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*NATURE AS A SOURCE FOR ARCHITECTURAL INNOVATION*

BACHELOR STUDIO WINTER 2019

“HYPNEROTOMACHIA NATURAE“

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# INDEX


[6]

INTRO

[10]

THE BEGINNING
ORGANIC ARCHITECTURE

[32]

PRE-BIOMIMICRY
LAYING THE FOUNDATION
FOR BIOMIMICRY

[64]

NEW POSSIBILITIES

[70]

BIOMIMETIC
METHODOLOGY

[74]

THE EARLY YEARS OF
BIOMIMETIC
ARCHITECTURE

[98]

SMALL DETOUR
- SEEING MORE

[108]

EMERGENT
TECHNOLOGIES

[132]

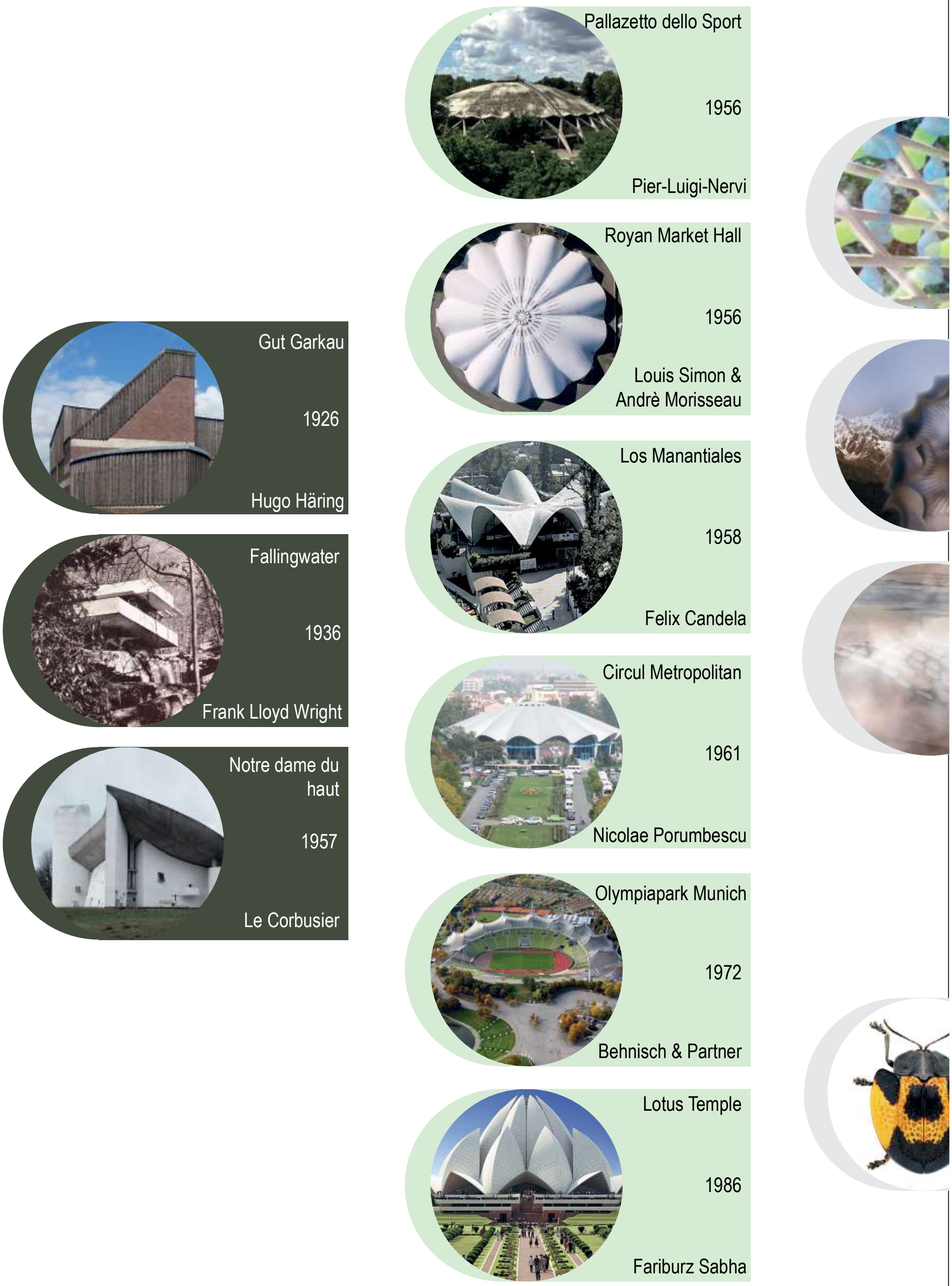
AN EXPERIMENTAL
APPROACH

[176]

OUTRO

[180]

