Fog collection in buildings as a method to meet the future water needs

- A research project about how a biomimic approach in architecture can change the way a building interacts with its environment

Degree project in Architecture
School of architecture, LTH, Lund University
AAHM01 VT 2020
Student: Adam Richter
Tutor: Gediminas Kirkdeikis
Examiner: Per-Johan Dahl

Abstract.

This research project examines how, by studying principles and systems that occur naturally among plants and animals, lessons can be learned that can be applied in the design of buildings to make them more sustainable.

Based on the water shortage prevailing in the Spanish region of Valencia, I explore different ways of working with technical systems that extract water from air as architectural elements in the specific context of the national park that surrounds Mt Montgó.

Keywords: Biomimicry, Fog collectors, Adaptive facades systems, Water shortage

Acknowledgments.

I would like to thank my examiner Per Johan Dahl and especially thank my tutor Gediminas Kirkdeikis for his support and guidance throughout the project.

Table of contents.

Introduction	11
Structure of work	15
Background	19
Biomimicry	23
Experiment	39
Valencia	46
Design	50
Evaluation	75
Bibliography	83
Illustrations	87

Introduction.

Man's lost relationship with nature

The ongoing corona pandemic has paralyzed the world and brought to light the problematic approach that our civilization has developed to its natural environment in a previously unprecedented way. The realization that we do not stand over other biological organisms and processes that occur around us seems to have struck humanity as a bolt from the blue and although it is too early to draw any conclusions about how this global disaster will change our society, it is safe to say that it will.

Possibly, this disaster can lead to a conversation that will focus on how to succeed in restructuring an economy based on fossil fuels, continuous growth and consumption to become more circular and harmonize with natural ecosystems and processes. Not least, the younger generations have been more receptive to trying to find new ways forward that are based on what is at the heart of sustainability. Creating good conditions for life in a way that does not damage the conditions for future generations.

But despite this little shred of hope and despite dozens of global climate agreements that have replaced each other where there seems to be a global consensus on the seriousness of the situation, a green transition seems at times impossible to implement under the prevailing social and economic system.

What is to come may be worse than feared

A report published in September 2019 by the UN Climate Panel warns that our climate impact is worse than we previously thought. Natural systems are complex processes where small changes can have many unforeseen consequences, which makes all possible future scenarios that researchers have presented highly hypothetical and the consequences of our actions can prove to be far more fatal than we are able to understand at present (IPCC, 2019).

Pandemic outbreaks are predicted to become an increasingly common phenomenon in a world that has long lost its connection to the nature that once nurtured us where livestock now is increasingly taking place on an industrialized level and the effects of extreme urbanization on humans health are becoming more severe.

We all know that there is therefore a tremendous responsibility on future generations to learn from the mistakes that have been committed in order to design a society that is more in harmony with its natural environment and leaves room for other lives to develop as well.

The impact of the construction industry

Unfortunately, architecture and urban planning have, throughout history, been a major contributing factor to this development. According to the Global Status Report, jointly funded by the United Nations environmental program, the buildings and the construction industry annually account for more then a third of the global energy use and energy-related carbon dioxide emissions (UNEP, 2018).

When politicians fail to deliver concrete solutions, it is therefore a tremendous responsibility on all of us others who are active in the most polluting industries to pull our straw to the stack. A responsibility that can sometimes feel burdensome as many different interests must be weighed against each other and where the economic pressure many times weighs the heaviest.

For me as a future architect who will soon be out and active in one of the most polluting industries that exists, it was therefore an awakening when I first heard about the term “biomimicry”. I felt that sustainability, despite its significance for our future survival, was still an aspect that was not treated with the priority it deserved in the architectural office based on the experiences I had.

Rather, I felt that sustainability as a concept had begun to be used primarily as a marketing tool in a way that was many times counterproductive to its purpose. I realized that if many architects with the enormous knowledge that one possesses about the seriousness of the situation were still not able to address such a clear existential threat with better precision, then there was clearly something missing in the understanding of what sustainability actually means and I wanted for myself to see if I could find that other meaning.

Biomimicry as a concept succeeded in formulating this new meaning in a way that became clear to me. I reasoned that biomimicry had the opportunity give me principles for my future professional career that could guide me in my decisions and practice. I began to explore the concept more thoroughly, a research that laid the foundation for this research project.

Structure of work.

Hypothesis

My hypothesis that I put forth is that by using fog-collection technology that emulates principles that occur in nature among organisms in arid regions, it will be possible to achieve a façade system that can provide a building with its water need by extracting water from humid air.

Research questions

What role can biomimicry play in minimizing the ecological footprint of the building industry?

Can nature work as an inspiration for a total re-evaluation of what a facade can be for a building?

Is it possible to create a system that, through its adaptation to its context, succeeds in exploiting hidden resources in the surroundings of a building?

Structure

This research project is divided into a theoretical part and a design part. The design phase aims to explore different methods of applying the theories in practice.

Method

Initially, I explored research that deals with the topic of biomimicry from a broader perspective but with particular regard to architecture. By gaining a deeper understanding of the core of what this research area is about, I was able to link the theories I studied to a specific problem that is expected to get worse as a consequence of climate change. I investigated the water shortage prevalent in many countries and began to seek inspiration in biology in order to find ways to address this problem through architecture.

The more knowledge I began to possess on the subject, the more I began to work in parallel with more design-related tasks where I began to sketch different solutions on how to integrate fog collectors into a facade system.

I also conducted experiments where I tested theories that I researched by mounting a humidifier to a wind tunnel I built where the steam produced could pass through so that the water absorption could be studied. This allowed me to analyze what effect different methods of using the mesh fabric had on the amount of water that was able to be collected.

In the end, my work resulted in a building in the context of the national park found at Mt Montgó, just south of the city of Valencia, that is able to collect water from the air. Through my design I explore how different aspects can be optimized in terms of the water absorption capacity.

Among other things, by finding the form through wind simulations achieved through the use of parametric digital tools and the application of adaptive facade systems that adapt to prevailing weather conditions. I explore through my work various methods based on biomimicry to optimize the building's energy efficiency from different perspectives.

Finally, I evaluate how well my design is in line with what I originally wanted to achieve in order to be able to draw conclusions about how well biomimicry has served as a toolbox during this project. I also try carefully to speculate on what role biomimicry might play in architecture in the future and how the integration of fog collectors in architecture may be used in other ways in the future.

I am also discussing whether biomimicry can change the role that buildings have historically had from being stone caves whose sole purpose is to protect us from the weather and wind to function more like living organisms that adapts to their environment.

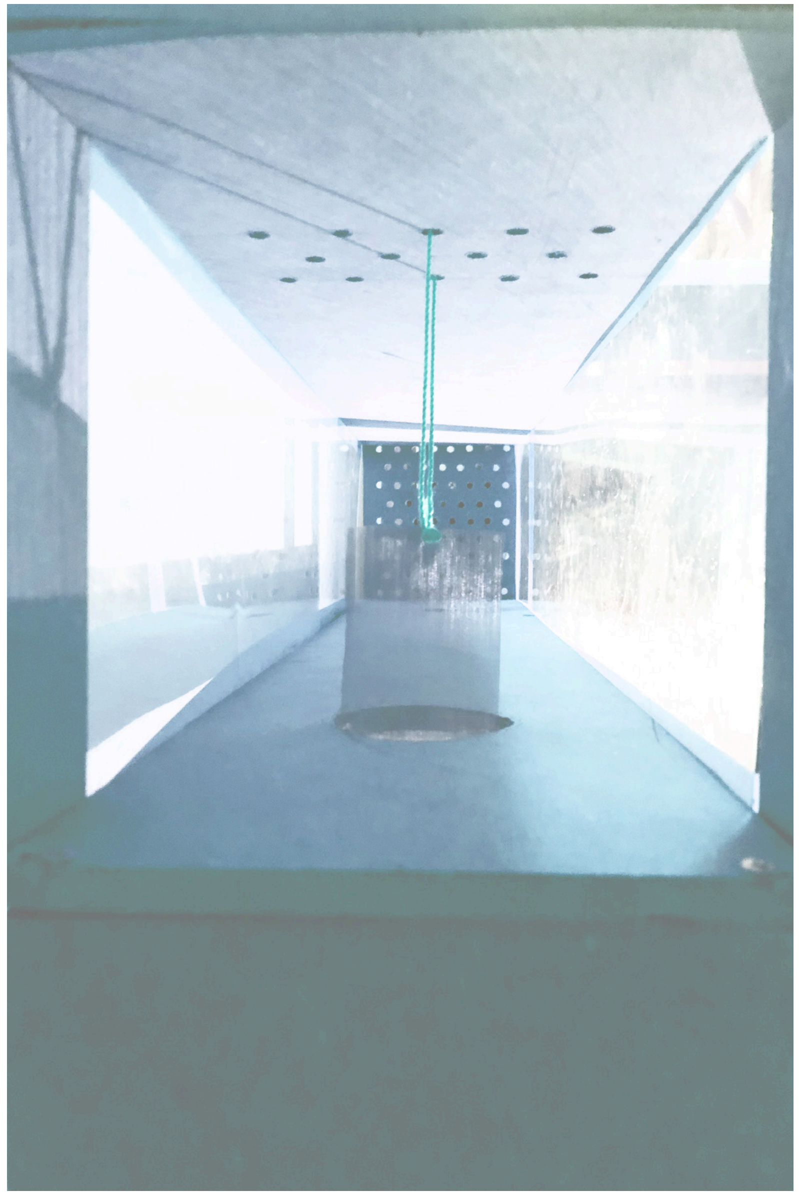


Image 1: Mesh fabric in wind tunnel (Richter 2020)

By building a wind tunnel to which I connected a humidifier, I could closely study the mesh fabric's ability to capture water from air.

Background.

Initial interest in biomimicry as a concept

Algorithms and geometric shapes that occur naturally in nature had always been an interesting subject for me and were initially what attracted me to learn more about biomimicry. But the more knowledge I gained, the more I realized that what I was really initially interested in was something called biomorphism. Instead, biomimicry was primarily about understanding the principles of nature and then emulating them in a context adapted to human needs. It did not necessarily have to be about copying a design language from nature to solve a specific problem that nature managed to achieve through evolution. Biomimicry as a concept encompasses much more than that and is instead a method for man to find his place back in an ecosystem based on the evolutionary adaptation and development from millions of years.

During the course of this work, I therefore wanted to explore what opportunities a holistic biomimic approach could have in an architectural context to address a specific problem linked to the UN's 17 sustainability development goals.

Water crisis

Being able to provide all people with clean drinking water and ensuring a sustainable management of those limited water resources can be found as the sixth of the UN SDG:s for agenda 2030. Water supply is predicted to be one of the most difficult challenges we face in the future and based on the water shortage prevailing and intensified in recent years in the Spanish region of Valencia, I therefore wanted to apply biomimic tools and models to design a façade system that, by emulating principles that we find in nature and by adapting to prevailing conditions, manage to reduce the water demand for a building. (Ayuntamiento de Valencia, Factor CO2, 2016).

The potential of fog collectors in adaptive facades

Today, many of the examples and products that exists and focus on extracting water from air are aimed at rural areas in poorer regions that have historically had the greatest difficulty in meeting the UN's sustainability goals and supplying its population with clean water. As an effect of the planet becoming warmer and the water supply in more countries are being threatened, I want to explore how these systems can be optimized and adapted to function as architectural elements.

Today, there are also many examples of architectural projects that have worked with adaptive facade systems with regard to daylight conditions where biomimicry has in many cases been the inspiration for the implementation of these systems (Al-Obaidi, Ismail, Hussein, Rahman, 2017).

These systems are basically about making a building's outer shell dynamic and adaptable to prevailing conditions in order to be able to utilize or keep out the heat that the sun's rays generate depending on the season.Similar systems could potentially be created for buildings with regard to favorable conditions for water production rather than daylight.

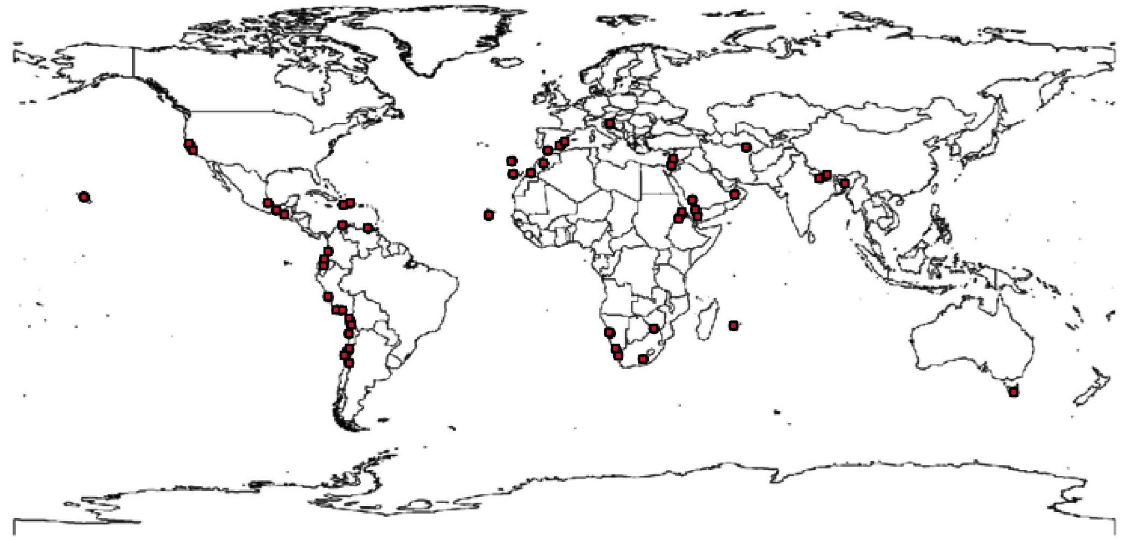


Image 2: Locations in the world where fog collection has proven to have potential (Klemm, O. et al. 2012).

Biomimicry.

History of Biomimicry

Although biomimicry as a concept mainly gained prominence and has become more well known in recent years, it was coined already in 1982 by the American engineer and biophysicist Otto Schmitt (Amer, 2018).

However, it lasted until 1997 when the term was popularized by the American author Janine Benyus who through her authorship made sure to introduce the term to a wider audience. Benyus is also one of the co-founders of the Biomimicry Institute, which works to help designers and engineers understand the processes and systems of nature by bringing them together with biologists so that they can apply these theories in their own work. The Institute also has a website with a knowledge bank and with examples from the reality where biomimicry has led to pioneering and sustainable products. During the course of my thesis work, the resources available there will be a great help to me and, guide me through models that describe step by step how a biomimic process should look like (Biomimicry Institute, 2020).

The core of Biomimicry

What is at the root of biomimicry is not contrary to what many people think of at first, imitating geometric shapes that occur in nature. It is, as I have previously mentioned, instead something that falls under the category of biomorphology. Biomimicry is instead about drawing lessons from nature in order to optimize technical solutions. It is not a question of recreating a particular material, a form or, for that matter, a function directly derived from its natural context for functioning in a human context. Instead, it is about understanding the principles that underpin why things in nature happen and look the way they do. This understanding can then assist in the creation and optimization of existing technical solutions to solve the problems you face as a designer or engineer (K.M. Al-Obaidi *et al.* 2017).

Multifaceted applications for biomimicry

The number of examples where biomimicry has been used is many. Janine Benyus, the co-founder of the Biomimicry Guild, particularly highlights these examples of being successful in their application of biomimicry (Benyus, 2009).

- In Japan, researchers managed to get mucus to recreate an almost identical copy of an existing rail system after being provided with a map where food could represent the various stops that needed to be linked.

- By analyzing, among other things, sluggish crawlers, which can be without water for very long periods and then reproduce themselves, it has been possible to create materials that mimic the properties of producing materials that rebuild themselves. Progress in that research has led to that there is no need any longer to keep vaccines refrigerated, which has simplified the work of healthcare professionals.

- By studying the shell of the mussel, which begins to decompose after exactly two years, one can understand principles that assist in the development of synthetic materials with the possibility of breaking down themselves organically in a timely manner.

- Maybe by studying the spider's silk production we can in the future start using chemistry with fewer environmental hazards as a consequence.

- Bacteria can show the way in which we can successfully extract minerals from, among other things, wastewater, which can reduce the need for mining, which we know carries great risks.

- Self-assembly is another exciting research area inspired by biomimicry. It is a proven method in nanotechnology, but it is also widely used in architecture, although not on such a large scale yet. In nature, there are many examples of self-assembling properties, however. For example, the shell of the mother of pearl is a self-assembling material. It consists of a layered structure of minerals and polymer which makes it very strong and durable. But the most interesting is its self-assembling properties that inspired a variety of new products and concepts. In the same way that the shell is mounted outside, within and around the organism itself, there are today examples of ceramics that bind themselves and create structure only by dipping into a liquid.

- In architecture, there are today many products that have been inspired by nature. Lotusan is a company that has developed a paint that, by imitating the bulges that frequently appear on the lotus flower after drying, succeeds in cleaning itself, which can be an ingenious, albeit small, contributing factor in reducing the ecological footprint of a building.

Biomimicry at a cycle level

Biomimicry as a model can also be used as in the case of "The Mobius Project" . A proposal that works with a multifaceted program where different parts complement each other to minimize the amount of waste produced. The project houses a restaurant in a greenhouse and went on to plan for different functions within the same project that can utilize each other's waste. Among other things, it involved converting all degradable waste from the immediate area into heat for the greenhouse and electricity that was returned to the electricity grid. It was also provided with a system for converting wastewater into clean water with only plants and microorganisms as well as a fish farm which was supplied only by the food waste generated by the restaurant which would then generate fish back to the restaurant (Pawlyn, 2010).

