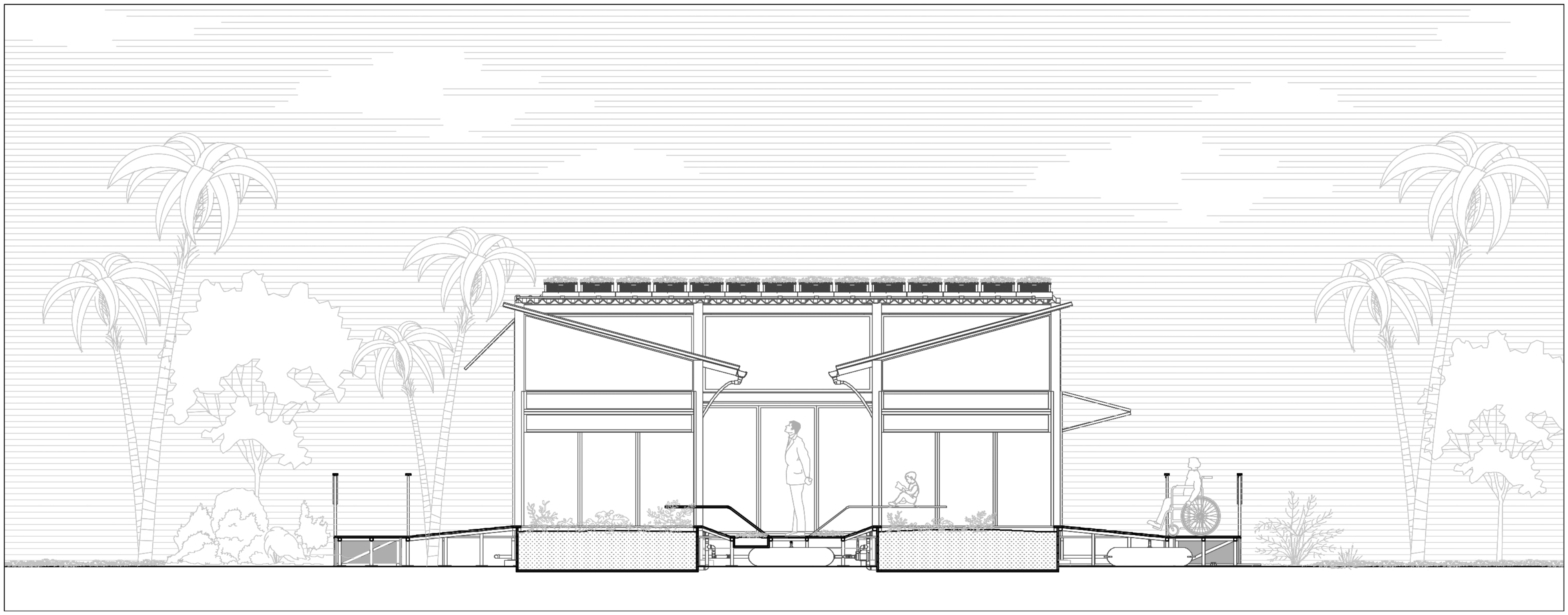
The Green Machine general plan. Scale 1:100