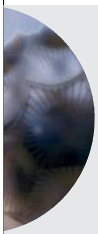
LIST OF REFERENCES



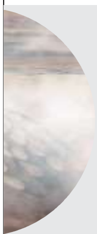



*[Img. 1] : Timeline of projects analyzed*

Uraniah moth



Snow leopard

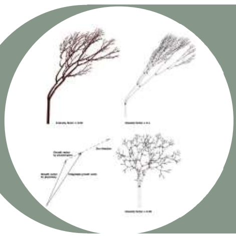


Beetle

Insects:
Models for Design

2019

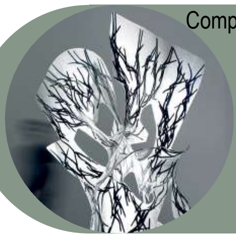
21_21
Design Sight Tokyo



Branching

2010

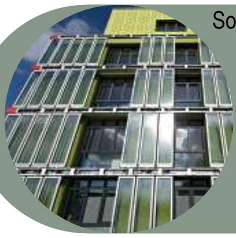
Pavel Hladik



Composite Prototype

2013

Kokkugia



SolarLeaf Facade

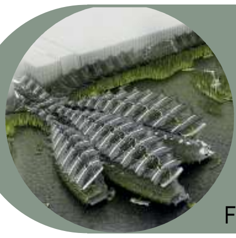
2013

Arup

Research Pavillon

2016/17

ICT/ITKE Stuttgart



Hydramax

2012

Future Cities Lab

Endemic Interstices

2012

Alisa Andrasek

Echoviren

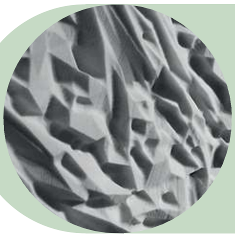
2013

Smith | Allen

Alien Within Familiar

2015

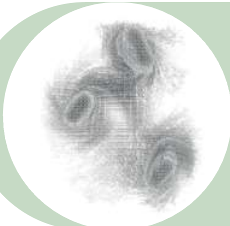
Alisa Andrasek



Morhphocyte

2016

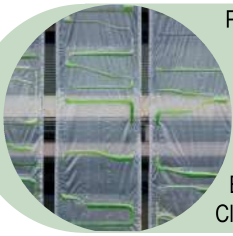
Alisa Andrasek



Cloud Pergola

2018

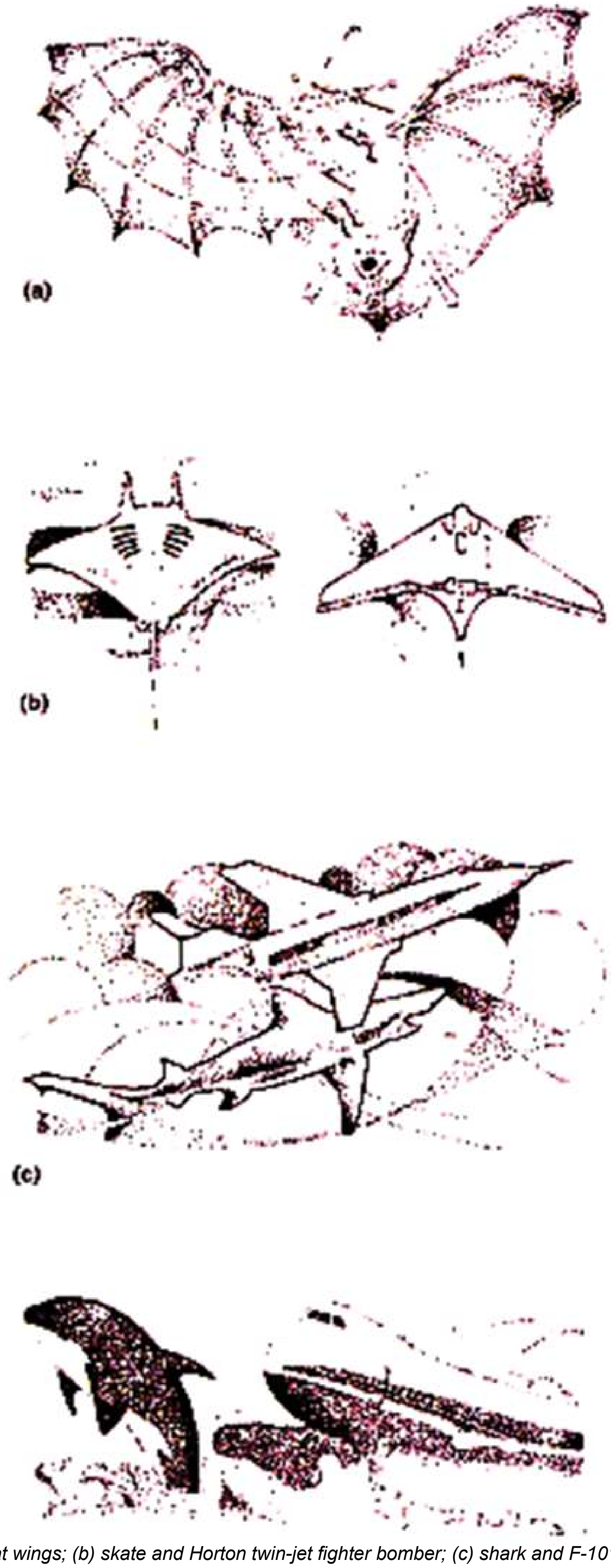
Alisa Andrasek



Photosynthetica

2018

EcoLogic Studio
Claudia Pasquero



[Img. 2] : (a) Flying Machine and bat wings; (b) skate and Horton twin-jet fighter bomber; (c) shark and F-101A jet; (d) killer whaleand jumbo jet

# INTRO

Early in our existence, we stayed very close to nature, we coexisted with nature. Time passed and humans grew in number and knowledge. Their attitudes changed to their surroundings, learning to protect themselves from weather and enemies. To restore a balanced relationship with nature and reduce the strains on natural resources we need to reintegrate science, technology and the human back into its natural environment.