Circular economy

This approach goes back to the idea of a circular economy where we tend to see goods and products as constituents in different cycles rather than something with a single purpose that needs to be disposed of after it has fulfilled its purpose. If we can understand the value of more of what was previously considered residual products and which has also been put a lot of energy into getting rid of, we can reduce the gigantic ecological footprint that our current civilization has on the planet. For example, if we were able to gain a deeper understanding of the processes underlying the photosynthesis that occurs everywhere around us, then future generations may succeed in creating innovative solutions that enable us to look at carbon dioxide as a resource rather than a residual product (Benyus, 2009).

However, what is important to remember when it comes to biomimicry is that biological systems are based on their genetic code and guided by natural selection. These systems have been developed for millions of years and therefore cannot be directly applied in human-engineered systems around for over the past hundreds of years to solve specific tasks. It is necessary to be fully aware of these differences in the application of biomimic working methods. Technical systems generally want to achieve something, while biological systems produce functions of chance that prove to be favorable (Lurie-Luke, 2014).

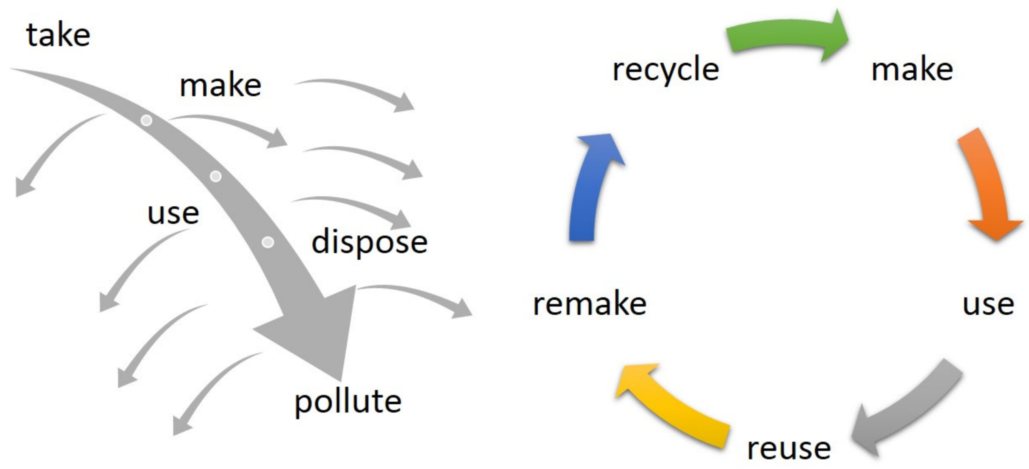


Image 3: Linear vs Circular economy (CC 3.0 Catherine Weetman 2016).

The six-step process

The Biomimicry Institute talks about how the biomimic work process needs to go through six steps in order to successfully apply natural systems to technical solutions. This process is necessary to ensure a successful result as many natural solutions are not optimized for human issues and problems (Biomimicry Institute, 2020).

The first step is to define the problem or issue that you are seeking to solve.

The second and third step both aims to examine current research that addresses the problem you are trying to solve and shows what it can look like when different natural systems and organisms facing the same problem solve this. In short, it involves copying attributes of an organism in the form of materials, appearance, components and more.

The fourth step is about abstraction when trying to understand in depth the principles that underlie nature's solutions. It involves looking deeper into how to recreate an organism's development and procedure within its medium to mimic nature.

In the fifth step, which is the most complicated, you copy the form and processes from a specific ecosystem. The mimicry is then applied to a large platform.

In the final step you evaluate your process before starting over.

Difficulties in a biomimic application

There are many identified difficulties and challenges in using biomimicry, especially as it is a relatively new research area that requires major changes in structures that are cemented in many industries' views on how things should go. Many times, solutions are simplified to follow the traditional linear problem-solving approach because projects and clients require it or because there is simply no understanding of how a circular economy works. Another problem with biomimicry is that in many cases there is a limitation when working with such widely varied scales in how well different processes and solutions are suitable for what you want to achieve.

However, the greatest difficulty that prevents biomimicry from striking on a wider front in architecture, in particular, can probably be largely attributed to the lack of a clear and systematic methodology. Admittedly, there are actors such as the aforementioned "Biomimicry Institute" who are working to develop concrete methods for how to successfully apply biomimic in their professional practice, but these can be perceived as difficult to approach for someone who is not familiar and also often requires a great time investment.

Various methods to which biomimicry can be applied

In general, biomimicry can be applied in architecture on three different levels. It usually occurs either at an organism, behavioral or ecosystem level. At an organism level, the inspiration comes from the organism itself and you apply its shape and / or functions to a building. At a behavioral level, a building can emulate how an organism interacts with its environment to create a structure that blends more naturally into its environment. At an ecosystem level that tends to take place on more urban projects on a larger scale, you emulate the processes that occur in nature when many different components interact with each other (Zari, M.P. ,2018).

Many times, these definitions and focus areas overlap, which is also desirable in a project that aims to fully represent all of the natural processes and systems that overlap and interact in nature.

	Eco-system	Behaviour	Organism
Form	The building looks like an eco-system.	The building looks like it was made by the organism.	The building looks like the organism.
Material	The building is made from the same material as the eco-system.	The building is made from the same material that the organism use.	The building is made from same material as the organism.
Construction	The building is assemb-led in the same way as the eco-system.	The building is made in the same way as the organism build.	The building is made in the same way as the organism.
Process	The building works in the same way as the eco-system.	The building works in the same way as the home of the organism would.	The building works in the same way as one organism.
Function	The building functions in the same way as the eco-system.	The building works in the same way it would as if the organism built it.	The building functions the same way as the organism.

Solution and problem based approach

You can adress a problem from two different approaches in biomimicry. One is a solution-based approach that involves using existing knowledge of biological systems and principles that exist to identify useful behavior that can then be abstracted into technical solutions. In such a case, the design process depends on the scientific progress made in various biological research areas (Peters, 2011).

The second approach is the problem-based approach, which is based on an identification of the goals you want to achieve, but also the limitations that you have to adapt to specific project conditions.

After formulating a problem for oneself, one turns to nature to seek answers in how similar problems are encountered by various different organisms and systems. By exploring and being inspired by nature, the designer solves a specific question or succeeds in highlighting a specific design that is better suited for the purpose you want to achieve. During the course of my work, I will mainly use a problem-based approach based on the water crisis that in the long term threatens the Spanish region of Valencia.

Image 4: Water droplets on a leaf (Krejci 2009).

Water absorption among biological organisms

So the first step in a successful biomimic problem-based approach is to study and understand how biological organisms solve the problem you are facing. In this case where the project aims to solve a prevailing water shortage, there are many organisms to study. The most well-known organism that uses vapor absorption to meet its water needs is the Namibian desert beetle, which has become relatively well-known and has already been the inspiration for a variety of products that emulate its water absorption technology (Hamilton & Henschel & Seely, 2003).

It lives in an environment that is notorious for its dry and warm climate where there can be many months between moments of rainfall. The beetle has therefore, through millions of years of evolution, developed a method for extracting water from the moist air that the sea winds bring. It goes to a place where the wind reaches it, folds up its wings and allows the fog to condense on its surface. The wings have bulges on them that allow the fog to condense and then to be transported to its mouth before it gets absorbed.

By folding out its wings when conditions are at its best for extracting water from the air, the insect manages to utilize a resource that many other organisms pass by. How this ingenious evolution has come about is something that we will probably never fully understand, but the lessons we can draw from the fact that it actually works have already proven to have significant consequences for many communities living in similar climates and struggling with the same issue.

How the beetle has managed to find another area of use for its wings that already fills perhaps the most important purpose of its life is a logic we can try to emulate on an architectural level. By likening a facade to the insect’s wings, one can imagine a facade that, when all criteria for high water uptake from the air are met, can be adjusted to be able to capture and exploit this resource. Not only does the facade fulfill its original purpose of protecting from weather and wind, but by being adaptable to its surroundings, it can now also provide its users with an existential condition for life.

However, what the Namibian water beetle is unable to do as this would have resulted in a greatly impaired flight capability which probably would not have been evolutionarily advantageous is to optimize its wings to be able to absorb a higher amount of water. However, by studying other biological organisms we can draw conclusions about what type of surfaces are the most advantageous for fog absorption.

Many plants that depend on being able to capture water from air for their survival have proven to have one thing in common. They are characterized by their long narrow leaves which, through their rosette-shaped constellation, allow the wind to pass through them. This allows for more water to be captured then the condensation that occurs on solid surfaces where wind forces are liable to arise which can pull the droplets away from the surface (Martorell, Ezcurra, 2007).

This knowledge is the reason why the most common technique for extracting water from fog that has proved most successful so far in technical systems is through mesh fabrics. They are normally designed either as so-called SFC (standard fog collectors) by standard dimensions of 1x1m or as LFC (large fog collectors), usually rectangular modules with longer horizontal dimensions due to aerodynamics. But they work the same way. Water droplets are formed on the perforated fabric when wind pass through it which are then pulled down by gravitational forces and collected in a tank.

There are also other systems that uses surfaces where water can condense at night more accurate to how the Namibian insect does it and also systems that include chemical absorption and desorption processes. However, if one compares the different methods currently available, it seems clear which method has the greatest potential and therefore is also the most widely used method today and that is through the use of mesh fabrics (Caldas, Andaloro, Calafiore, Munechika & Cabrini, 2018).

It is also the method on which most research is carried out in order to optimize the system. The most widely used fabric with relatively large openings is far from being optimized for its purpose and it has been possible to demonstrate a significant increase of up to 50% of water production by, among other things, treating the fabric with hydrophobic material but also by reducing the hole size in the fabric and adding mechanical systems.

Image 5: Cylindrical Mesh (Richter 2020).

Image 6: Waterproofing spray (Richter 2020).

Image 7: Wind tunnel (Richter 2020).

Experiment.

Purpose

The purpose of the lab is to gain a deeper understanding of what happens when you extract water from the air through fog collectors. The purpose is also to be able to draw conclusions about which aspects are important to consider in order to optimize the system's capacity in an architectural context.

Question

How much does the wind direction and wind force affect the mesh fabric's capacity to extract water?

What conditions are needed for water droplets to condense on the mesh fabric?

How can you design the mesh fabric in a larger context to optimize its capacity based on the climate data available for a specific site?

Theory

Kyoo-Chul Park, Shreerang S. Chhatre, Siddarth Srinivasa, Robert E. Cohen and Gareth H. McKinley in their report, "Optimal Design of Permeable Fiber Network Structures for Fog Harvesting", explores how the wire mesh radius affects the fabric's ability to capture up water. They note that the capacity increases as the radius decreases from 445 µm down to a radius of 172 µm. From 172 µm to 127 µm in radius, however, the intercept ability decreases.

Therefore, based on their results, I wanted to explore a mesh fabric with thinner thread than the typical Raschel mesh to study its ability to capture water but also explore how to modify the fabric to optimize its capacity.

Mithun Rajaram, Xin Heng, Manasvikumar Oza and Cheng Luo in their report "Enhancement of fog-collection efficiency of a Raschel mesh usingsurface coatings and local geometric changes" investigates how to modify the typical rachel mesh properties to optimize the amount of water that can caught up.

They note that one can increase the capacity by simply increasing the contact surface and at the same time reducing the pinning effect by applying a coating so that it gets smaller openings.
I therefore procured an agent used to make textile materials hydrophobic and treated my acquired mesh fabric with this.

María J. Estrela, José A. Valiente, David Corell and Millán M. Millán in their report "Fog collection in the western Mediterranean basin" examine the specific conditions for fog collection at four different locations in the Spanish region of Valencia. They also draw conclusions about the different climatic conditions that must be met for the systems to work. Among other things, they conclude that both the wind strength and the wind direction have a great effect on the system's ability to capture water. A big part of their work forms the basis of the issues i explore in this lab.

Hypothesis

After treating the examined mesh fabric with hydrophobic spray, water droplets will form on the fabric when exposed to an air filled with water vapor.

Since the conditions are difficult to compare with natural conditions, the focus will be on comparing the difference in how much water can be collected between different methods that can be applied when testing the mesh fabric.

A rectangular surface, based on what we know from previous research, will capture more water than a circular shape when a larger surface is exposed perpendicular to the wind direction. A higher wind speed will also increase in a higher collection of water.

Materials

I started with treating the mesh fabric with NIKWAX TX.Direct Spray On to make it water repellent.

The mesh fabric I used was a woven wire made of stainless steel with 0.125 mm hole openings, 80 µm around wire diameter with a 33% open area. The fabric which was originally 30 x 100 cm was cut into smaller pieces. It is a fabric that is considerably thinner and less permeable than the fabric most commonly used in fog collectors today. I also used a humidifier with a 2 liter tank which I placed under my wind tunnel. The wind tunnel was built mainly of MDF boards and transparent plastic film that trapped the humid air within a confined space which allowed me to control and study how the water vapor passed past my test object.

Method

I started by testing the smaller pieces of fabric I cut out. They were 5x5 cm in size, covering about 25% of the opening in the wind tunnel. I placed these in three different ways in my wind tunnel. First at right angles to the wind direction, then parallel to the wind direction and finally I formed the piece as a cylinder which significantly reduced the proportion of the opening surface covered.

Then I tested to cover the entire opening of my wind tunnel with mesh fabric. These were of the size 10x10cm.

I tested the different methods by activating a fan two meters away from my wind tunnel which directed the water vapor produced by my humidifier to pass through the studied fabric. I then allowed the entire tank volume of 2 liters to evaporate and then measured how much water had been captured by the fabric.

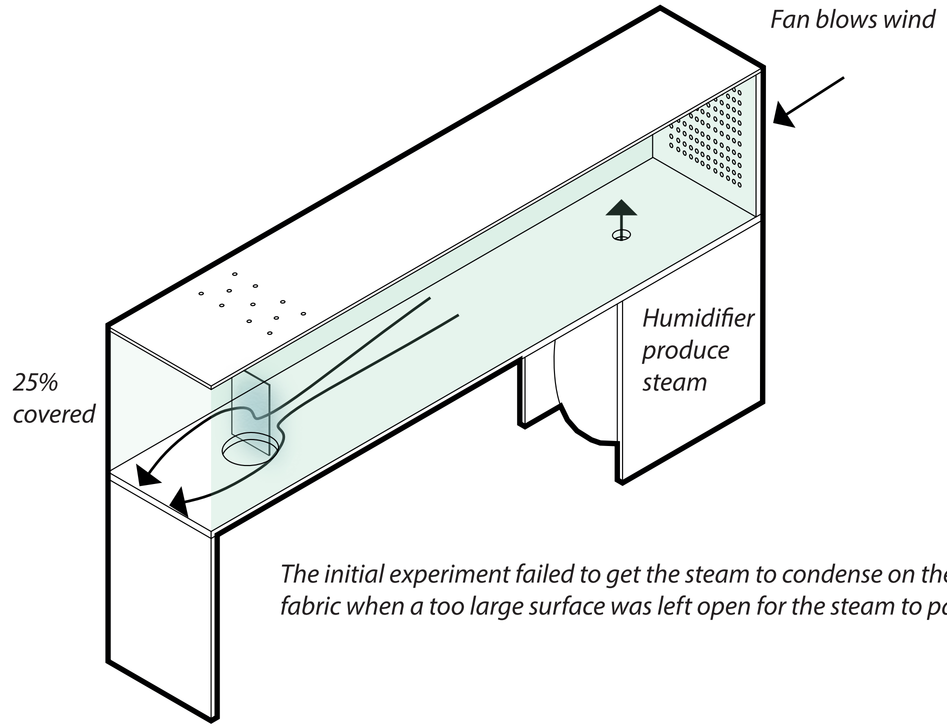
Results

The initial experiments when only part of the opening were covered did not prove to be very successful. No measurable amount of water could be captured for any of the fabrics as the water vapor treated the fabric as a smooth surface and passed through the wind tunnel on the sides left open. A greater amount of water was collected on the covering plastic that were placed to protect the MDF board than on the mesh fabric itself.

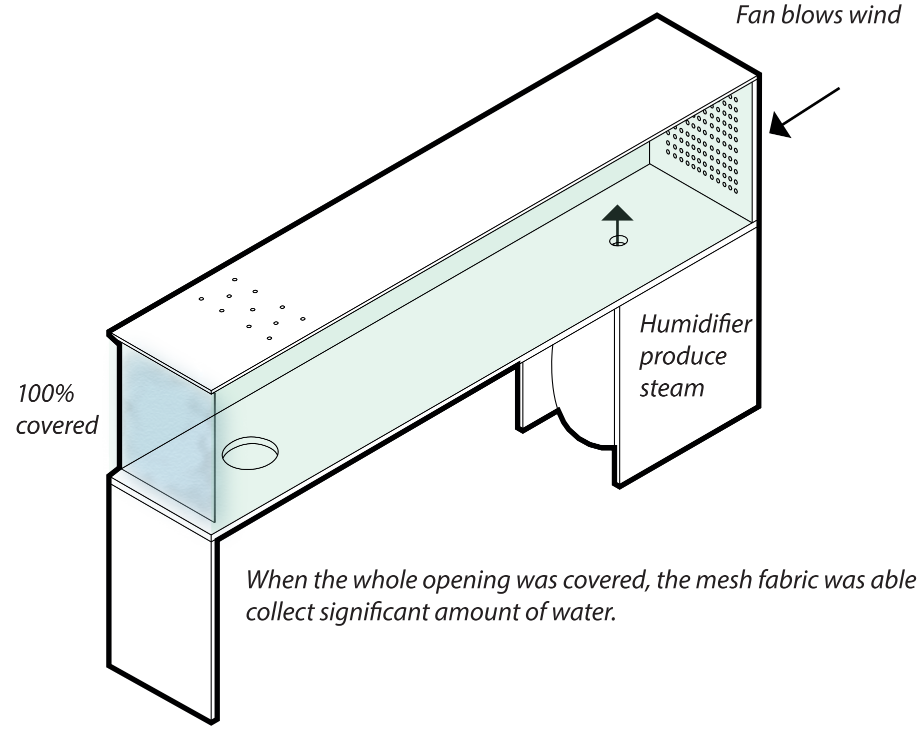
However, when the entire opening was covered and the water vapor was forced to pass through the suspended mesh fabric, the difference was significant.