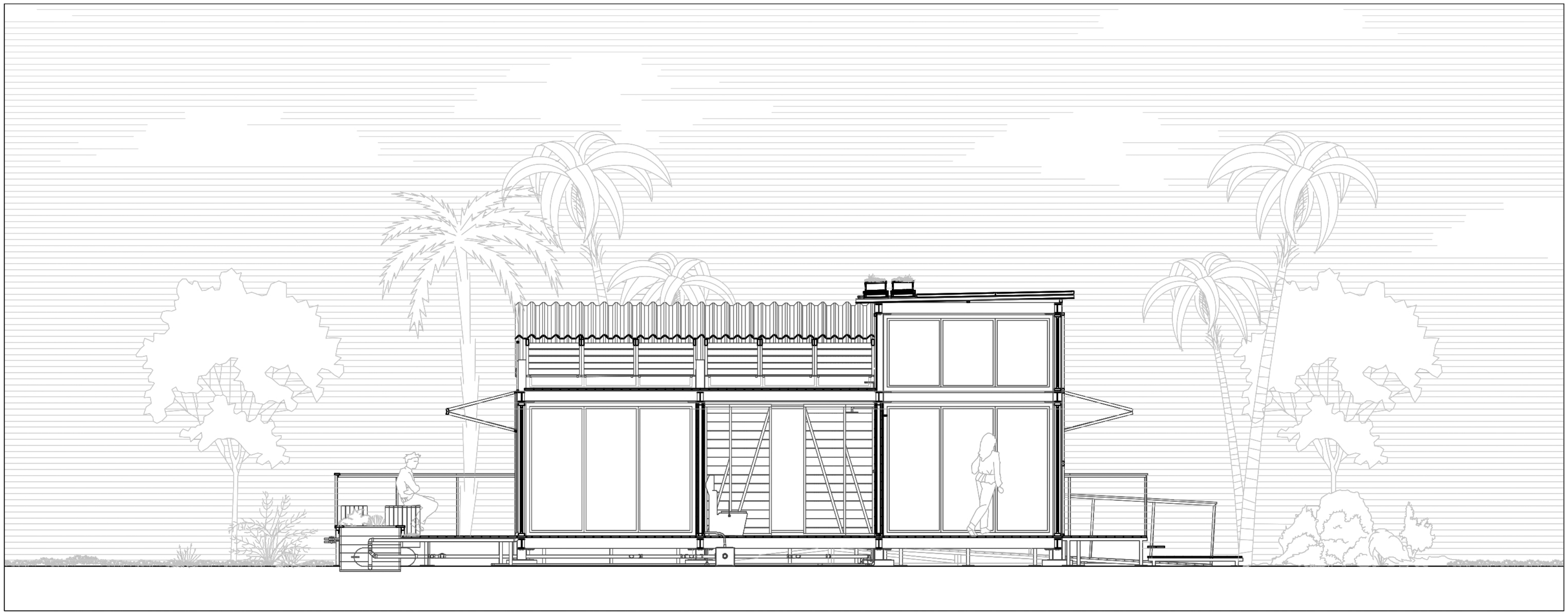


Blue-Green roof system plan. Scale 1:10

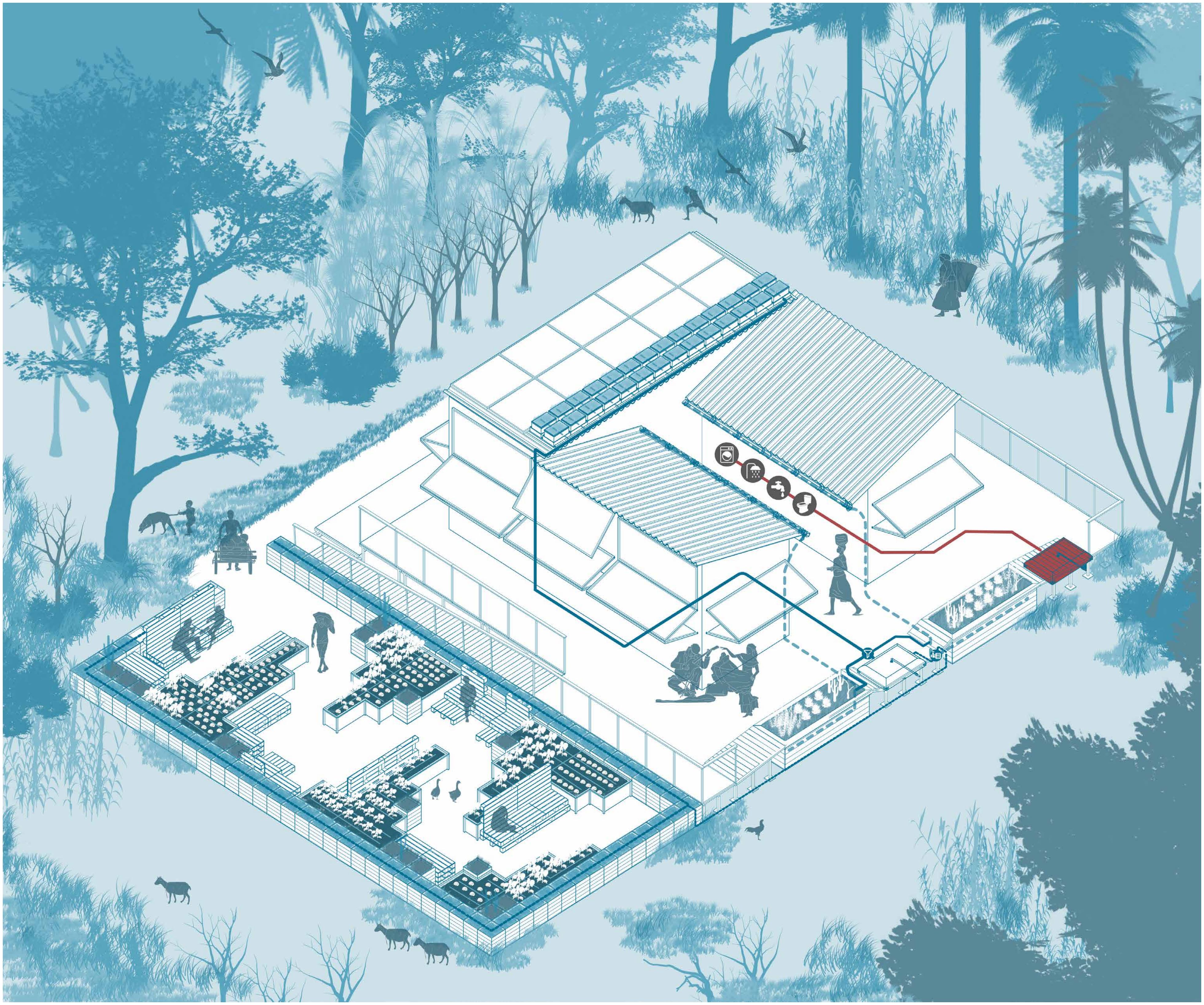


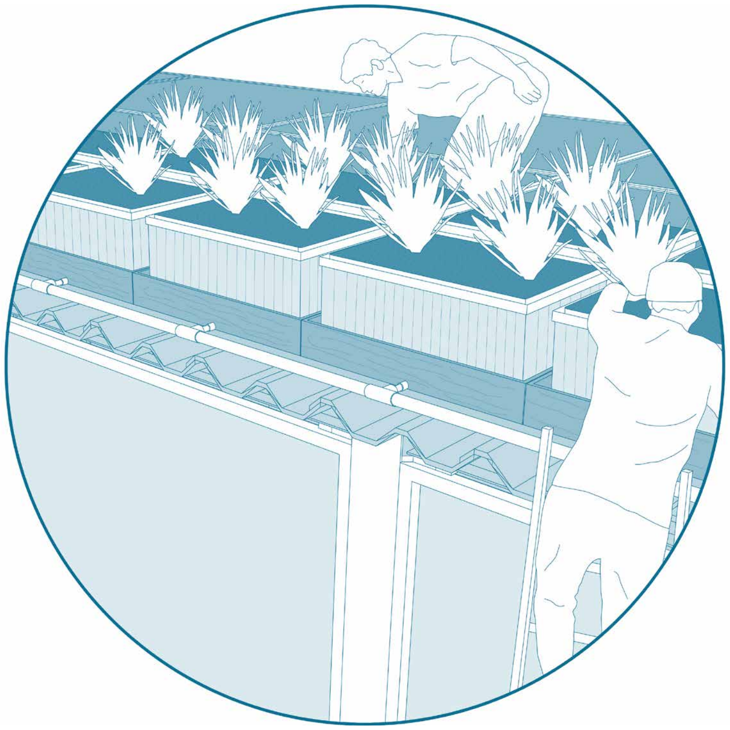
The Green Machine sections. Scale 1:100

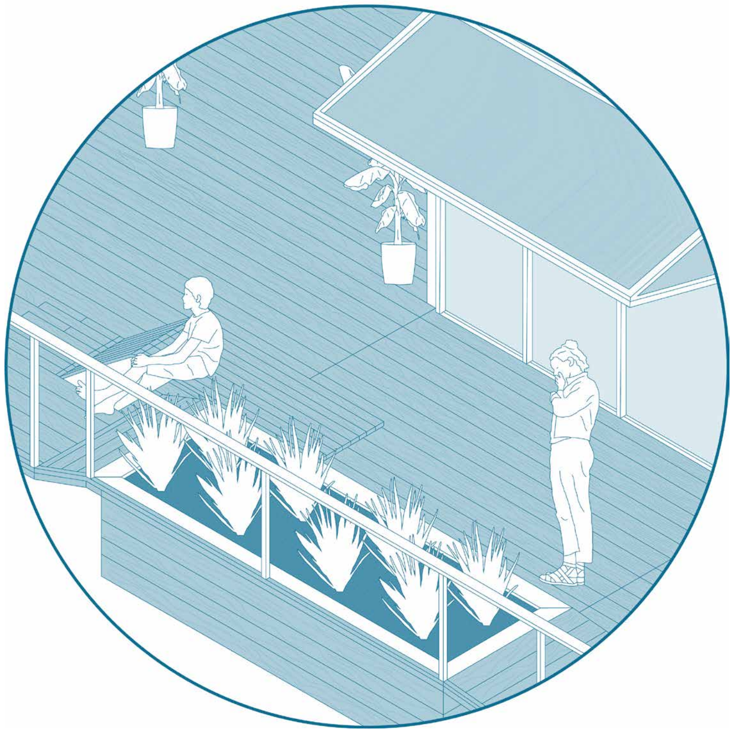


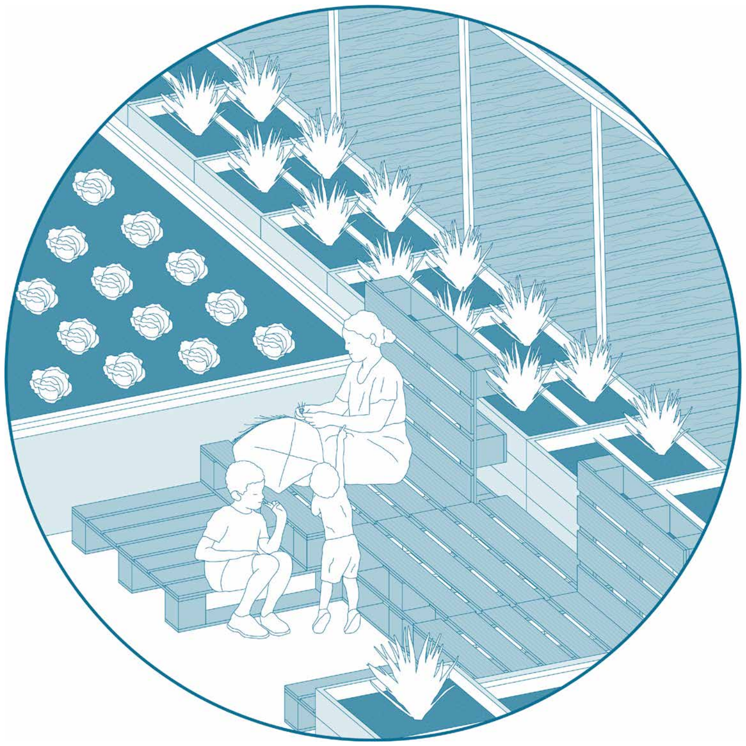


The Vivienda Azul - Verde









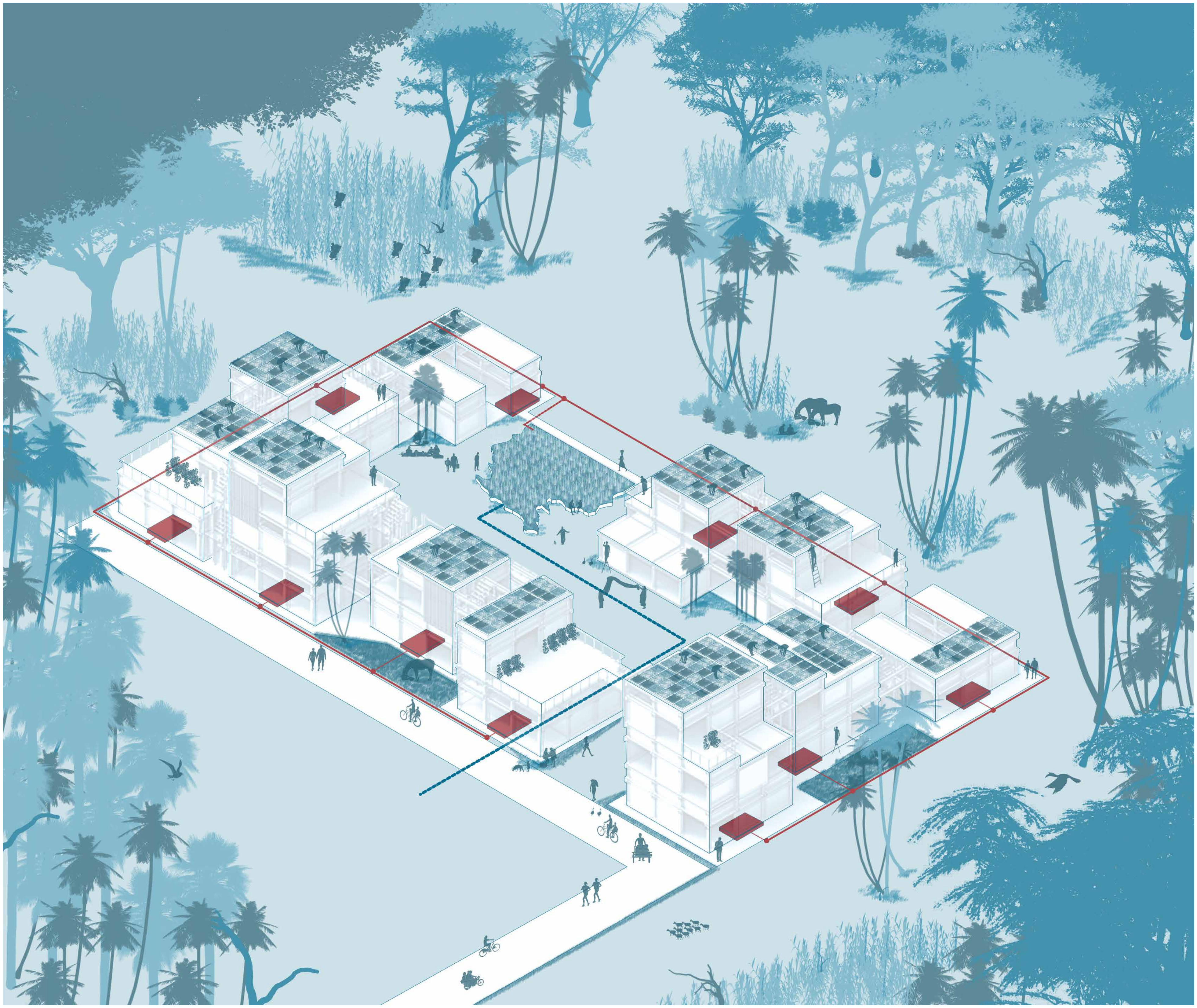
Interconnected archipelagos

The drawing represents the schematization of the rainwater management in the building, from its collection through the channels, the green modules and the rainwater garden, to its storaging and possible disposal. In particular, in this case the exit point is identified as the irrigation point of the garden on the side of the house prototype. This green area was not built during the competition, but was designed as an appurtenant space of the house. In the case of the construction of a single dwelling the water collected, therefore, would meet the needs of the green areas of the house, in addition to being used for other uses, depending on the choice of the owner. This scale is the one that has been examined in more detail, also through the direct experience of construction during the Solar Decathlon. In this case the grey water, indicated in red, is collected in a tank and, in the case of the individual module, disposed of directly on site. To the side are painted some possible scenarios that illustrate how blue-green technologies can be experienced by the inhabitants.