In a time of industrialization, technology and detachment from nature, an alternative, organic architecture, formed, more concerned about humans and their environment, more interested in natural, rational and aesthetic shapes. Buildings should grow from the ground - as one with their site - while also providing occupants with a connection to the exterior. But we weren't just interested in the shape of nature, we wanted to look deeper into the organism, the system behind nature.

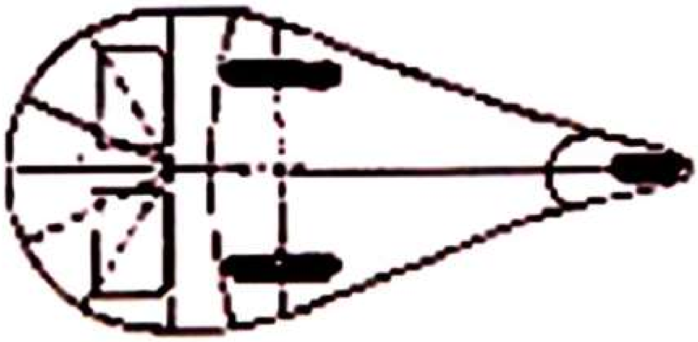
Some aspects of nature are undetectable to the human eye but have been discovered by science. It has been established for example that bats can fly in an oriented and precise fashion without optical vision because they have their own radar. Studies of this type are being carried out within the very young science of Bionics in order to apply them to human needs. The word "Bionics" derives from the Greek ios (life) and ikos (unit): a living unit. a term that refers to all artificial constructions modeled after living systems. Bionics is interested in the creation of functions and forms analogous to those of the living organism. This is achieved by means of observation and through research, analysis and synthesis. This science does not attempt to trace or copy: it works on the thesis that every model can potentially provide ideas for the design of new methods and mechanics that will improve those currently existing. (cf. Senosiain, 2003)

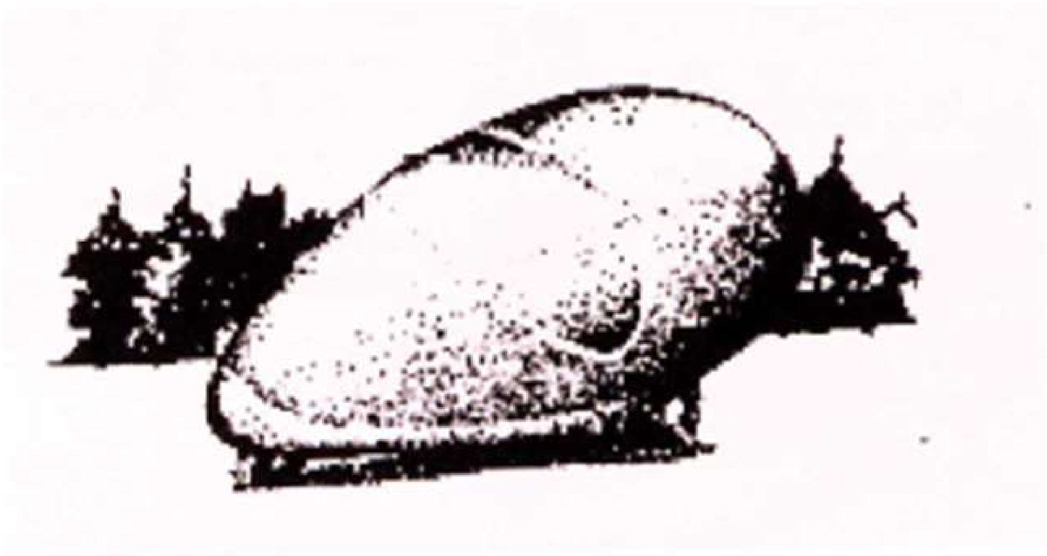
An architect‘s aim in design is to shape things in such a way that they fulfill their functions perfectly. Bionics studies not only the physical and chemical aspects of a natural model, but also the morphology of its structures in order to apply them to the construction of artificial devices and systems that will later be used by people. An ever-changing evolutionary process is maintained in nature so that inefficient systems disappear while those characteristics that are better able to adapt to prevalent or developing environmental conditions can be perfected. Then inspired by these models we can take advantage of this process of improvement and adapt it to our designs. (cf. Senosiain, 2003)

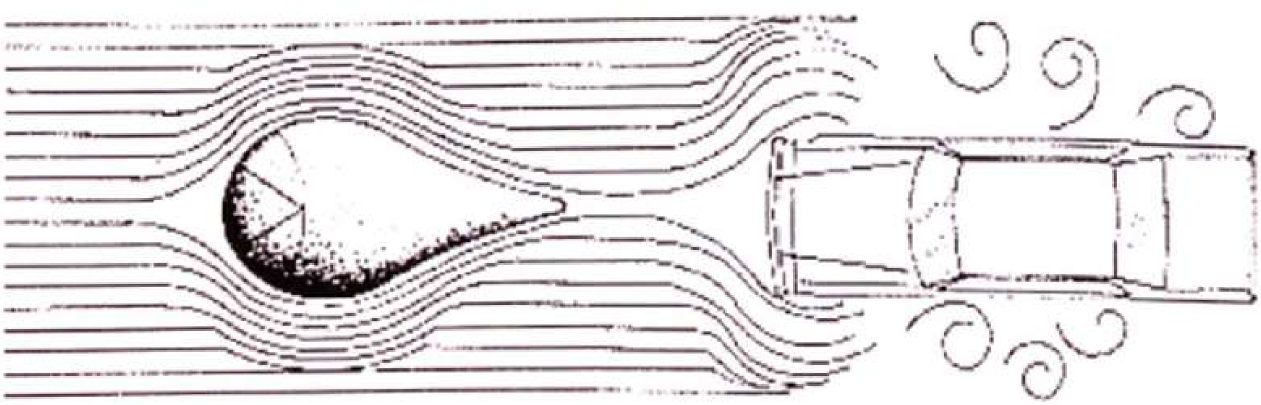
Throughout history nature has inspired humans to progress in science and technology. In the year 400 BC. Democritus., a philosopher from ancient Greece, said: "We learn important things from imitating animals. We are apprentices of the spider, imitating her in the task of weaving and confecting clothing. We learn from the swallows how to construct homes, and we learn to sing from both the lark and the swan ..."
(Senosiain, 2003, p. 3)