After only about 10 minutes, small droplets began to form and these quickly grew in size. In the final stage, the entire mesh fabric was covered with running water drops that were pulled down by gravity

Image 8: Wind tunnel diagram (Richter 2020).



The initial experiment failed to get the steam to condense on the mesh fabric when a too large surface was left open for the steam to pass by.



When the whole opening was covered, the mesh fabric was able to collect significant amount of water.

to be captured by the measuring instrument. About 2% of the tank's total volume was captured by the mesh fabric. However, this number is likely to be higher as a large amount of the water vapor still managed to either spill through cavities in the wind tunnel even before it reached the mesh fabric or could condense on other surfaces. So we can assume that the percentage of water vapor that was successfully captured by the total amount of water vapor that actually passed through the mesh fabric is slightly higher than the amount collected.

Discussion

When I chose to examine a more fine-grained mesh fabric to test for my experiment rather than the rachelmesh that is most common in the fog collection context, I did so partly on the basis that there were previously mentioned studies that showed that fabric with thinner thread could capture larger amounts of water . However, these studies showed at the same time that there was a limit to how thin the thread could be before capacity began to decrease again. The fabric I purchased had a thread radius that was below this limit, which I thought would be offset by the fact that the fabric would be subjected to such a strong steady stream of water vapor in a closed environment that it would play no major role for the purpose of my experiment. .

However, what my initial results showed was that I had underestimated how water-repellent this fine-grained material was. No matter how I designed the fabric, no large quantities of water could be captured and I could clearly see in my wind tunnel how the water vapor was detouring around the test object as soon as the opportunity was given. In combination with treating the fabric with water repellent, its fine graining had made it complete repellent to the steam produced by the humidifier. This limited me in my continued experiments and I could not, among other things, draw any major conclusions about how much lower capacity a cylindrical catcher would have compared to a rectangular rectangular catcher of the same area that I had originally hoped for.

What this result, however, made me understand was the importance of the direction, movement and strength of the wind for a mesh fabric's ability to capture water from the air. As I increased the area of the test object and thus the open area left for the water vapor to pass through the wind tunnel decreased, the amount of water collected increased exponentially. We can therefore conclude that for such a system to function in a larger context, it is of great importance to work with how the wind passes through these collectors to ensure that there is a constant steady stream of humid air passing through them.

In an architectural context, the collection surface can be conceived as a facade. To ensure that this surface is exposed to a constant flow of humid air, you need to work with the wind flow around and through the building mass as a whole. If you do not do this, there is a risk that the wind will move around our building volume and find alternative ways to pass through the placed collectors just like what happened in the initial experiments.

In my continued work where I will work more with design and conceptual proposals to test different ways how fog collectors can be integrated into facade systems, I realize that I can not ignore working even with building volumes and wind flows through them as an obvious part of this work. Fog collectors as architectural elements will not be successful in their design if they are treated only as separate facade systems but need to be designed with many other architectural aspects to ensure functionality.

The experiment did not give me the answers that I had initially hoped for, but it gave me invaluable insights on new aspects that I must consider in my continued exploration of how fog collectors can function as architectural elements and as part of the expression of a building.

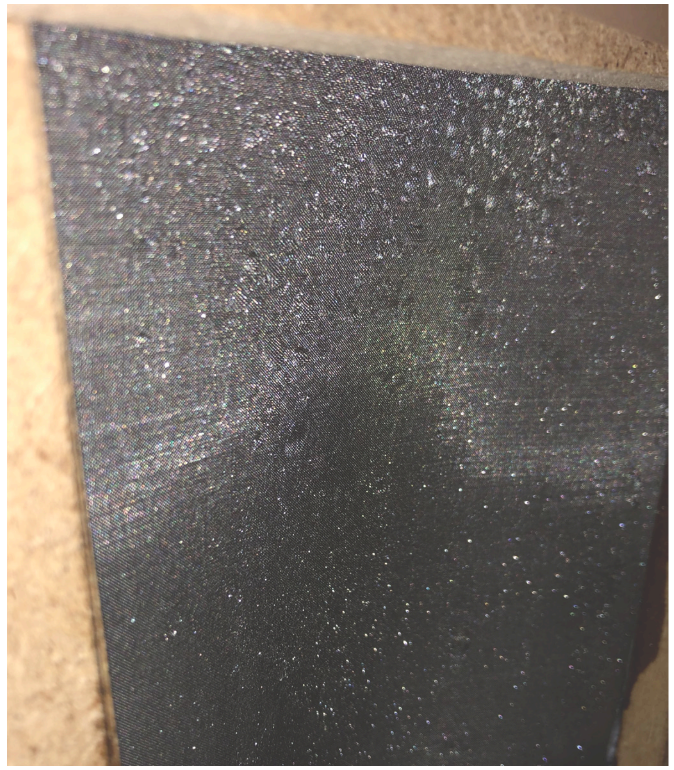


Image 9: Water droplets on mesh fabric (Richter 2020*)*.

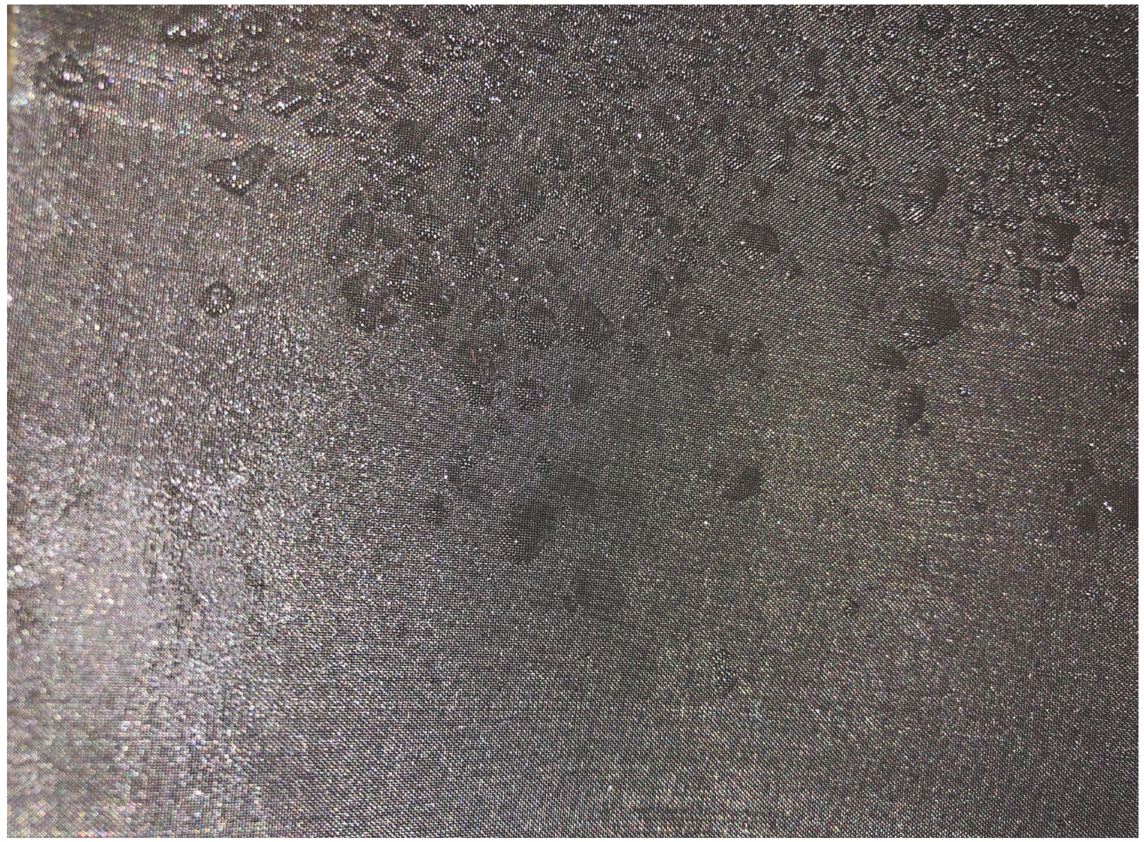


Image 10: Water droplets close-up (Richter 2020*)*.

Water droplets condensing on the fabric when opening is fully covered.

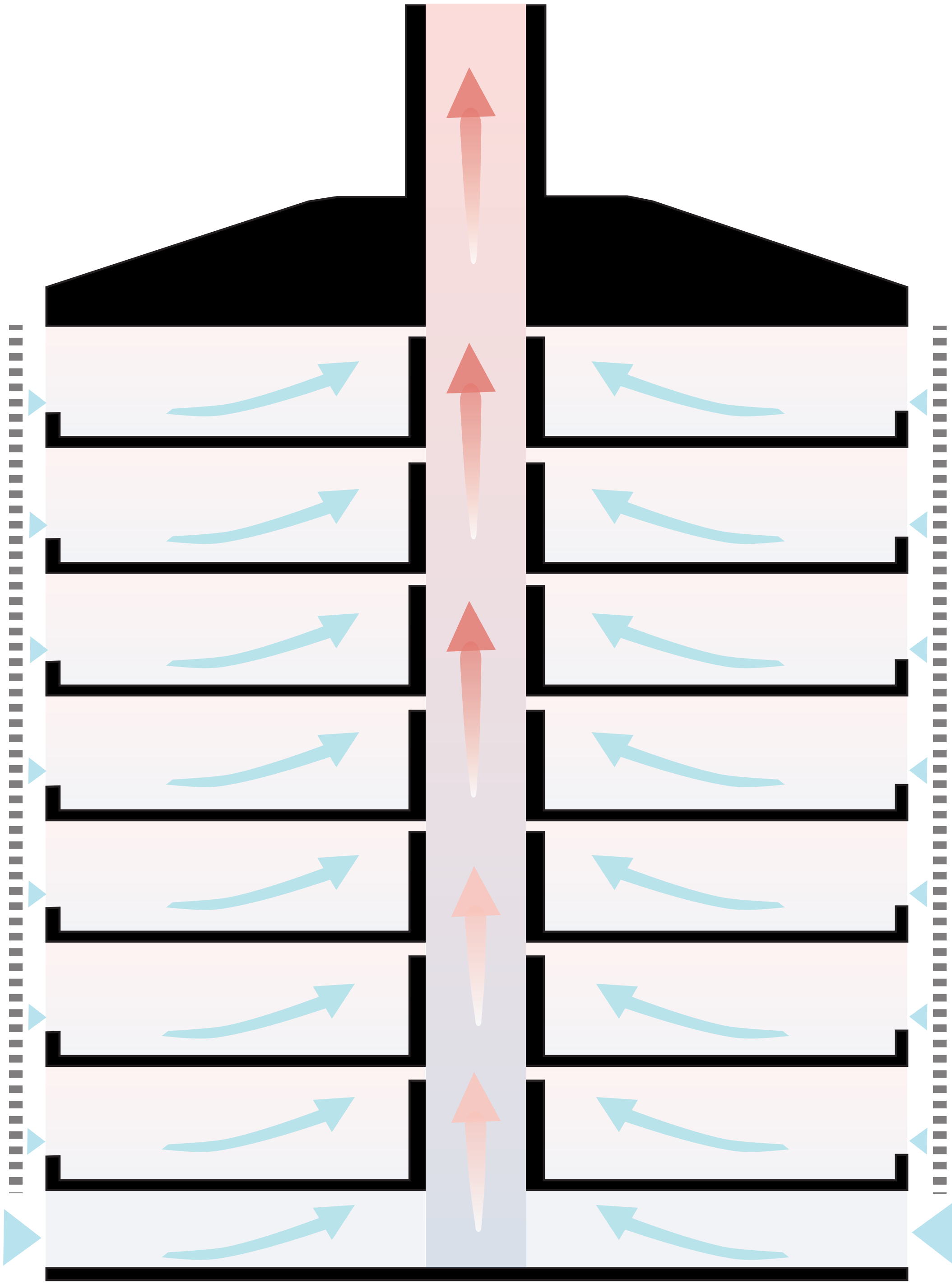


Image 11: Natural ventilation in Eastgate Center, schematic. (Richter 2020).

Cold air ventilate rooms through openings in facade thats shaded. Warm air rise in centrally located core with openings in roof and fans in the basement maximize this draft.

Natural ventilation among biological organisms.

Termites as a role model for natural ventilation

I now knew that in order to optimize the water absorption capacity of my façade system, I had to partly control the direction of the wind that would pass through these and that a stronger wind would result in higher production. I therefore began to explore what opportunities I had through the design to influence these factors, which once again led me to focus on natural systems and processes that occur in the plant and animal kingdom.

Natural ventilation is something that humans have practiced for probably as long as they have been human. The fact that wind drifts arise through voids on a mass or that hot air rises and therefore creates an underlying wind trait is general knowledge that has been the basis for, among other things, the wind towers used historically built mainly in the Arab world, but also around the Mediterranean not too far from my site. This knowledge is also possessed by a certain type of termite which, by combining these two methods, has managed to build its nests with cavities in itself that pass through small strips of air to a centrally located core where the warm air rises, which ventilates and creates a pleasant climate inside the entire nest. This despite being located in one of the hottest places in the world (Klein, 2019).

The Eastgate Center

This insight was the basis for how the architects designed a shopping center in Zimbabwe. The Eastgate Center, designed by architect Mick Pearce, is a distinct biomimic project in which the termite ingenious solution is emulated to create a building that uses 90% lower energy than a nearby building of the same size. By creating cavities in the construction that lead air into a centrally located atrium, you achieve the same effect as in the termite nest, which has led to that much less energy to mechanical ventilation than similar buildings is required (Klein, 2019).

Natural ventilation as a driving force for optimization of the fog collectors

By emulating this principle that have successfully succeeded in in the Eastgate Center, you could control the wind flow around a building volume and place fog collectors in areas of the facade where the wind will pass through. Bt carefully studying what conditions are optimal for the fog collectors capacity, it can be noted that when the conditions for using fog collectors are the greatest, the need for natural ventilation is also the lowest. This creates opportunities for how these different systems can be combined to take maximum advantage of each other. I found this insight interesting and decided that I would explore this more in my design proposal and therefore began to look more closely at the specific conditions of one specific site.

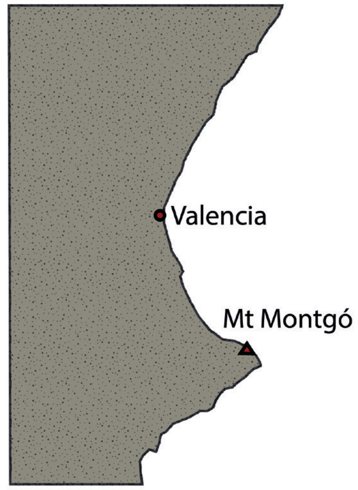


Image 12: Spain (Richter 2020*)*.

Image 13: Valencia Region (Richter 2020*)*.

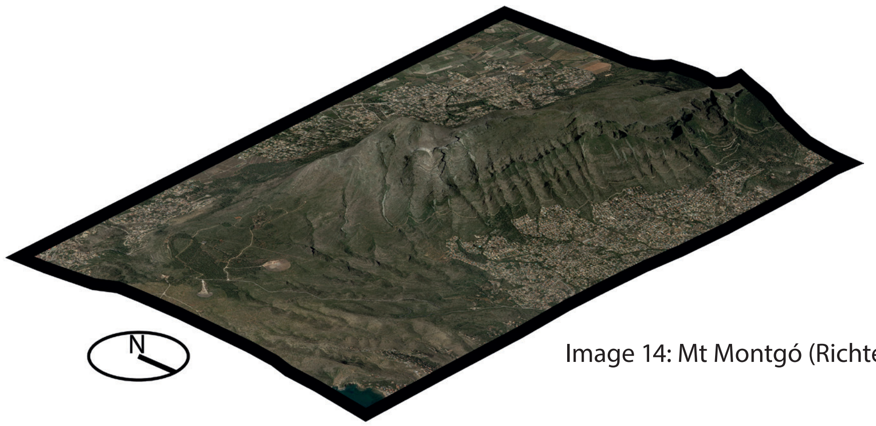


Image 14: Mt Montgó (Richter 2020*)*.

Valencia.

Valencia is an autonomous region of eastern Spain with a long coastal strip towards the Mediterranean. The region has a dry Mediterranean climate with generally warm temperatures. The typography is characterized by a relatively mountainous landscape with a complex orography where narrow coastal plains turn into a hilly terrain towards the countryside through dramatic slopes and ridges where the altitude difference in some places can exceed 500 meters. The region rarely experiences rainfall, especially during the summer period, but due to its coastal location, it has a relatively high humidity (Estrela, Valiente, Corell, Millán, 2008).

The regional capital, which shares the same name, is Spain's third largest city with 1.6 million inhabitants in the metropolitan area and is located along the coast. The city has a long and complicated relationship with water. In addition to having the Mediterranean just next to it, the river Turia also passes right next door, which together with the river Jucar supplies the metropolitan metropolis with its water needs. In 1957, the river Turia was flooded which led to a great devastation in the city. It was then decided to redirect the river so that the city of Valencia would not be in an equally exposed position. Along the old stretch, a well-visited and popular park has been built today with opportunities for sports and recreation.

The city of Valencia is surrounded by a cluster of agricultural land under the name l´Horta. Agriculture has a great cultural significance for the region and has been around ever since the medieval Islamic

period when ditches and irrigation systems were established by farmers in connection with the two major rivers to be able to irrigate their crops, which today mainly consist of citrus fruits, vegetables and rice. The rice not only has an important economic significance for the region but also plays an important function for many of the ecosystems found there (Ezine, 2018).