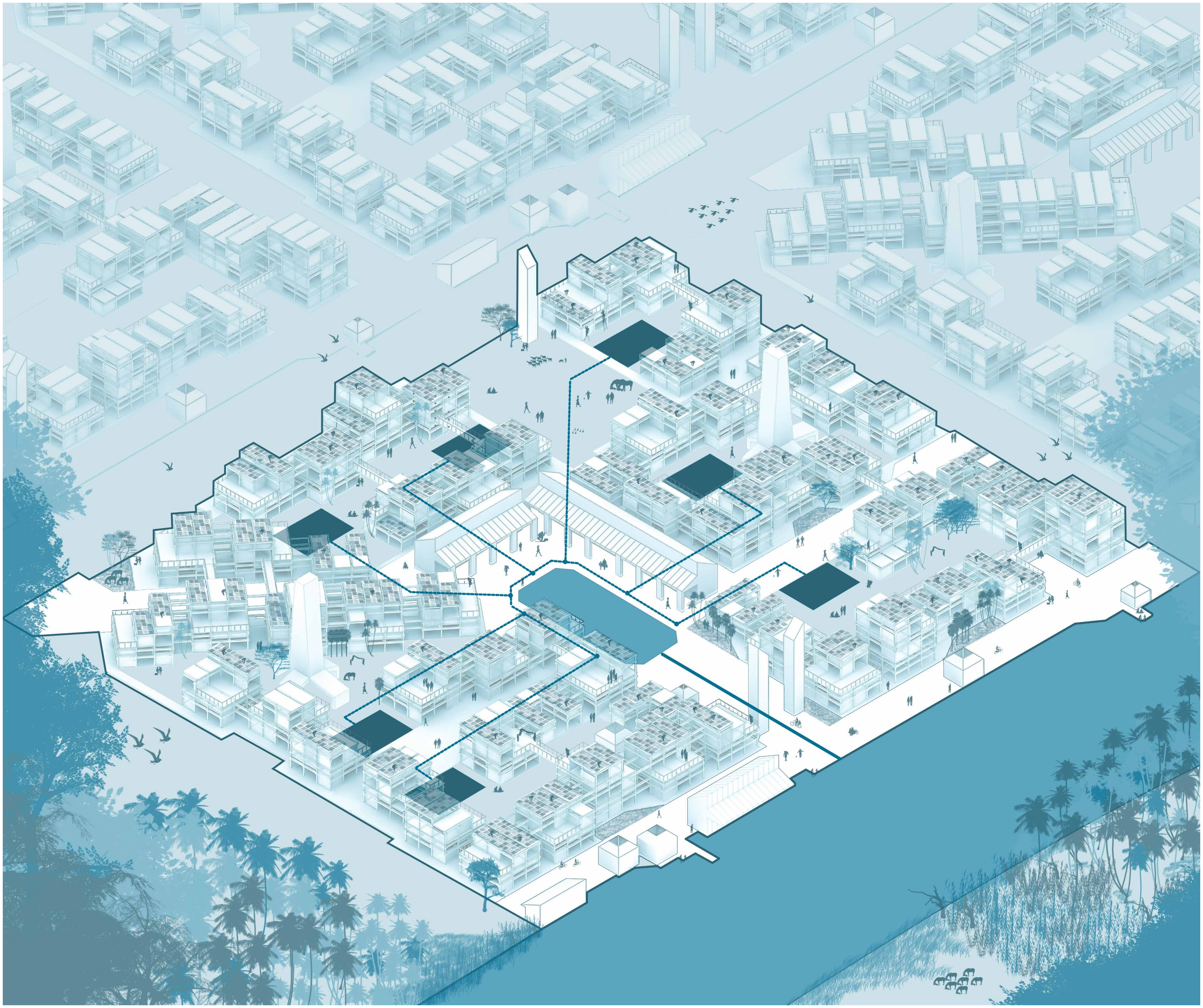
The intermediate scale represents the subsequent evolution of the single prototype, which is developed through different repetitions in height. In this case the rainwater system is shared by several units, as are the collection and storaging technologies. One of the possible scenarios for the re-use of residual water is presented with a particular attention to a circular economy. In fact, it is proposed the insertion of a phyto-purification basin to clean the residual water coming from the sanitary fittings of each house, so that it can be storaged, purified and reinserted inside the houses or exchanged with other groupings of the same size. In this case the size and configuration of the basin are purely illustrative in nature and are intended to represent one of the possibilities for achieving integrated and sustainable management of water resources within the urban proposal submitted for the Solar Decathlon competition.

The last case represents the largest scale, in which several groups are joined together in an archipiélago. In this case the prototype of the house is related not only to public spaces shared by all users, but also to the system of channels that characterize the Pozon territory. The main idea is that by repeating the proposed scheme in the small scale, the water resource is shared throughout the group, always in the concept of a closed circle. In this case, through the large-scale collection of rainwater, ponds are proposed, which, in addition to contributing to the cooling and paving of the area, act on the canal system. Guaranteeing a certain flow of water that enters the channels, also characterized by a certain degree of purity, in fact, it could contribute to rebalancing the ecosystem of the *Ciénaga de la Virgen*.