Bionics is applicable to the designs of different branches of science, in land, sea and air transportation, and elsewhere. The first cars that used an internal combustion engine looked like simple boxes on wheels. They followed the design of a stagecoach pulled by horses but used a motor instead of the horses. Designers had not yet considered the resistance of air imposed on an vehicle.

In 1933 Buckminster Fuller designed a car based on a natural shape. By studying the shape of the raindrop. Fuller designed the Dymaxion automobile based on the same principles. He knew that air resistance increased in ratio to velocity squared. For example: if







*[Img. 3] Top: the Dymaxion car designed in 1933 by Fuller; Middle: prototype designed by General Motors for the twenty-first century; Bottom: effects of the wind: Dymaxion and conventional automobile*

the car tripled its speed, air resistance would be nine times greater: the faster it went, the more the strength of the motor would be reduced as it pushed air to the sides.

Fuller deduced that the shape of the car was inefficient and should be modified. He found the solution when he studied the few notes that had been written on the properties of aerodynamics which showed that when a drop of rain falls through the atmosphere, its spherical shape is modified: the front part of a raindrop remains rounded and supports most of the fluid, while the back lateral edge is shaped by air currents. In this way, the friction of a raindrop against the air gives it the shape of a tear. (cf. Senosiain, 2003)

This lead us to the theory of biomimicry. Biomimicry is a new approach of trying to imitate nature in a respectful way in order to reintegrate into the natural world and its ecosystem. Basically, technology has made it possible for humans to live in disharmony with nature through a border that seemed impenetrable, but the current situation – namely global warming and the climate crisis – shows that the effect of humans on earth, specifically since this complete detachment from a somewhat give and take relationship to a position where the human seemingly doesn't depend on nature, with all the resource depletion and pollution, is screaming for a new solution, either the extinction of humankind or a new way to think the relationship. What biomimicry offers is exactly a way to think this new relationship. To gain back perspective on how to integrate humankind back into its very own ecosystem earth, biomimicry is proposing to take nature as an example and implement its closed-loop-circle like approach to architecture. (Mazzoleni & Price, 2013)

## FUNCTION IN NATURE

One of the essential aspects of both natural and manmade design is functionalism. Function is intimately related to form: there is no form without function or function without form. Neither can exist without the other. In 1896 Sullivan declared that: "shape comes after function." Le Corbusier wrote that as far as he was concerned: "Plants grow from the inside out, the exterior part being the result of the interior." However on rare occasions form can also determine function. In any case, form-function or function-form is an unreal dilemma. (cf. Senosiain, 2003)

Architect Denkmar Adler was one of the first people to think about environmental architecture. He thought Sullivan's theory of "Form follows function" further to "Function and environment determine form" with emphasizing the importance of studies and observations of nature: (cf. Mallgrave; Contandriopoulos, 2008)

"…if 'form follows function,' it does not follow in a straight line, nor in accordance with a simple mathematical formula, but along the lines of curves whose elements are always changing and never alike; and if the lines of development and growth of the vegetable and animal organisms are infinitely differentiated, the processes of untrammeled human thought and human emotions are even more subtle in the differences and shadings of their manifestations….before accepting Mr. Sullivan's statement of the underlying law upon which all good architectural design and all true architectural style is founded, it may be well to amend it and say: 'Function and environment determine form,' using the words environment and form in their broadest sense." (Adler, 1896, p. 243f)

In nature things are functional in relation to the whole. The purpose of legs for instance is to support and move the body yet on their own they are unstable. If we study the shape and characteristics of many things in nature, we find that they have precise reasons for being as they are: their shapes fulfill functions, and they are therefore always beautiful. The nostrils of a human nose open downwards to prevent rain and perspiration entering. They are also located high enough to reduce the entrance of dust that floats near or at ground level. Hairs inside the nostrils serve to filter inhaled air. Function, as an autonomous architectural concept, has a physical and psychological aspect. Physical, material or physiological functions are comprised of concepts such as economy, time, movement and position. Psychological function is comprised of such concepts as joy, serenity and tranquillity (i.e. stability and achievement).
(cf. Senosiain, 2003)

# THE BEGINNING

## ORGANIC ARCHITECTURE

Organic architecture is the first approach to a relationship of architecture and nature in a new time of industrialization, technolo-gies and new ways of living.

This architectural movement took a quite metaphorical approach to nature. In a very romanticized idea of harmony between the built and natural environment, this style tried to embed the built environment into the natural one. The idea behind that was to think the building like an organism, with all its geometries, materials and principles of order becoming part of the larger composi-tion of the built and natural environment.

Furthermore, every element of the building, even the furniture, was considered, since it all related to each other.

Seeing this concept in a current view, one needs to consider that the tools architects at that time had at their disposal were very far from what is available now. Most of the projects are based on observations of nature, sketches, and experimentation.