Another important source of income for the region is tourism. Tourism is a necessary income for many communities along the Spanish East Coast and Valencia is no exception. During a few periods of the year, these communities experience immense pressure on their infrastructure and local environment in the footsteps of mass tourism. The city of Valencia received more than two million tourists in 2017 and the peak season coincides with the period when extensive agriculture is most in need of water which is challenging for the water supply system (Ezine, 2018).

Illegal water wells used in agriculture and corrupt authorities in connection with an increasingly warmer climate that has increased water consumption overall have led to historically low groundwater levels and a situation that threatens to burst. Already, authorities are being forced to act, but the problem is predicted to intensify in strength for decades to come. Between October 2013 and July 2014, the region suffered from an exceptional drought that led to a prolonged soil moisture deficit. In the long run, it can affect rivers and groundwater in ways that can have devastating consequences for the water supply in the region, which is largely dependent on them (Ezine, 2018).

The "Plan de Adaptación al Cambio Climático de Valencia 2050", which is a report prepared by the authorities to analyze the effects of climate change on the region, states that it is mainly three areas that will hit the region hard. Extreme weather conditions, an increase in temperature and a general decrease in rainfall are the challenges facing the city and which all risk exacerbating the fragile relationship with water that one currently has. Access to clean water is considered to be by far the most vulnerable resource in terms of public health, agriculture and the amount of ecosystems that depend on clean water (Ayuntamiento de Valencia, 2016).

Plan for change

How Valencia will be affected by an ever-changing climate has been relatively clear through various publications and research reports for a long time. However, it is only in recent years that they have also begun to focus on developing concrete action plans such as "Plan the Adaptación de la Ciudad de Valencia" to tackle these problems. These intend to preserve biodiversity in the region while at the same time preserving important agriculture to the same extent as it does today. Generally, there is a great hope for innovative technical solutions in the report. Another major focus of this action plan is on infrastructure and how to encourage people to choose greener alternatives for transporting both people and goods. Among other things, a bicycle ring has been established to make cycling a more attractive means of transport (Ayuntamiento de Valencia, 2016).

The biggest challenge, however, is about water supply. Even today, not even half of the reservoirs that supply the city with water live up to the EU's water quality assurance framework, and this development is predicted to be worse in the coming decades. At present, the authorities are working on a "bottom-up" approach, which is to disseminate knowledge among the local population to change the habitual behaviors associated with water consumption. The goal is to make people smarter in their water consumption and to make people realize the consequences of unsustainable use of the scarce resources available (Ezine, 2018).

Although it is of immense importance to spread knowledge about how one on an individual level can act to reduce one's ecological footprint, in order to really change the development that prevails, it is also necessary that political responsibility places demands on business in combined with actively investing in new technological solutions that make it easier for people to make the right choice.

Fog collection potential for the region

It is in the light of this that María J. Estrela, José A. Valiente, David Corell and Millán M. Millán examined the conditions, at four specific mountainous locations in the region, to extract water from air with high humidity. It was found that due to its coastal location and mountainous landscape, the region is well suited for the use of such products. Especially in the southern test stations one could see a great potential for fog water collectors. The Spanish East Coast generally lives up to most of the conditions required to successfully use fog collectors as mountain ranges with elevation differences of over 500 meters occur within a shorter distance than 10 kilometers from the coast. This allows for the passive absorption of the humidity that occurs through advection fog or orographic fog. The fog occurs when winds that rise over the Mediterranean enter the coastal mountain ranges. It is also primarily this fog that is interesting from a fog collector perspective since, for example, fog that occurs under calmer conditions at lower altitudes does not have the potential to extract water in any larger quantities. The studies were carried out with the help of cylinder-shaped fog collectors which are independent of wind direction, which allowed a more equitable comparison of the conditions of the various measuring stations.

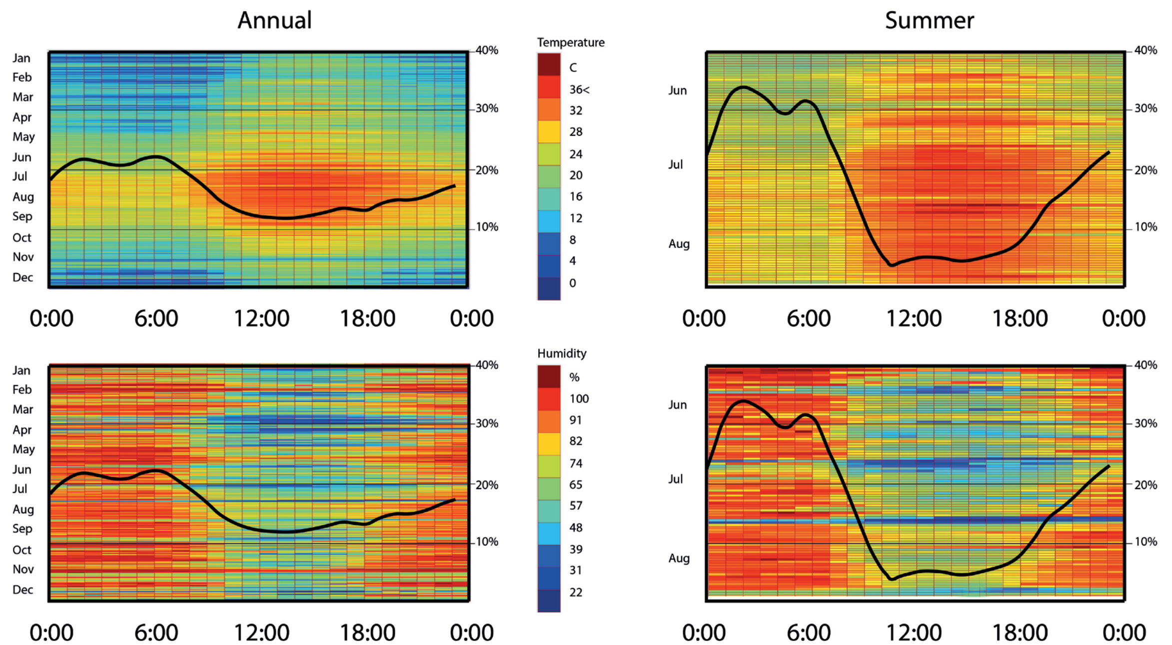
They could see that there was a difference in how the different stations performed, especially between the two northern stations and the two southern ones. The southern test stations generally measured higher results with the highest production during spring and autumn. But the southern stations were also the ones that performed best during the summer months and generally had a production less dependent on the prevailing seasonal conditions. The winter months accounted for the smallest water collection and it can be noted that the highest measurement results generally occurred during periods when rainwater was collected in combination with the collected fog. Then came the days of only fog pick-up followed by the days when only rainwater was collected. However, the days with only fog pick-up were relatively common and during the summer months they even accounted for a comparable amount of water collection, as with the amount measured as a combination of rainwater and fog pick-up.

It was also noted that the amount of water that could be collected differed depending on time of the day. In summer, this difference was greatest and it is mainly during the morning hours but also after dusk that the greatest quantities could be measured when the humidity is high and the temperature relatively mild. During the summer, this difference was significant, which is probably due to the fact that as the temperature drops, the water vapor in the prevailing winds can condense, which allows for the production of fog. The amount of water collected is heavily dependent on the prevailing winds and it was found that during periods when the wind force was below 10m / s, all measuring instruments performed poorly.

The authors summarized their studies by noting that the region has great potential for the application of fog collectors as a new source of water production. The southern measurement stations were able to show results that are equivalent and, in some cases, better than those measured in the Canary

Islands, Hawaii and other places in the world where this method has already been tried and used (Estrela, Valiente, Corell, Millán, 2008).

Percentage of hours with fog water collection occurrence in Mt. Montgó, Valencia, Spain.



(M.J. Estrela et al. / Atmospheric Research 87 (2008) 324–337)

Image 15: Fog Water Collection and Climate Data combined (Richter 2020).

Design.

Having spent most of my work up to this point studying and trying to understand the principles behind the technology used in extracting water from air and also researching the local conditions for a specific site that could benefit from this system, the project now entered a new phase. .

This phase was characterized by more design-related tasks where, in parallel with my research work, I also began to sketch what it might look like if these systems were treated as architectural elements as part of the expression of a building rather then as separate objects.

My research work had provided me with conditions that could be summarized as this. To ensure that the fog collecters had the potential to extract water, they were required to be exposed to a steady stream of humid air.

Early sketches

Initially, I worked with the entire volume as a potential surface for water production that, like the cylinder-shaped test stations tested in the "Fog collection in the western Mediterranean basin", is less sensitive to changing weather and wind. I sketched on different facades covered with ventilation openings in themselves that led to an atrium to achieve a constant flow of air.

In front of these openings, I placed the fog collectors, which could thus benefit from this wind draft that was formed to optimize their production.

However, upon closer analysis of the wind data available for the region, it was found that winds exceeding 10 m / s, which is a prerequisite for the fog collectors to function, were mainly found in one direction. It was mainly the eastern Mediterranean winds that could come up in such strong winds. This motivated me that instead of treating the entire building as a fog collector, I chose to focus on working with the part of the facade that had the best conditions for functioning as it.

Designing a smaller system would also result in less maintenance, which increases the chance of the system being taken care of in the way it requires to function. This, in turn, would result in a longer service life, which would reduce the total material needed.

Image 16: Early sketch of collectors in facade (Richter 2020).

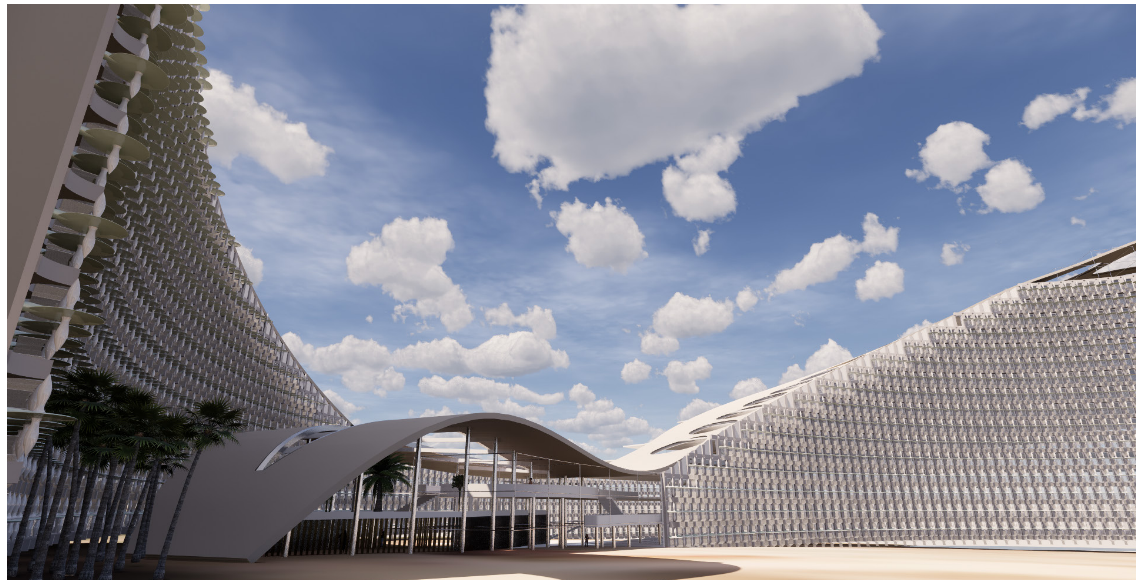
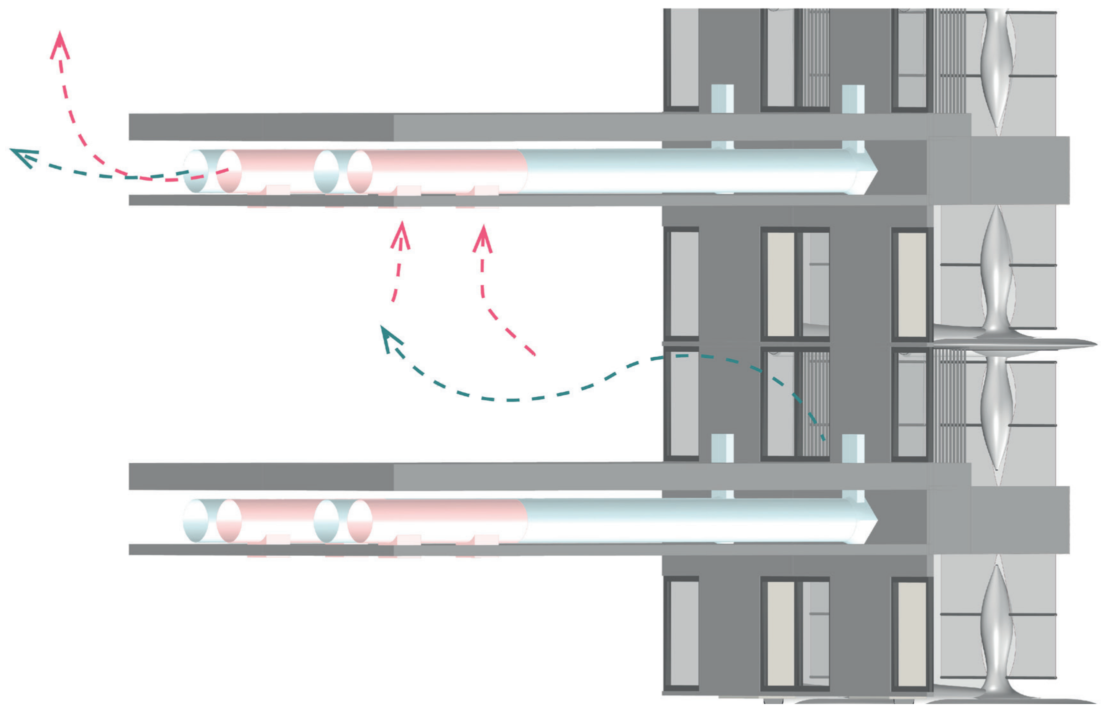


Image 17: Early sketch diagram over natural ventilation (Richter 2020).

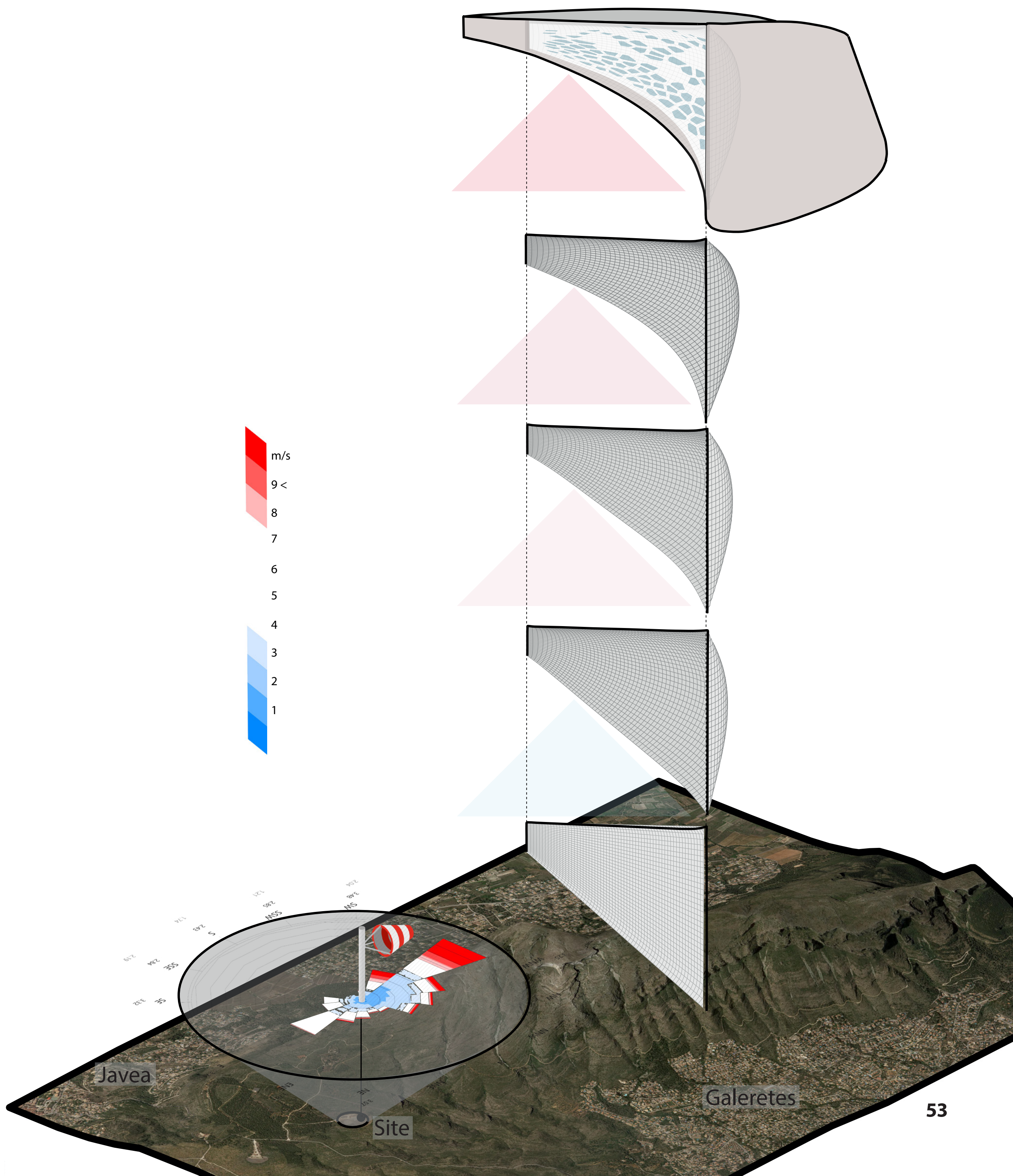


By focusing on the eastern facade, I had more opportunities to work with several aspects of the building to optimize the system's capacity. The eastern facade became the starting point for the design of the building, which had its shape formed by the local climatic conditions that the site has.