The Manzana Azul - Verde



The Archipiélago Azul - Verde



Conclusions

The various stages that led us to the writing of this thesis were all fundamental in determining our work through a non-traditional approach. The research of the fundamental theme of the thesis - the reinterpretation of nature based solutions - was not conceived a priori, but rather it was the path and experiences that led us to consider the research inherent to these technologies and their application in contexts such as those examined.

Being part of an international design team was the first step that allowed us to approach the theme of water. Working within a team structured and organized according to project themes allowed us to understand the importance of dialogue and compromise, the importance of teamwork and the organic nature of the architectural artefact. What better experience to fully understand the various parts of a building than those of the design from the conception phase to the execution and subsequent realization? In addition, having the opportunity to speak directly with some figures who had also participated in the previous phase of the urban project we had the opportunity to know the project site of the informal neighborhood *El Pòzon* in *Cartagena de Indias*. These first contacts were fundamental to determine the case study of this thesis and to bring us closer to a context far removed from the cases examined in a European academic context. This cognitive experience shifted our point of view into a very different reality, in which we had to immerse ourselves completely in order to understand the needs we later decided to face. The construction experience in Cali has allowed us to get closer to practical aspects of construction by substantially changing our idea of the importance of architectural language within the executive context. We understood the need to translate project inputs into executive outputs, the importance of project management and the detailed organization of the various phases of work. We understood the importance of time economy during these phases which must be considered before the opening of the site and nothing can be left to chance or free will. Finally, the considerations of the construction phase have changed our approach to the project, bringing us closer to the figures of the builders who have to realize what is designed on paper.

This wealth of experience led us to Cartagena de Indias, eager to begin the inspections of the project site that had been analysed until then through diagrams, drawings and presentations. The direct cognitive experience has a strength not comparable to the images translated by others. The natural places on the shores of the *Ciénaga de La Virgen* lagoon, the problems presented to us during the interviews and the state of degradation observed during the inspections have directed our research to consider of the utmost importance to maintain a green footprint in our proposal, trying as much as possible to decrease the impact of the disposal of wastematerials and enhancing the value of water resources to promote the economic independence that people seek within realities such as the informal neighborhood of El Pozòn. The key to the entire thesis work is the continuous comparison with different figures that have made the project born not only from a personal research base, but also from the dialogue with those who work in the field and live the territory.

This resulted into a research topic focused on a more comprehensive solution than single modular technology; in fact, the solution itself represents only one of the possible ones, while the methodology with which the research was approached, the material and compositional characteristics of the green module and the didactic function of the representation are intended to be an innovative proposal in the field of sustainable design for the contemporary city. This general methodology, moreover, here customized to the case study, it is conceived as adaptable to other realities where the tendency to search for local materials and the do it yourself practice are spreading not only as a necessity, but also as a design method attentive to environmental and social sustainability.

As in the case of the Maquina Verde project, where an adaptable living module was proposed to form an entire extension of El Pòzon, in the same way the green roof technology module makes multiscalarity its own connotation. Although in this case the focus is on the scale of the building, it is important to underline how the effectiveness of the proposed model increases proportionally with its application on a large scale. The attempt was therefore to present a pilot project, based on the reference study and the application of our relaborated nature based solutions technologies, and its strengths, to then move on to a large-scale application that could actually benefit not only the micro-system of the building, but also the macro-system of the neighborhood. The implementation of this low-tech solution at the building level, as well as presenting instant benefits that play a key role in raising people's awareness of the resilient project, is even more important in adapting to climate change. For example, the collection of rainwater for secondary irrigation reuse of a possible garden attached to the building systems in the PEI team's urban proposal would avoid waste of drinking water provided by the main network of the city of Cartagena de Indias. The cultivable gardens could provide basic food within the community, fostering sociality and exchange within the archipelagos. Our work focuses on the impact of nature-based solutions at the project level and seeks to stimulate further insights into both the effectiveness of do it your-self technological solutions and their performance at the macro-scale level.

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CONTAINMENT
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