Frank Lloyd Wright coined the term ”organic architecture“. It is broadly used to describe any building, the shape of which mimics nature and harmonizes with its natural environment. (cf. Finsterwald, 2011)

Organic architecture stems from an understanding that the wellbeing of the human psyche cannot be nurtured by removing people from the natural world in which they belong. To this end, organic buildings grow from the ground - as one with their site - while also providing occupants with a connection to the exterior. This kinship with the environment in Wright‘s words meant, for example, “not to build on top of a hill in dominance, but beside it in partnership“.
(cf. Wright, 2005)

Frei Otto also had its own view on this topic:
“The goal today is to build houses and cities that are natural. To be natural, a human product need not look like a plant or a tree. The major goal is (...) for houses and cities to grow together with plants and animals to constitute a natural biotope, i.e., for the house not to be aimed against nature, but for man and technology to form an inseparable part of nature.”
(Frei, 1982. p.7)

# ANIMATOR OF SPACE
## FRANK LLOYD WRIGHT

Wright‘s proposol was Organic Architecture, “Organic“ must be understood as the unique, the inseparable, the integral. From his first designs, up to the Guggenheim Museum of Art in New York (1956-1959). Wright, an American architect. moved forward to the prototype of organic, integral architecture.
(cf. Senosiain, 2003)

Falling in to the ternptation of synoptic analysis, we could say that Wright‘s proposal is based mainly on four fundamental elements:
- inspiration by nature
- oriental influences
- reminiscences of the constructions of primitive cultures
- and the incorporation of living nature

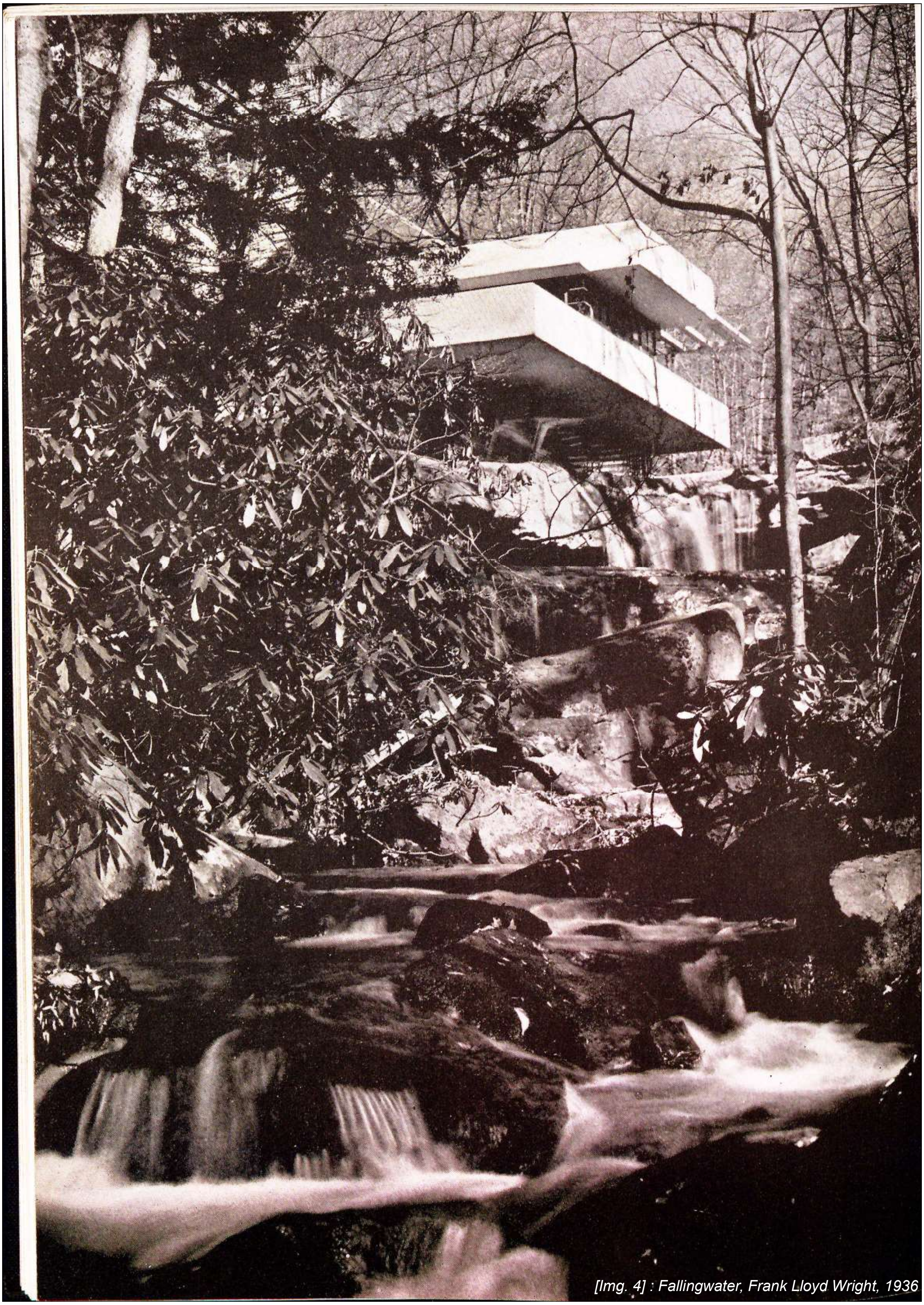
into his work, principally in gardens, patios and terraces