By simulating a wind force on a flat surface that is standing perpendicular to the strong Mediterranean winds, the facade takes the form of a sail and captures the humid air, which allows us to control how the winds move past and through our volume.

By capturing the humid air while creating a space between our fog collectors and our facade that can be kept cool and protected from the sun's rays, good conditions are created for the fog collectors as well as for the natural ventilation in the atrium.

Image 18: Sail simulation on surface diagram (Richter 2020).



Through the cavities at the bottom of our sail cold air is led into an atrium where hot air rises and is released through skylights in the roof. As a result, a natural wind draft occurs.

This wind draft helps reduce the energy requirement for mechanical ventilation in the atrium while leading to a constant new supply of air to the in between space behind the fog collectors.

This results in a constant flow of humid air passing through them which will increase the capacity for water production.

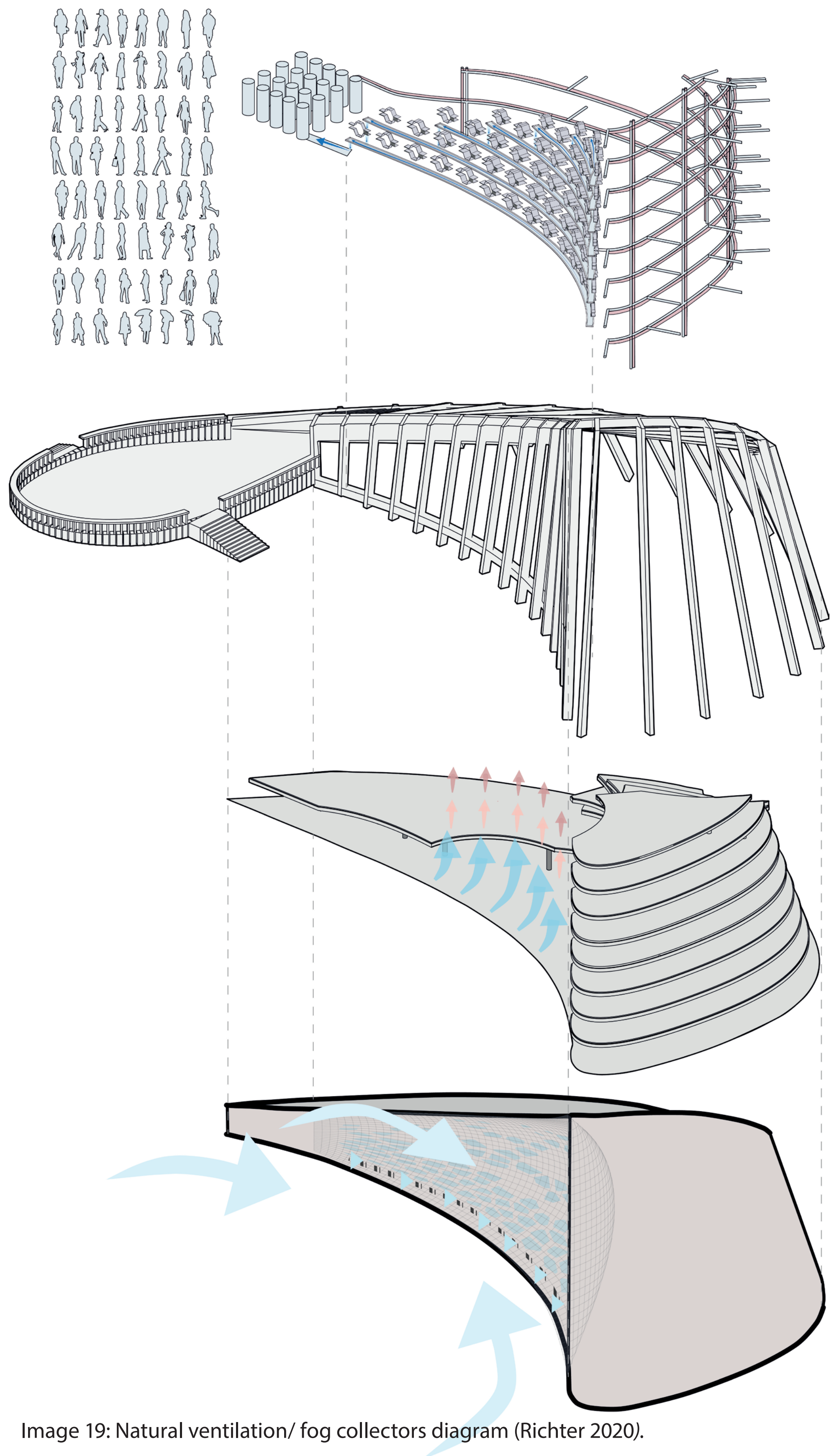


Image 19: Natural ventilation/ fog collectors diagram (Richter 2020).

During the daytime, these are mainly open to allow maximum air to pass through while providing shade for the atrium and intermediate area.

However, when the conditions are suitable for collecting fog, these mesh fabrics unfold over our façade through an origami honeycomb technique. Through two mechanically controlled tubes that control the rotation of two of the mesh fabrics, this construction unfolds over the facade.

Below is a gutter that not only captures the drops that are formed on the mesh and has fallen down, but it also collects rainwater. These gutters are equipped with bulges which ensure that the water enters the side pipes before it is absorbed for further transport to the water tanks found in the south-facing technical space.

If a building of this size for example would function as a hotel, about half of the guests' water needs could be met in this way under favorable conditions.

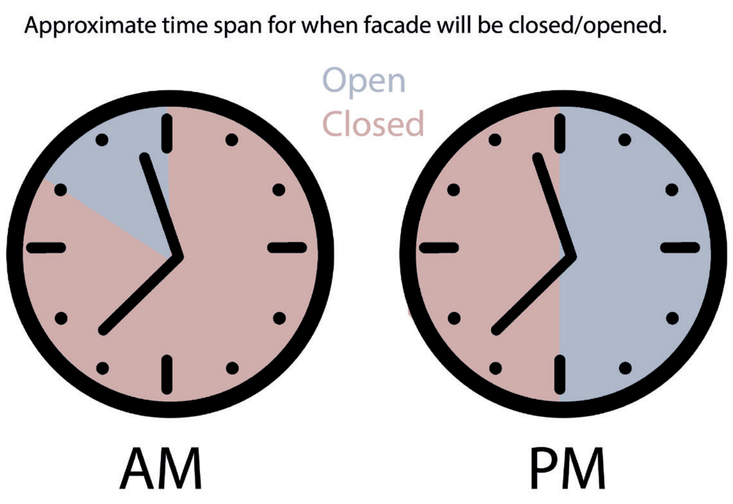


Image 20: Hours for fog collection (Richter 2020).

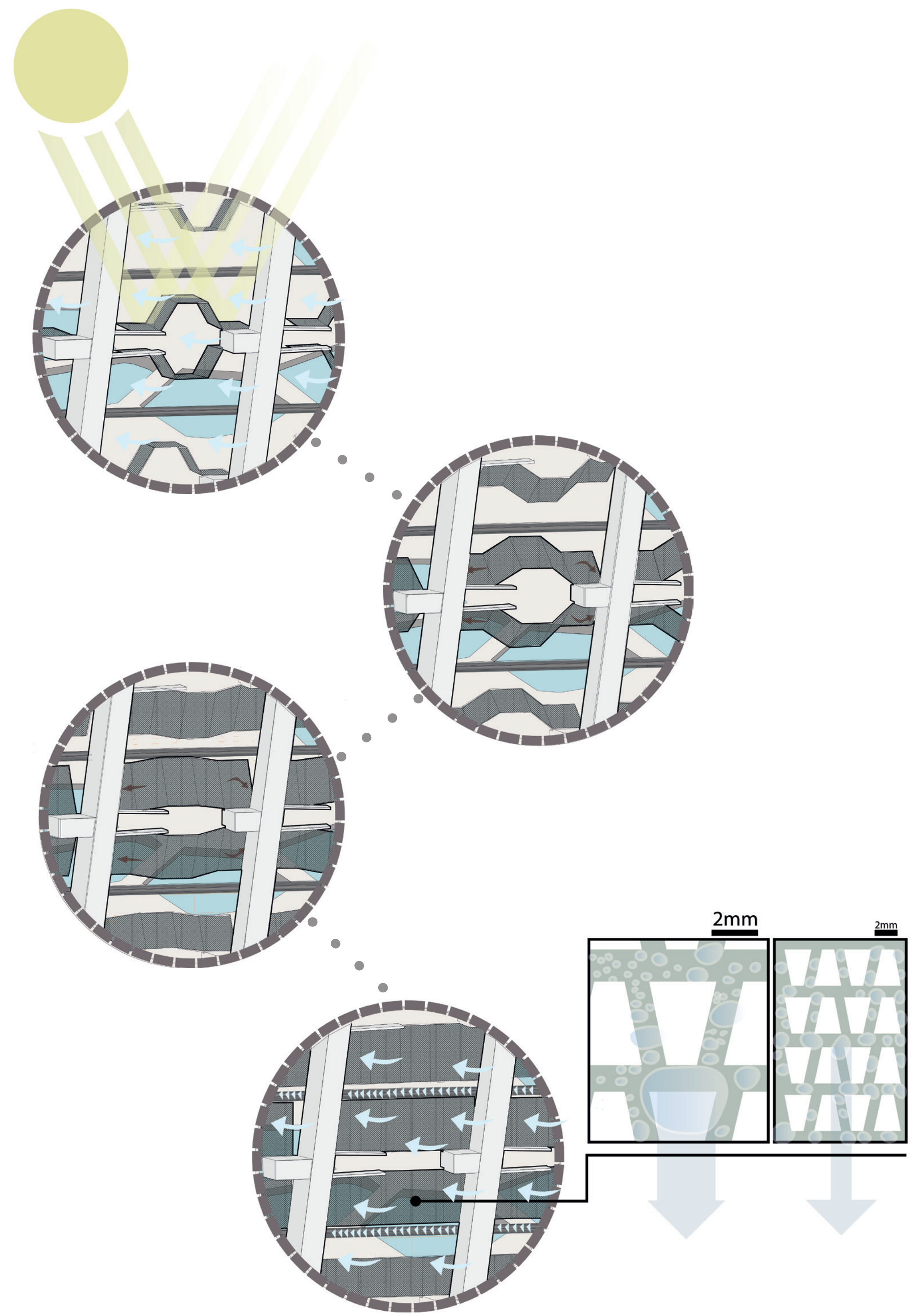
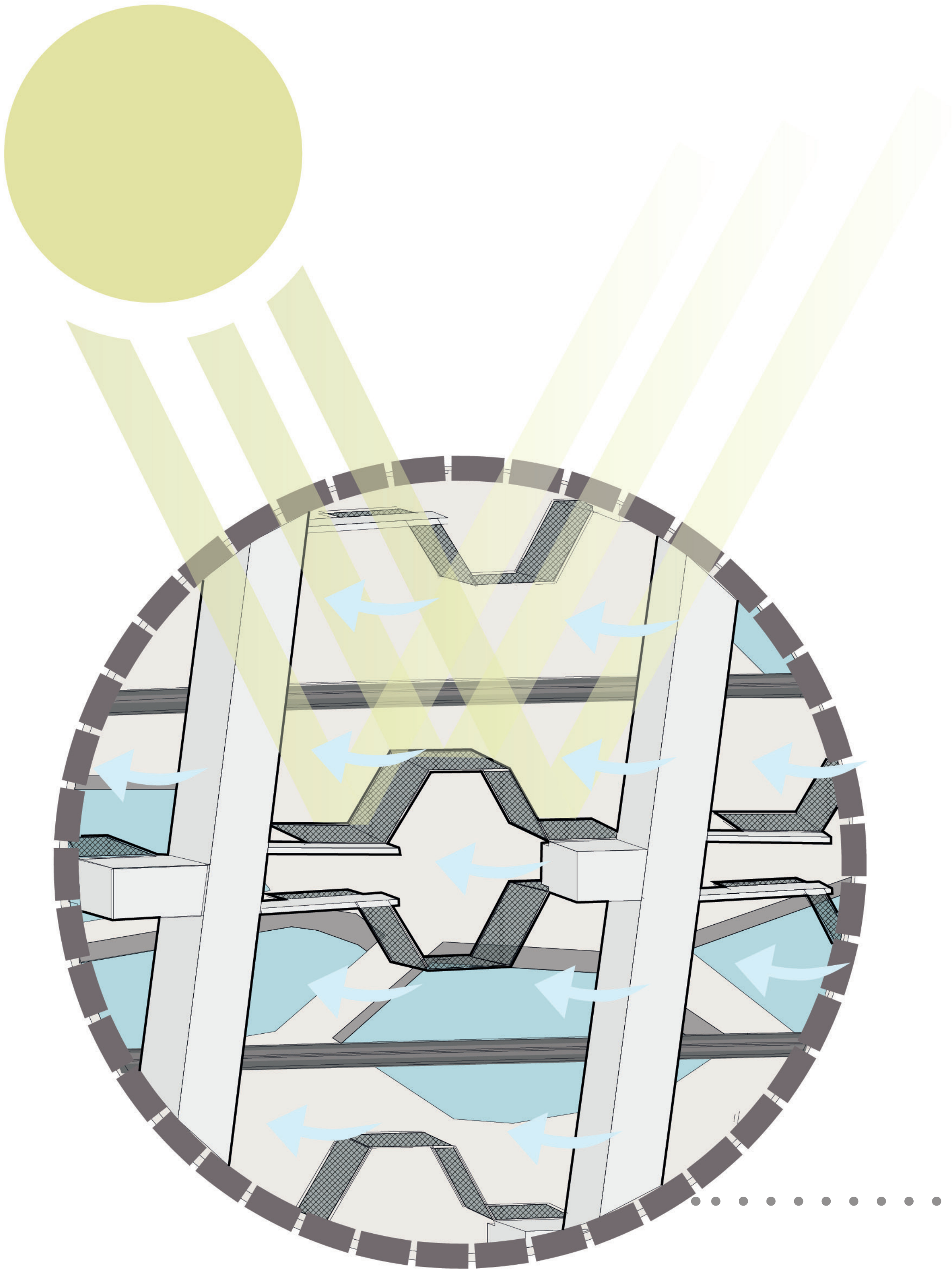


Image 21: Dynamic facade (Richter 2020).

Image 22: Open facade (Richter 2020).



During those times of the day when the need for natural ventilation is the greatest and the conditions for fog collection are poor, the panels are open. They provide shade and allow maximum wind to pass to optimize the effect of the natural ventilation.

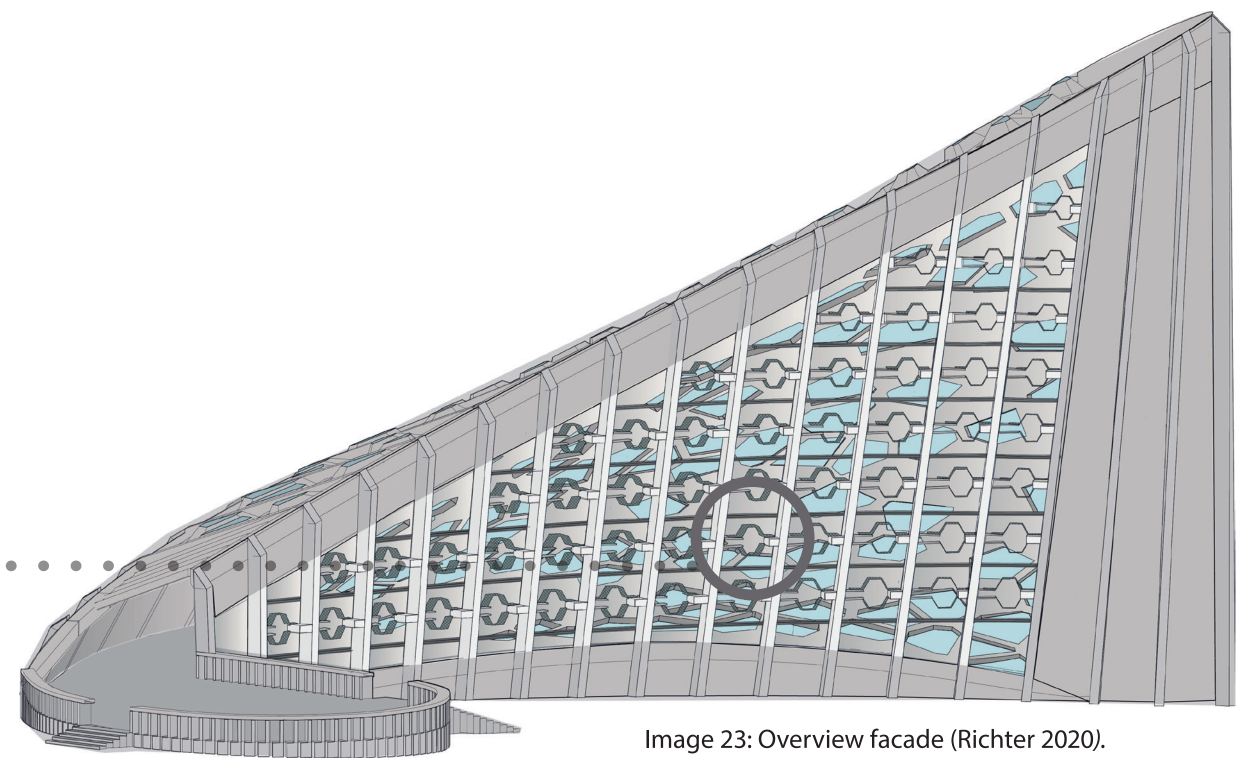


Image 23: Overview facade (Richter 2020).

10 panels make up each unit. The panels are clamped between tubes connected to each other. These connections only allow a certain rotation which allows the entire system to be operated by controlling only two panels mechanically. The two panels on the right in the picture are connected to a box that drives their rotation. The two panels on the left in the picture are connected to a rail that only allows lateral movement. The inspiration comes from classical origami principles and the system can be operated without any major mechanical interference, which reduces the need for maintenance.

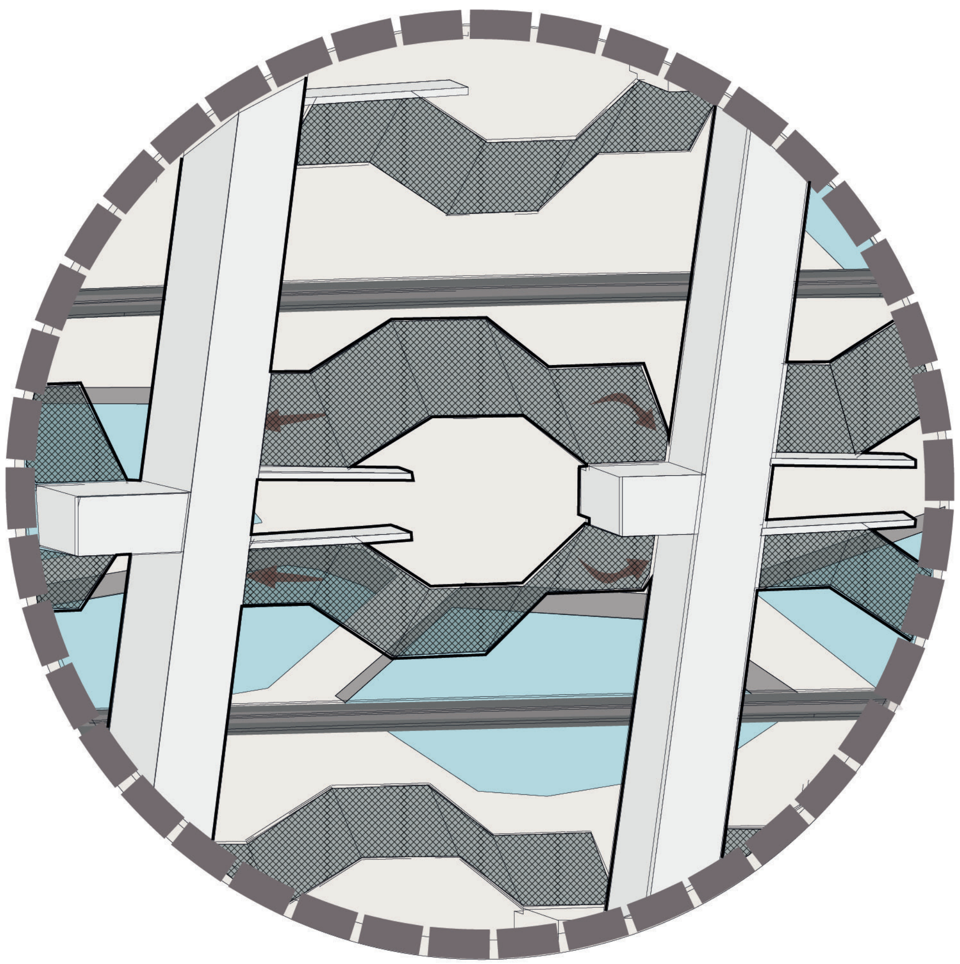


Image 24: Honeycomb 1 (Richter 2020*)*.

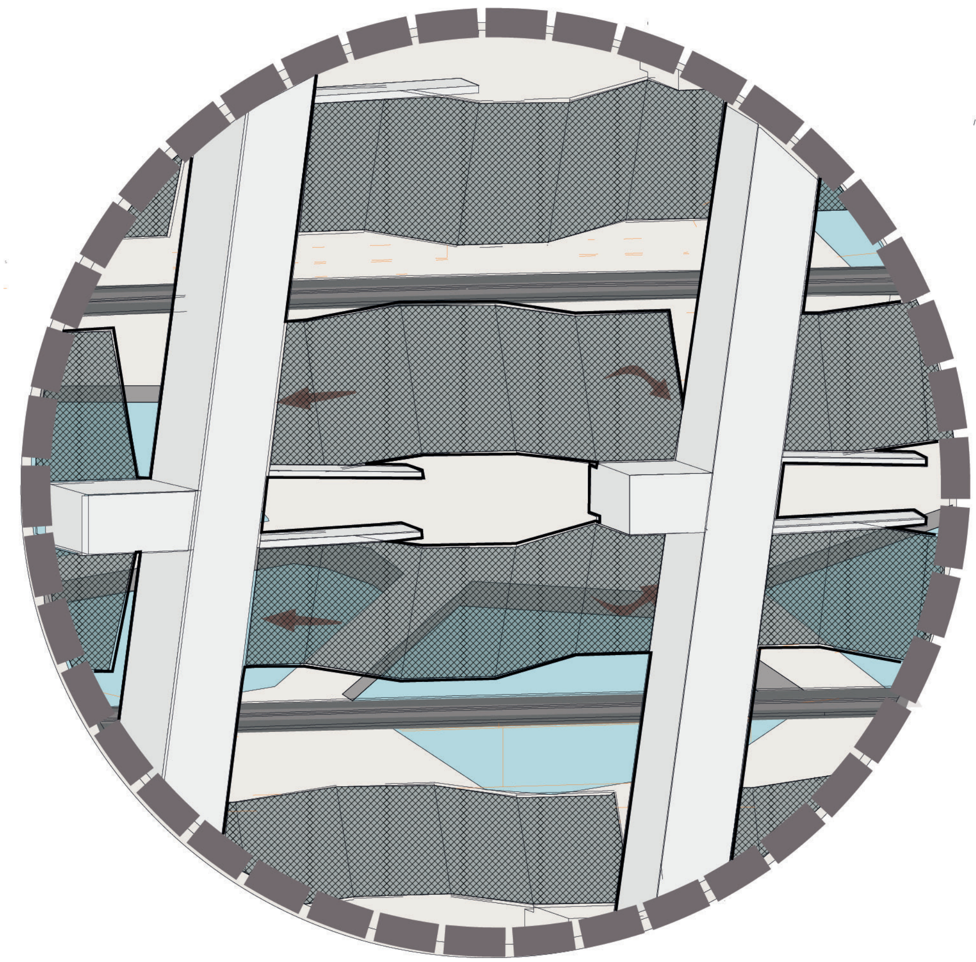
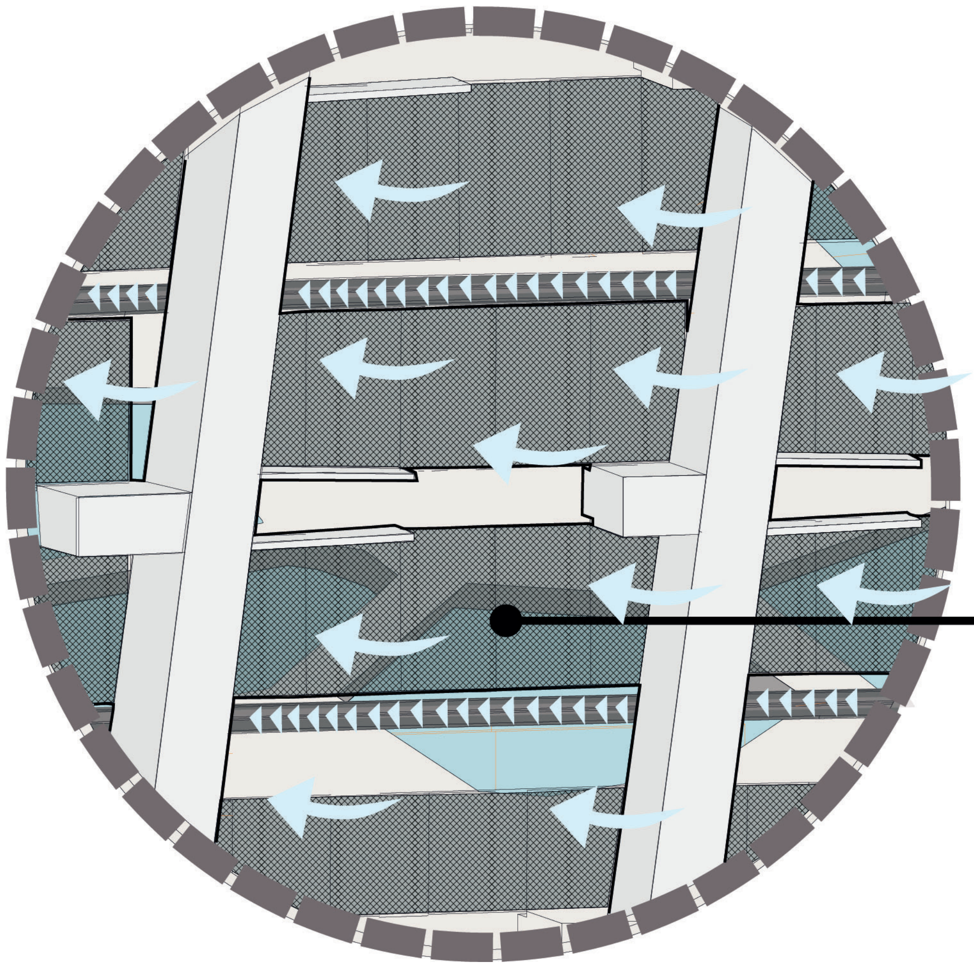
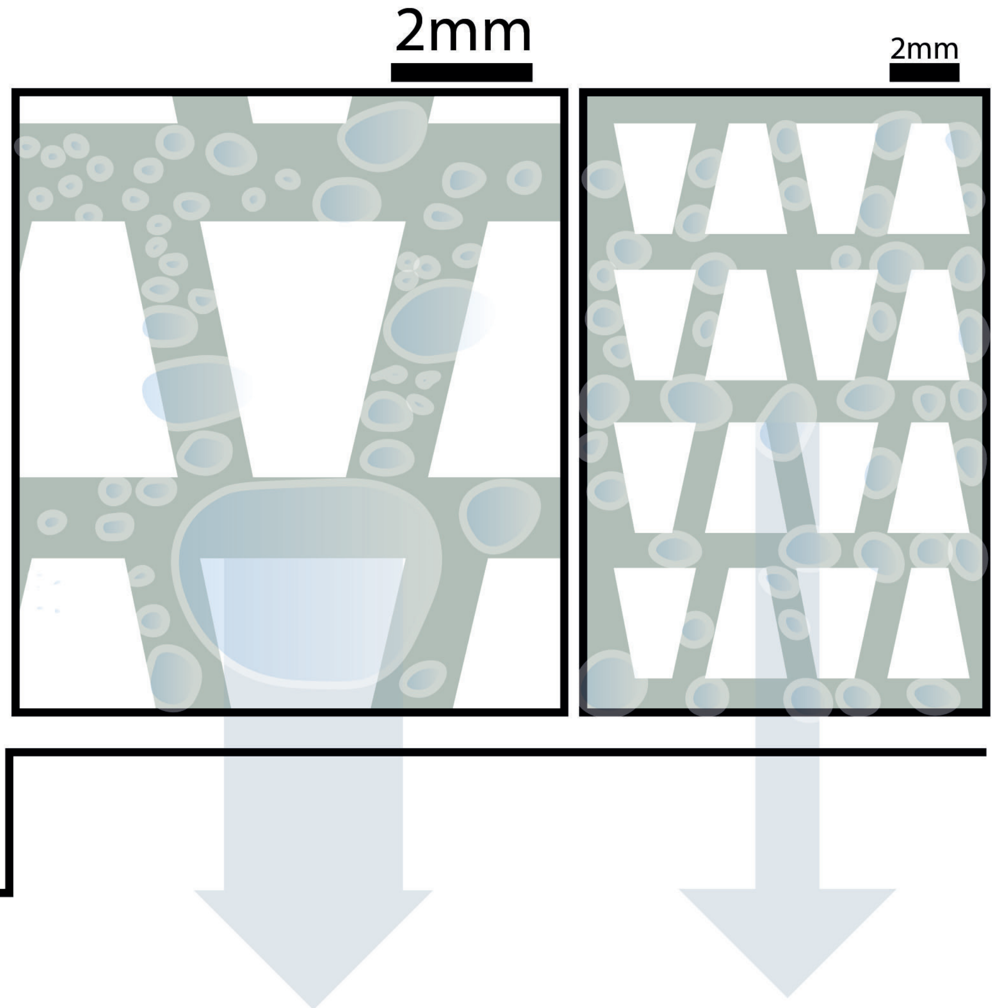


Image 25: Honeycomb 2 (Richter 2020*)*.

During times of the day when the conditions for catching water from air are favorable, the panels are precipitated. Based on climate data from the region, we can conclude that this time approximately occurs from 18: 00-10: 00 with large variations depending on the season.





As the Mediterranean winds blow over the mesh panels, the moist air condenses and forms small water droplets that unite and grow. When the droplet has grown large enough, gravity pulls it down and it is collected in the underlying gutter. There, a large amount of water is collected, which is transported through pipes to a technical space in the ground floor where it is treated and stored in tanks for use when needed.

Image 26: Fog collecting facade (Richter 2020*)*.

Image 27: Facade from far when collecting water. (Richter 2020).

Image 28: Facade from far when collectors are folded. (Richter 2020).

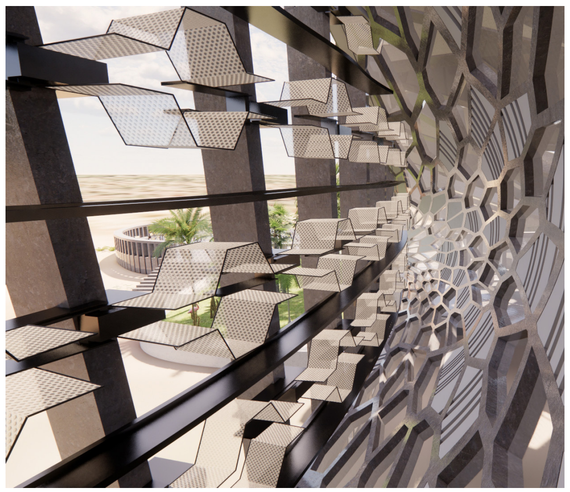


Image 29: Close up open. (Richter 2020).

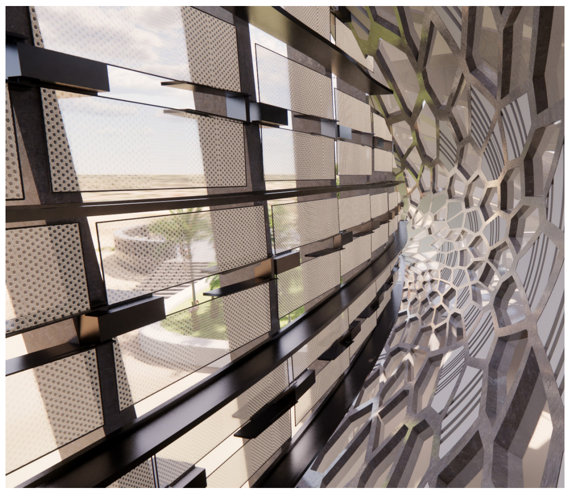


Image 30: Close up closed. (Richter 2020).

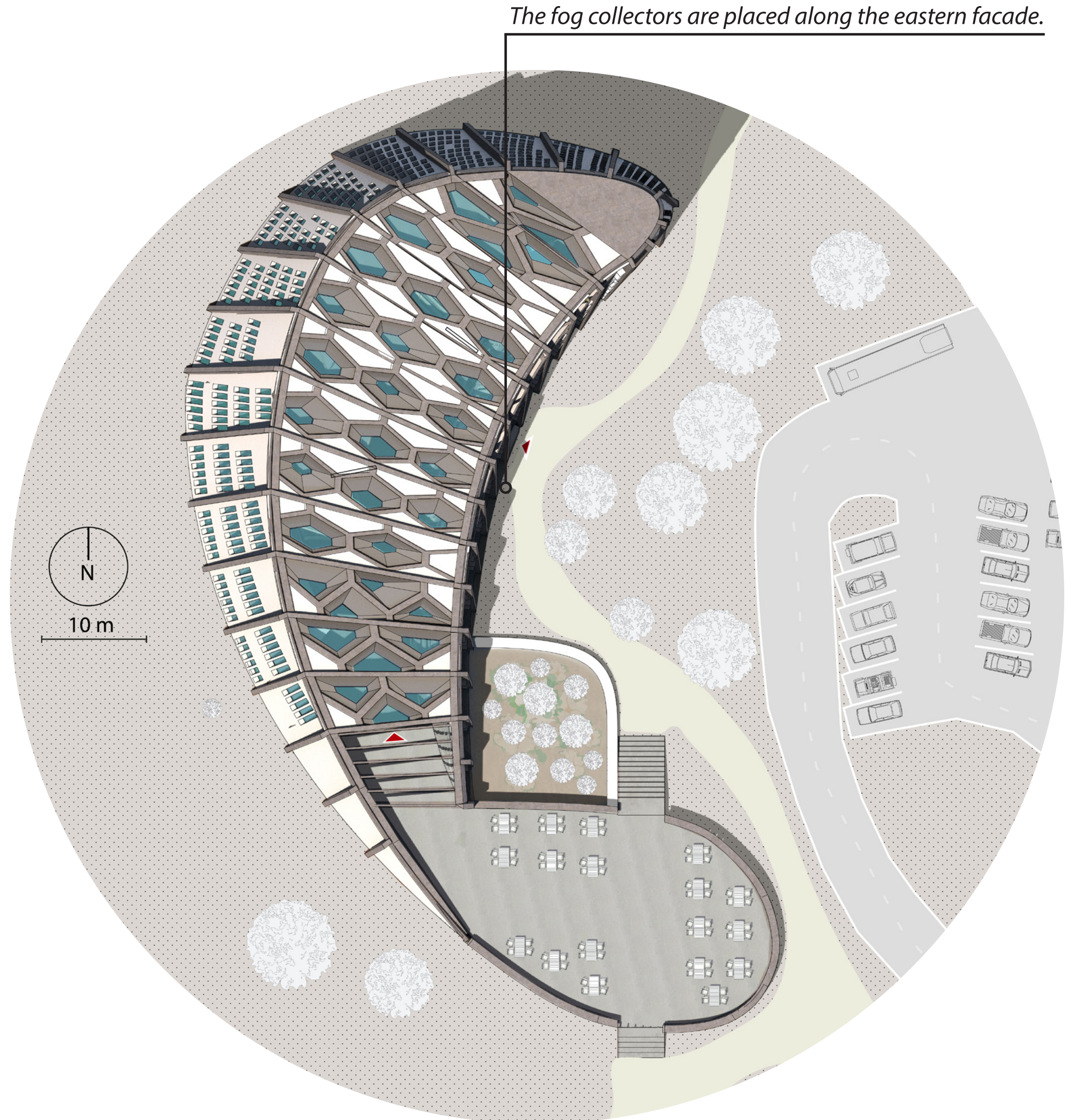


Image 33: Roof plan. (Richter 2020).