For Frank Lloyd Wright: the word organic in architecture denotes not only what can be hung in a butcher shop, carried on two feet, or cultivated in a field. The word organic also refers to the entity, and perhaps it would be better to use the word integral or intrinsic. As it was originally used in architecture, organic means a part of the whole and all of the part.
(cf. FInsterwald, 2011)

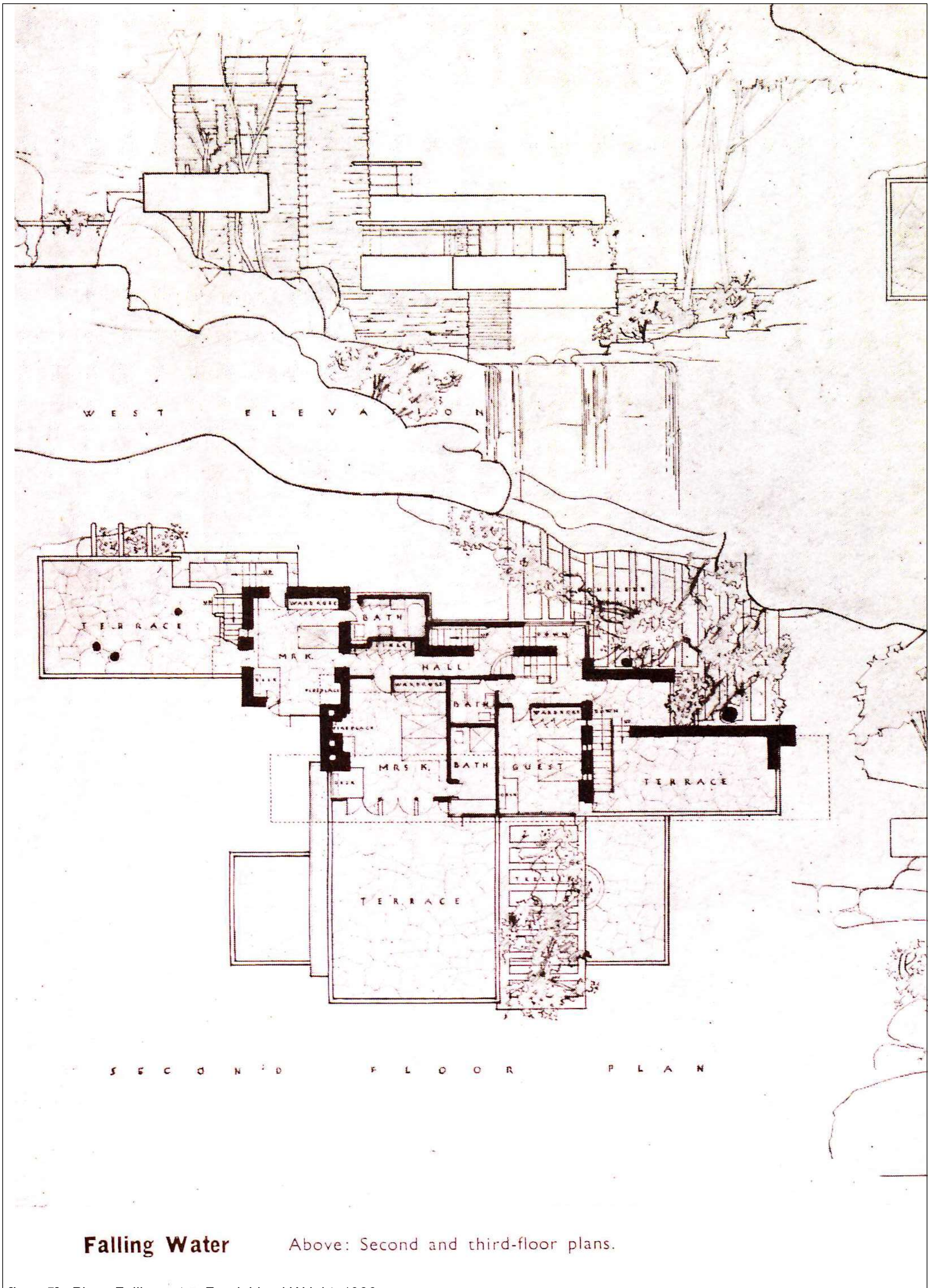
The interpretation of „organic architecture“ turns out to be more complex, since this specific type of building in its different and multi-dimensional form, which means in construction and materiality in relation to the function, above all was determined by an individual relation to nature.

“Organic simplicity is the only kind of simplicity that can answer that stange, compelling question for us:
Now what, architecture?”