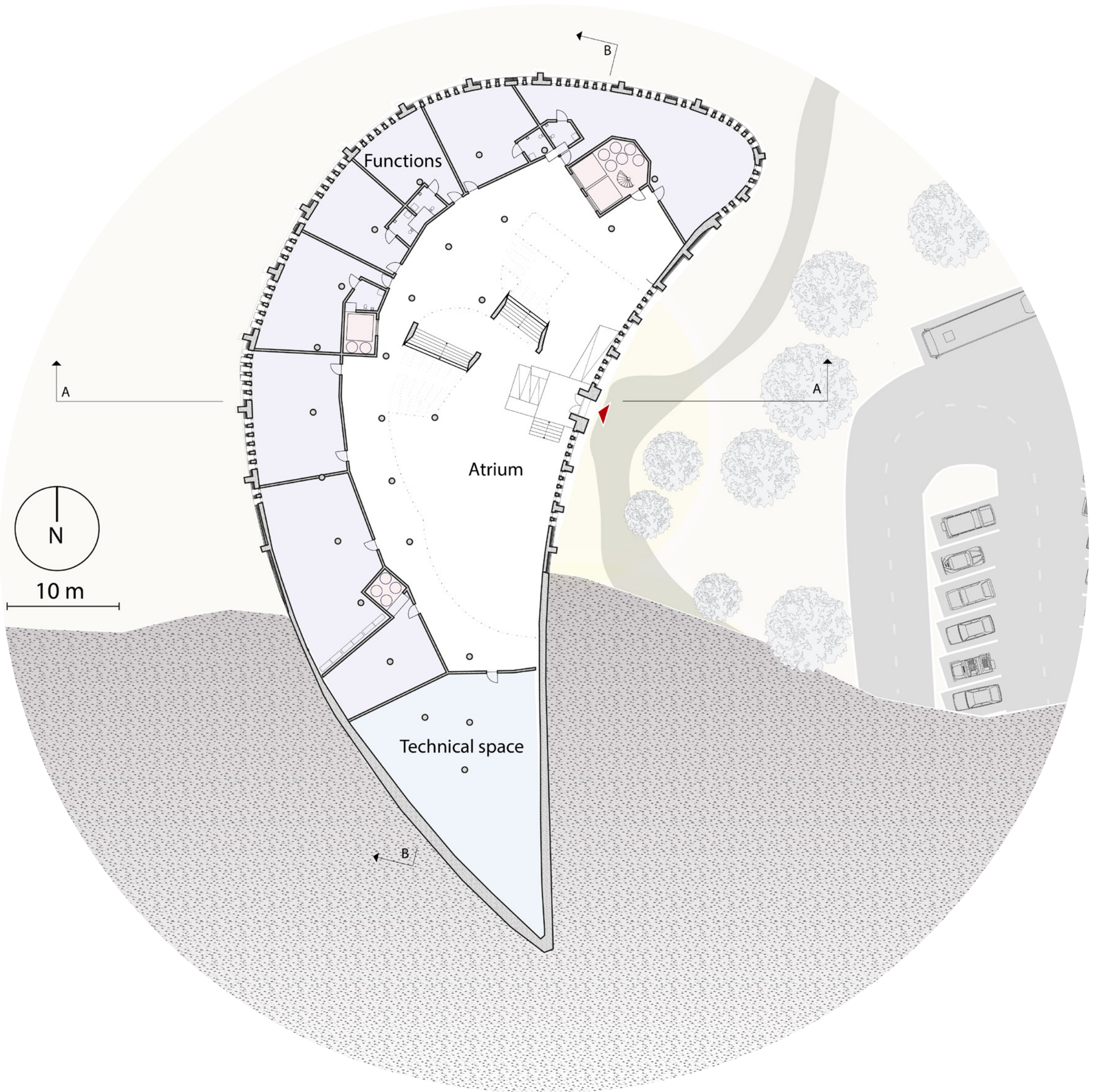


Image 32: Ground floor plan. (Richter 2020).

By planning functional spaces along an open atrium, the building can benefit from the wind draft that arise as a consequence of its design.

The gutters that collect the water from the meshes are led through pipes to tanks found in the technical space in the ground floor.

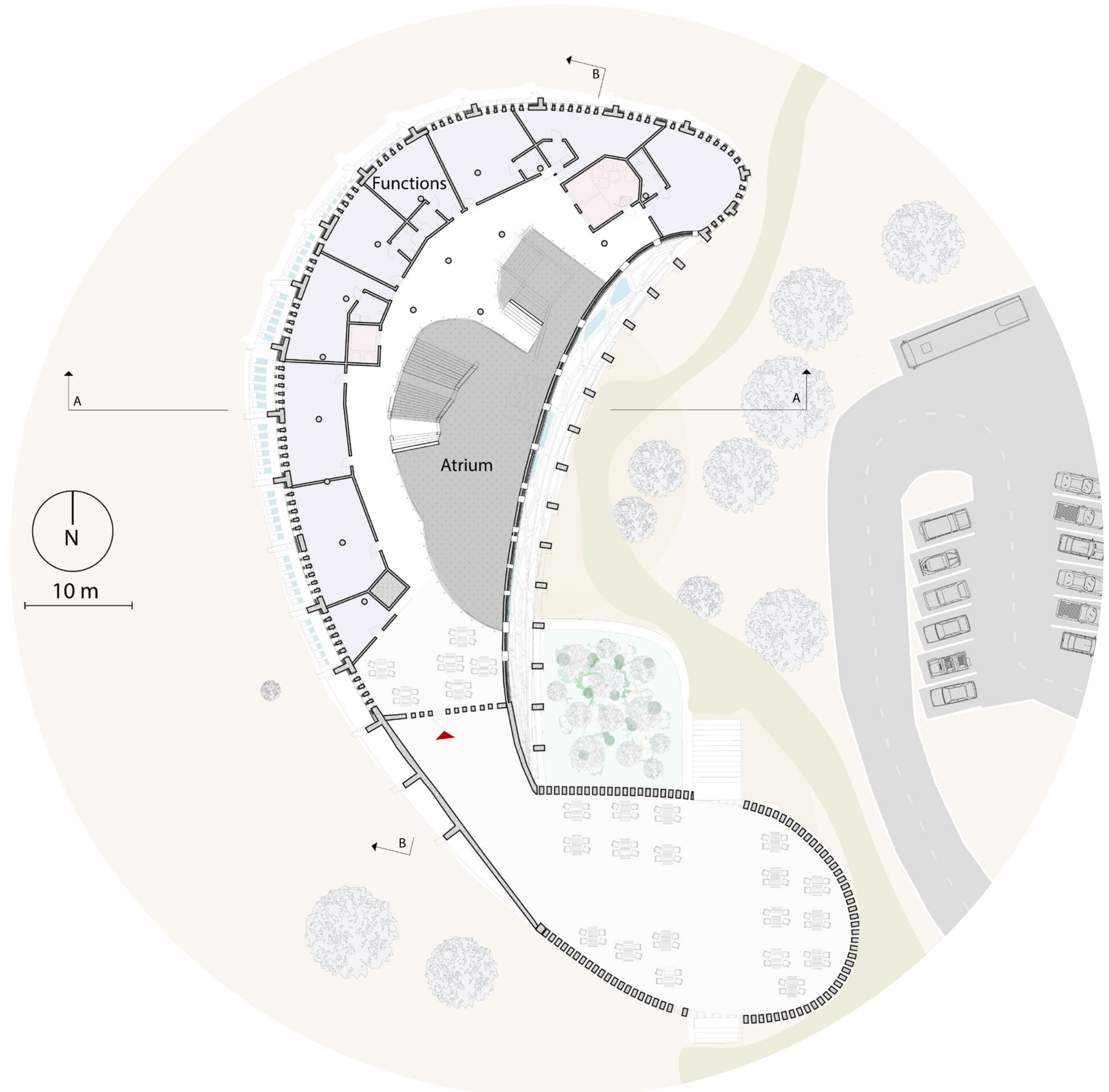


Image 33: First floor plan. (Richter 2020).

Along the eastern facade that runs along the atrium, the fog collectors are located.

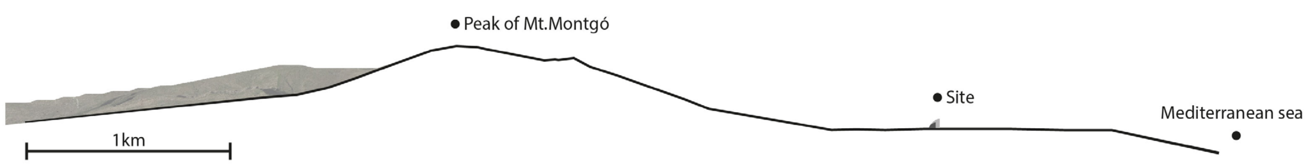


Image 34: Section zoomed out. (Richter 2020).

Advection fog occurs when winds that rise over the Mediterranean enter the coastal mountain ranges. These winds approach our building from the east and are caught up by the fog collecting façade.

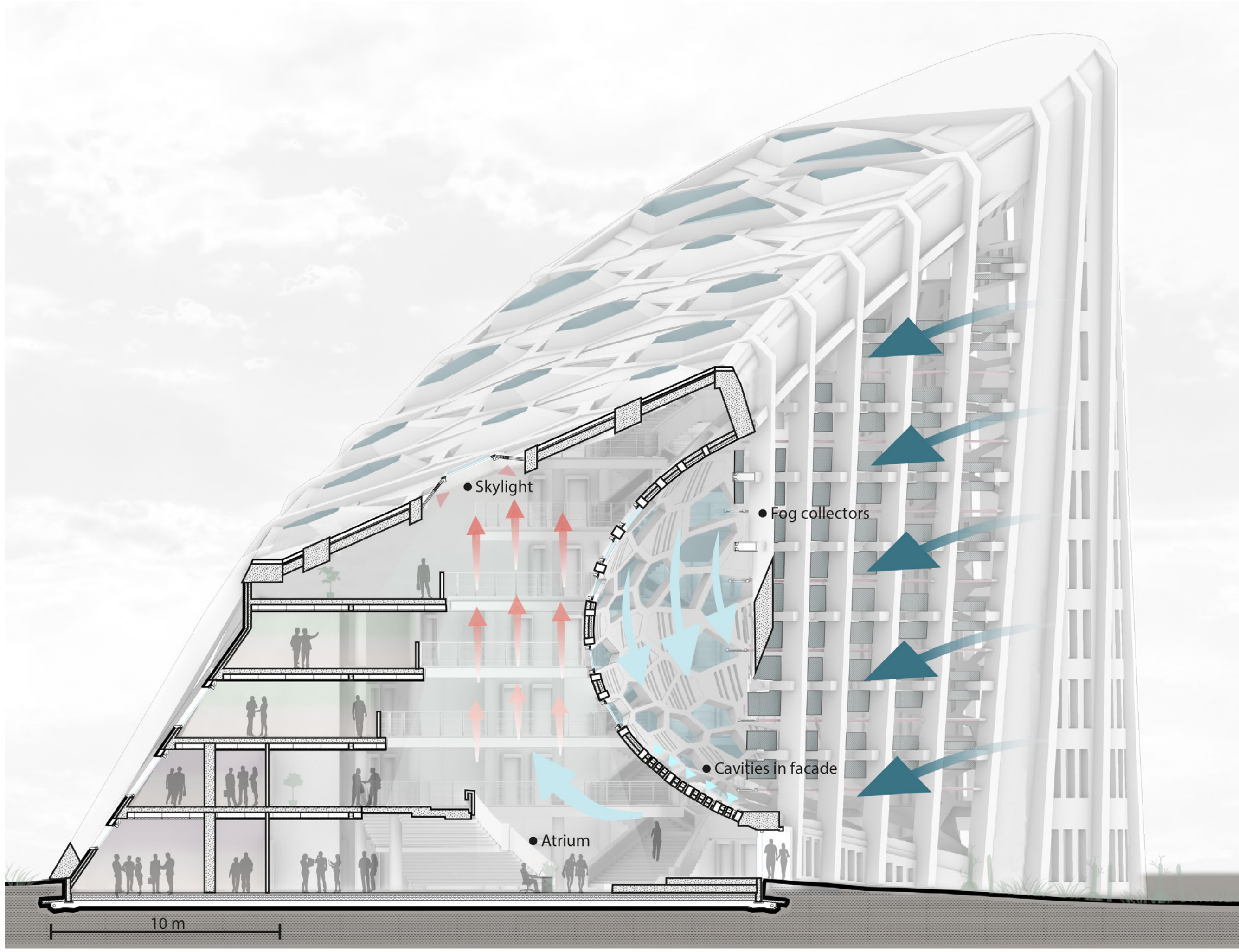


Image 35: Diagrammatic section. (Richter 2020).

When the air pass through the mesh fabrics, water droplets are formed and collected in gutters. The mesh is suspended on pipes that connect to straight standing pillars the furthest out from the building.

Behind the fog collectors, a shaded space allows for cold air to enter the building through cavities in the bottom of the façade. The warm air rises through a centrally located atrium and are released through skylights in the roof construction leading to a constant wind draft.

Section A-A

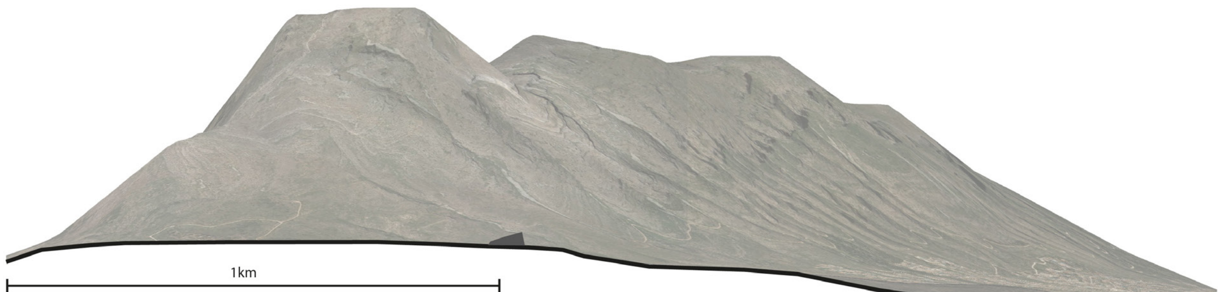


Image 36: Zoomed out long section. (Richter 2020).

The site is located between the Mediterranean and Mt. Montgó which is a popular hiking destination.

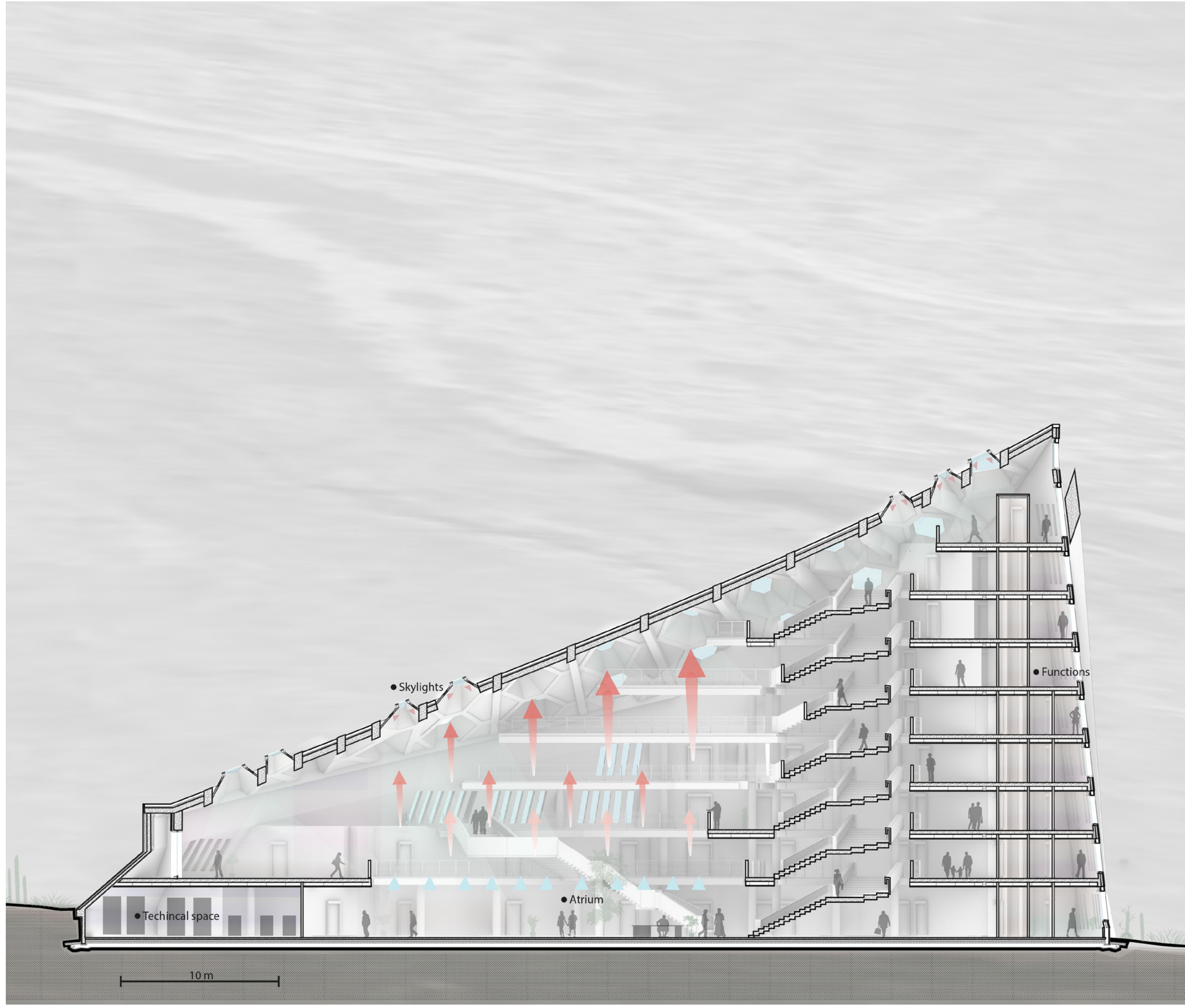


Image 37: Diagrammatic long section. (Richter 2020).