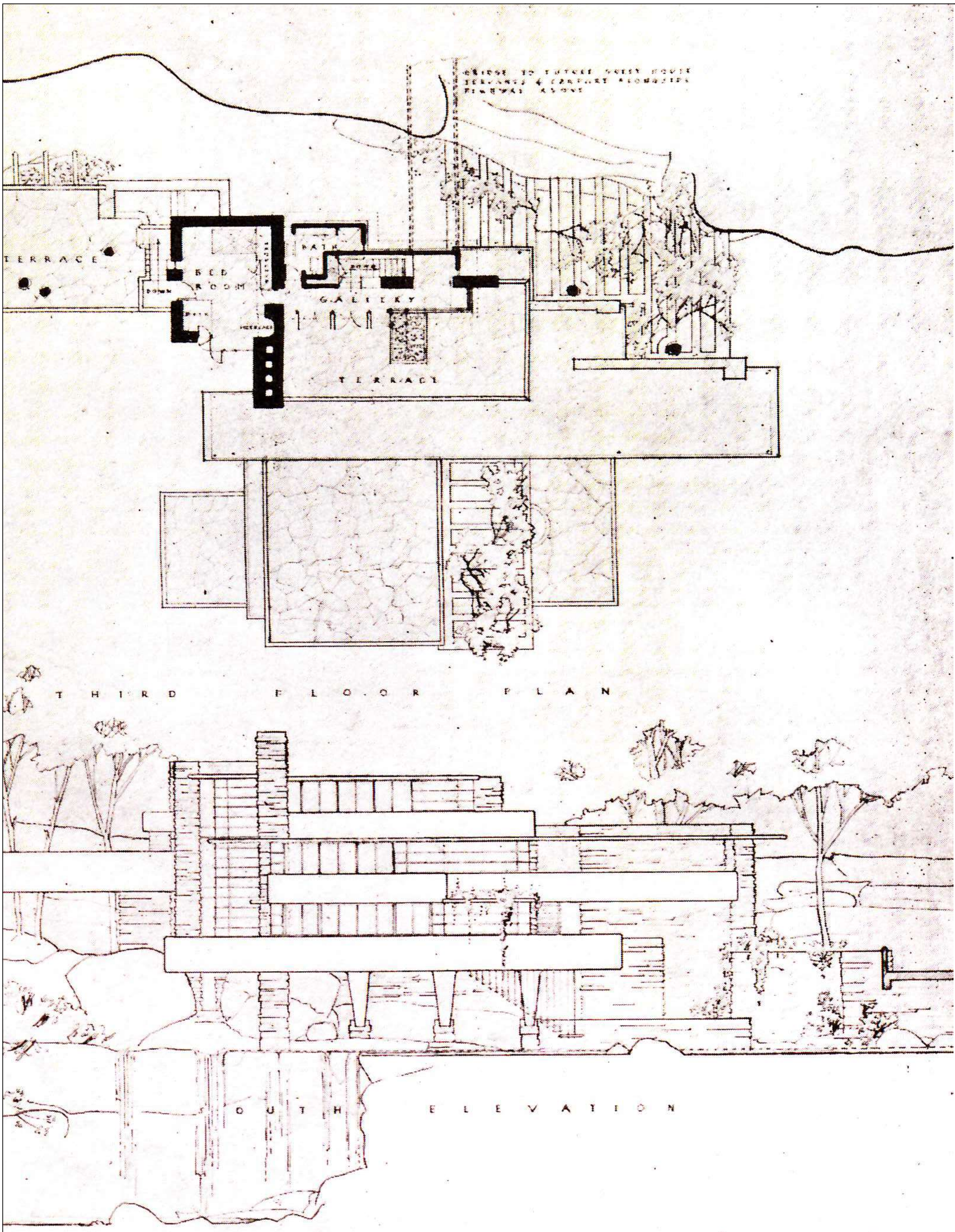
Frank Lloyd Wright



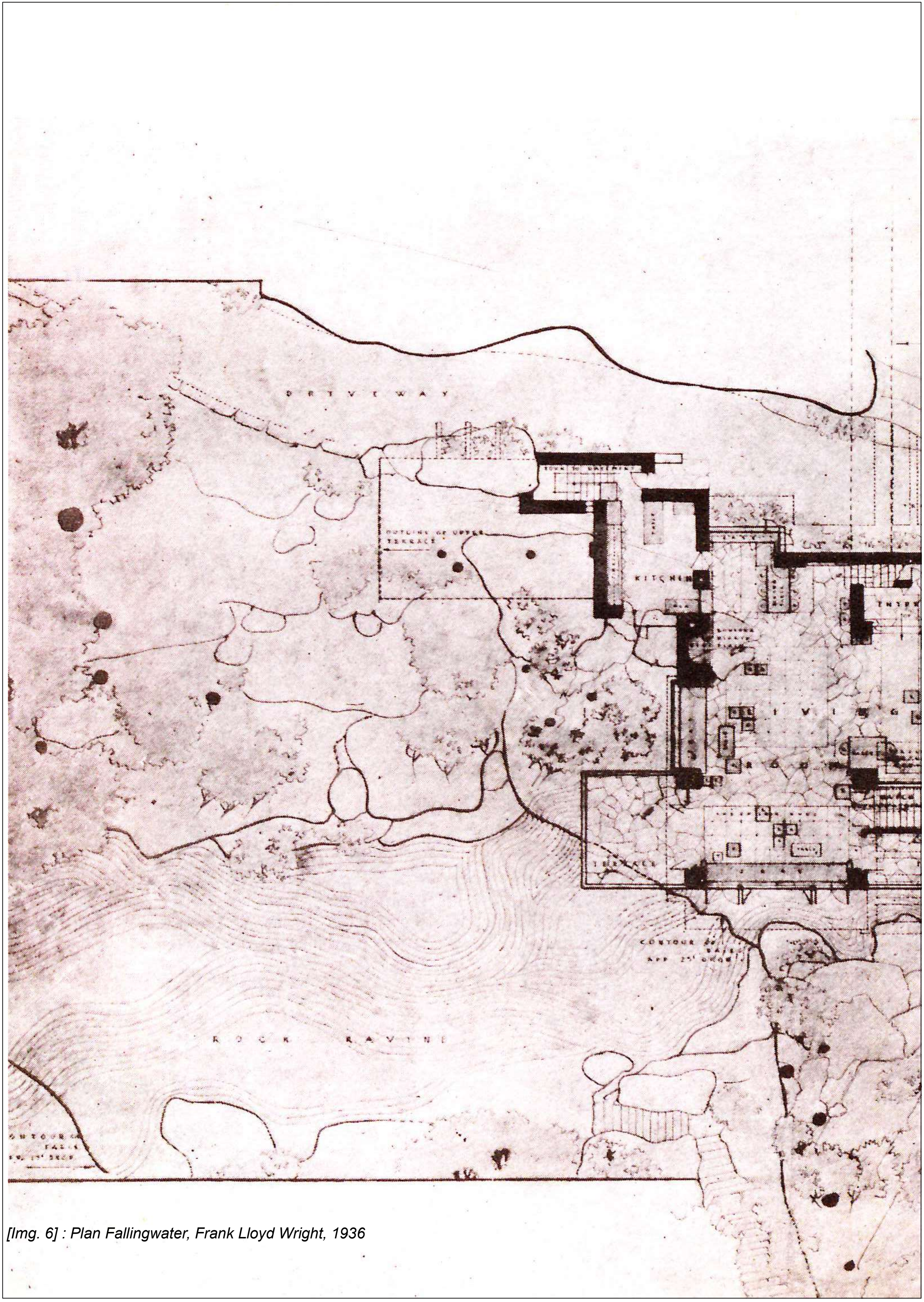
[Img. 4] : Fallingwater, Frank Lloyd Wright, 1936