Functions are placed in rooms along a centrally located atrium that is being naturally ventilated by the wind draft that occurs.

The high ceiling height in the atrium not only contributes to creating a spacious room, but also works in the same way as a wind tower, which significantly reduces the need for mechanical ventilation.

Section B-B

Image 38: Interior view, atrium. (Richter 2020).

Evaluation.

Re-evaluation of goal

I wanted to explore what possibilities a biomimic approach could have on an architectural design project with a particular focus on making a building self-sufficient in water.

However, during the course of the work I began to question whether my original goal with this work was in fact still characterized by a very linear approach to a problem that could not be reconciled with what I perceived as the core of the entire biomimicry. Applying a biomimic tool model is basically about reprogramming our entire way of thinking about what a project should be and what a building should do. In my eagerness to use nature as a model for this utopian vision of the future, I was afraid that I myself was falling into the trap that I initially criticized the industry for constantly falling into and that the use of biomimicry would only be perceived as another gimmick among many others under the category of sustainable architecture.

I realized that the great potential in biomimicry does not lie in the fact that every designer or engineer must find ingenious solutions in the plant and animal kingdom where organisms have succeeded in solving seemingly impossible tasks in ways that can be emulated into technical systems. It is usually in these terms that biomimicry is described when it gets mentioned in the media because these stories are easy to absorb for the general public. It is based on the idea that nature has the answers to all questions. However, it is a description that fails to explain the true potential that I have come to believe biomimicry has in the field of architecture.

Potential for biomimicry in architecture

In reality, I believe that the greatest potential for biomimicry in architecture, in particular, is found in the deep understanding that everything has a purpose for something else. This understanding can be expressed in many different terms in an architectural project, but among other things by seeing resources in things that have traditionally been seen as waste. Programming functions in conjunction with each other that may have an exchange of waste where this can serve new purposes as in the case of "The Mobius Project". Or, as in my proposal where I reevaluate a phenomena that arises around buildings as a consequence of weather and wind and which has long been perceived as problematic into something resourceful that can be used to optimize the effect of another system in order to reduce the total energy demand in a building.

This is where I think nature has a lot to teach us and it is when designers, architects, urban planners and others start to use nature as a template in all aspects of their work based on this that I think we will be able to reduce the total ecological footprint of the construction industry.

Re-evaluation of goal

Designing a building that is completely self-sufficient on water that was my original goal, I realized, was problematic from several different aspects. Firstly, I came to realize that the systems available in the market today suffer from many purely technical limitations. Even in places with the most favorable conditions in the world for this method, these systems cannot be used during a large proportion of the days of the year when weather does not allow this. This means that the amount of water that can

Image 39: The Al-Bahr Towers. (Inhabitat 2014*)*.

The Al-Bahr Towers is an example of an adaptive facade that also takes advantage of origami folding principles to adapt, but it does so to prevailing solar conditions.

be produced are hard to calculate. To be able to ensure that there is always enough water stored, one would need to design for a huge system that could supply the guests with water regardless weather conditions.

However, such a large system would entail large additional costs and require a great deal of maintenance, which in the end would not be sustainable.

Had I chosen that instead of a hotel designed an office building where the water demand is considerably lower per square meter, it would not have been impossible to create a fully water self-sufficient building on my site. On the other hand, an office building on my site would have been very misplaced and in this scenario I would have had to choose a more centrally located site where it would be reasonable to add more office space. This would have resulted in that the geographical conditions for being able to produce water from fog would have been severely affected.

But staring blindly at an issue with a specific goal that I initially did, I came to realize during the course of the project is problematic even as such a target image fails to address all other aspects of a building's ecological footprint. Particularly ventilation systems that are mechanically driven and require large amounts of energy to operate play maybe the biggest role in how much impact a building has on the climate during its use and should always be taken into account in the design of a building.

If I followed my original plan and managed to achieve a building that was completely independent of municipal water pipes for its water supply but did not address how to reduce the ventilation requirements for a building, I would not have achieved a project that met the criteria I initially had set up for what a biomimic project should be.

Holistic view of a building's climate impact and adaptive facades

The further into my work that I came, the more I began to shift my focus from providing a water self-sufficient building to achieving a project that, on a holistic level, successfully managed to address several different aspects of the energy optimization of a building. I began to explore ways to combine different proven methods that were out there with the technology available for water absorption from the air and began to focus on adaptive facade systems.

Today, adaptive facade systems are primarily associated with the systems that adapt to the sun's position, weather and season in order to keep out or let in the heat that the sun's rays generate. In many ways, this type of facade exemplifies some of the most important aspects of biomimicry based on how a building is no longer treated as a static object but as a dynamic organism capable of adapting to its environment in order to become more energy efficient. Through my project, I wanted to explore other uses that a dynamic facade could potentially have in architecture and I therefore decided to design a system whose main purpose would be to utilize the moisture that was in the air but which through its design would also offer shade and contribute to a reduced need for mechanical ventilation.

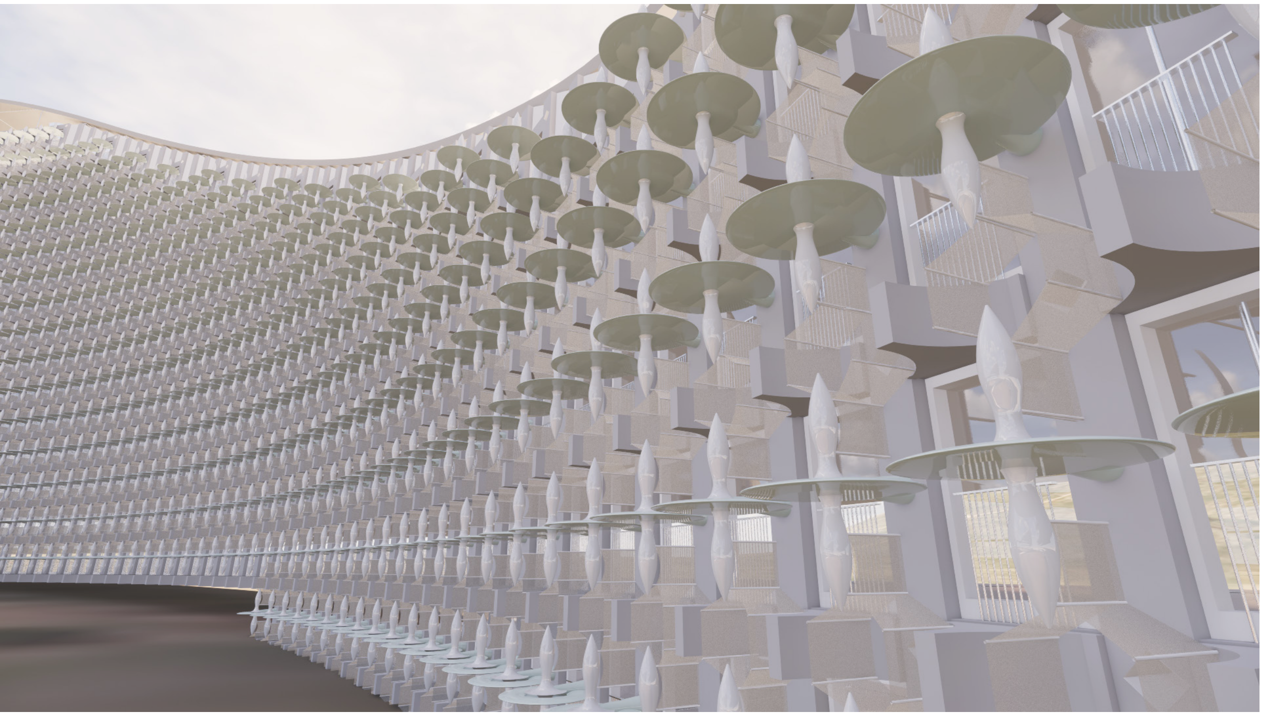


Image 40: Early sketch close up. (Richter 2020*).*

Early sketch proposal on a system that used the entire facade rather than a selected part.

What to consider when designing a system that captures water

During the course of the work, I was confronted with the dilemma of whether I would allow the entire facade that my initial drawings suggested for fog collectors or if I would rather work with a selected part of the facade that I had greater opportunities to work with in terms of optimizing wind speed and direction. I chose the later for several reasons. On the one hand, a system that captures water droplets from the air requires maintenance, which means that if the number of fog collectors increases, so does the costs of keeping the system running exponentially.

What we know about adaptive facade systems that require manual control is that these tend to be left unused after a while as users simply do not have enough incentive to care for them as they require. It was therefore important for me to design a system that was partly automatically controlled but also did not involve too many different mechanical parts to have to take into account. By copying classical origami principles, I managed to design a system that is driven only by two rotating pipes that drive the movement in all panels by how they are connected to each other.

What all research and even my experiments suggested was how important wind direction and speed were for the ability to extract water droplets from the air. If I had given the entire facade to fog collectors, not only would the need for maintenance have increased significantly, but the amount of water produced per square meter would also have greatly decreased. Other architectural values such as the opportunity for guests to look out at the landscape from their windows independent time of the day and how the building appeared to people passing by were also taken into account and the decision to instead work with a smaller area of the facade but in different ways optimize the wind that passed through was taken.

Fututre potential for fog collectors in architecture

I believe that there is a great potential in the integration of fog collectors in architecture, as the water shortage prevailing in large parts of the world is at risk of becoming a major problem that communities will have to contend with. Whether it will be through adaptive facade systems or through simpler structures that complement a building rather than be part of the expression of it remains to be seen. At present, passive fog collectors have only proved useful in a limited number of places on earth where high humidity prevails as a consequence of sea winds blowing over mountainous coastlines. However, there are many indications that in the future it will also be possible to extract water from air in places where this technique has proven to be fruitless so far with the help of technical optimization. If development continues to move forward and the market for these types of solutions becomes larger, I believe it is only a matter of time before this type of projects becomes increasingly more common.

Today, there are a number of different conceptual proposals out there, but what most have in common is that the fog collectors are still treated as separate objects rather than architectural elements and with my project I wanted to treat these objects more as a part of the expression of the building.

I am convinced that fog collectors integrated into façade systems can have a future in architecture, but primarily as a complement to existing water supply, like how solar cells mounted on roofs complement the existing electricity grid. Something I've become aware of is the uncertainty in many systems that rely entirely on natural sources and processes. It is important to not exaggerate the potential of something that you would very much like to believe in, but that you can critically look at whether something can achieve what it claims to do.

Just as a building with solar cells on a cloudy day is forced to rely on other energy sources, buildings with their own water production will have to rely on municipal water on days when it is too cold or too quiet for the systems to operate. But fog collectors still have an incredible capacity and the fact that a hotel can supply half of its guests with their water needs during a week with favorable conditions can play a very important role in the water supply in many regions where every drop of water is significant.

Summary

When I summarize this project, I have come to realize that it is not whether I succeeded in designing a building self-sufficiency in water or not that is most improtant, but how well I managed to apply the biomimic working models in my work. I started with a problem that mainly came to concern water supply but realized the full potential of biomimicry when I dared to depart from the original plan to take into account other aspects of a building's ecological imprint.

By reevaluating the idea of what a building is based on biology, I was given the opportunity to explore different methods of working with adaptive facades, which came to leave its mark on the entire project. I believe adaptive facade systems have a huge part to play in the future and as digital tools that facilitate the sketching of these types of systems - with a precision that physical models do not come close to and where you can also incorporate climate data - becomes both more prevalent and better optimized.

Biomimicry, as I have shown during the course of the project, can help designers not only solve specific problems by emulating natural systems and processes, but can also act as a reminder for us as designers to constantly seek solutions that better utilize the resources available around us.

Biomimicry can also help us understand the importance of not considering things with a start and end date but as parts of the cycle where everything can serve a purpose which hopefully in the long run can re-evaluate the whole view of what role architecture has to play in minimizing effects of climate change.

Bibliography

K. M. Al-Obaidia, M. Azzam Ismaila, H. Hussein, A. Malik Abdul Rahman, (2017) Biomimetic building skins: An adaptive approach, Renewable and Sustainable Energy Reviews 79, pp 1472–1491

N. Amer, (2019) Biomimetic Approach in Architectural Education: Case study of 'Biomimicry in Architecture' Course, Ain Shams Engineering Journal Vol.10, Issue 3, September 2019, pp 499-506

Ayuntamiento de Valencia, Factor CO2 (2016), Plan de Adaptación al Cambio Climático de Valencia 2050

F. Bagheri (2018). Performance investigation of atmospheric water harvesting systems, Water Resources and Industry 20, pp 23–28

J. Benyus, (2009), Biomimicry in action, [video], https://www.ted.com/talks/janine_benyus_biomimicry_in_action

Biomimicry Institute (2020). https://biomimicry.org/ [2020-06-01].

Caldas, Luisa & Andaloro, Annalisa & Calafiore, Giuseppe & Munechika, Keiko & Cabrini, Stefano. (2018). Water harvesting from fog using building envelopes: Part I. Water and Environment Journal. 10.1111/wej.12335.

Ezine (2018) Urban Climate Adaption Valencia. Ezine 2-2018. https://www.urbanclimateadaptation.net/ezine-2-2018/

Hamilton, W.J. & Henschel, Joh & Seely, M.. (2003). Fog collection by Namib Desert Beetles. South African Journal of Science. 99.

IPCC (2019), Special Report on the Ocean and Cryosphere in a Changing Climate, https://www.ipcc.ch/srocc/

Klein, J. (2019) Chew On This: Like to Whittle Down Your Energy Bill? Get a Termite's Advice. New York Times, April 2, 2019, Section D, Page 2. https://www.nytimes.com/2019/03/26/science/termite-nest-ventilation.html

Klemm, O. et al. (2012) Fog as a fresh-water resource: Overview and perspectives', Ambio, 41(3), pp 221–234.

L. Caldasa, A. Andaloroa, G. Calafiore, K. Munechika, S. Cabrini, (2018), Water Harvesting from Fog Using Building Envelopes – part I, Water and Environment Journal · May 2018

J. de Dios Rivera, D. Lopez-Garcia (2015). Mechanical characteristics of Raschel mesh and their application to the design of large fog collectors, Atmospheric Research 151 pp 250–258

M. J. Estrela, J. A. Valiente, D. Corell, M. M. Millán, (2008), Fog collection in the western Mediterranean basin (Valencia region, Spain), Atmospheric Research 87, pp 324–337

M. Haase, F. Marques da Silva , A. Amato (2009). Simulation of ventilated facades in hot and humid climates, Energy and Buildings 41, pp 361–373

E. Lurie-Luke (2014), Product and technology innovation: What can biomimicry inspire?, Biotechnology Advances 32, pp 1494–1505

Martorell, C., Ezcurra, E. (2007) The narrow-leaf syndrome: a functional and evolutionary approach to the form of fog-harvesting rosette plants. Oecologia 151, pp 561–573

K. Park, S. S. Chhatre, S. Srinivasan, R. E. Cohen, and G. H. McKinley (2013). Optimal Design of Permeable Fiber Network Structures for Fog Harvesting, Langmuir

M. Pawlin, (2010), Using Nature's Genius in Architecture, [video], https://www.ted.com/talks/michael_pawlyn_using_nature_s_genius_in_architecture

T. Peters, (2011), Nature as Measure: The Biomimicry Guild, Architectural Design, November 2011

M. Rajaram, X. Heng, M. Oza, C. Luo (2016) Enhancement of fog-collection efficiency of a Raschel mesh usingsurface coatings and local geometric changes, Colloids and Surfaces A: Physicochem. Eng. Aspects 508, pp 218–229

C. M. Regalado, A. Ritter (2016), The design of an optimal fog water collector: A theoretical analysis, Atmospheric Research 178–179, pp 45–54.

UNEP (2018), Towards a zero-emission, efficient, and resilient buildings and construction sector.

Zari, M.P. (2018). Biomimetic Approaches to Architectural Design for Increased Sustainability. Vellington. Victoria University.

Illustrations

Inhabitat (2014) Al Bahr Towers by AEDAS [photo] by Inhabitat is licensed under CC BY-NC-ND 2.0. To view a copy of this license, visit https://creativecommons.org/licenses/by-nc-nd/2.0/

Klemm, O. et al. (2012) Fog as a fresh-water resource: Overview and perspectives [map], Ambio, 41(3), pp 221–234.

Krejci, K. (2009) Water Droplets on Leaf [photo] is licensed under CC BY 2.0. To view a copy of this license, visit https://creativecommons.org/licenses/by/2.0/

Richter, A. (2020). (photos from private collection and illustrations made by author)

Weetman, C. (2016) A simple diagram to contrast the 'take, make, waste' linear approach to the circular economy. [diagram]