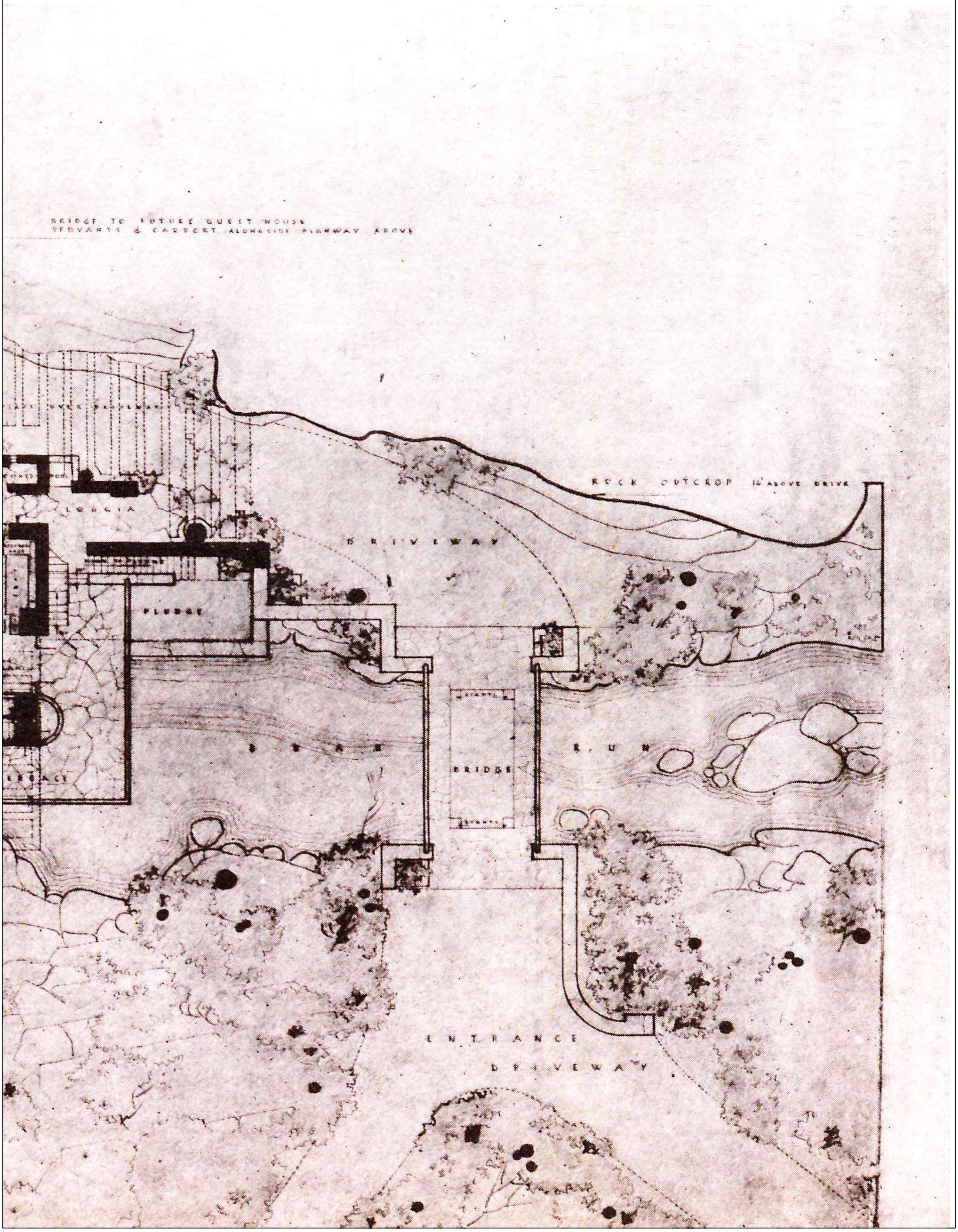

*[Img. 5] : Plans Fallingwater, Frank Lloyd Wright, 1936*




Below: Ground-floor plan.

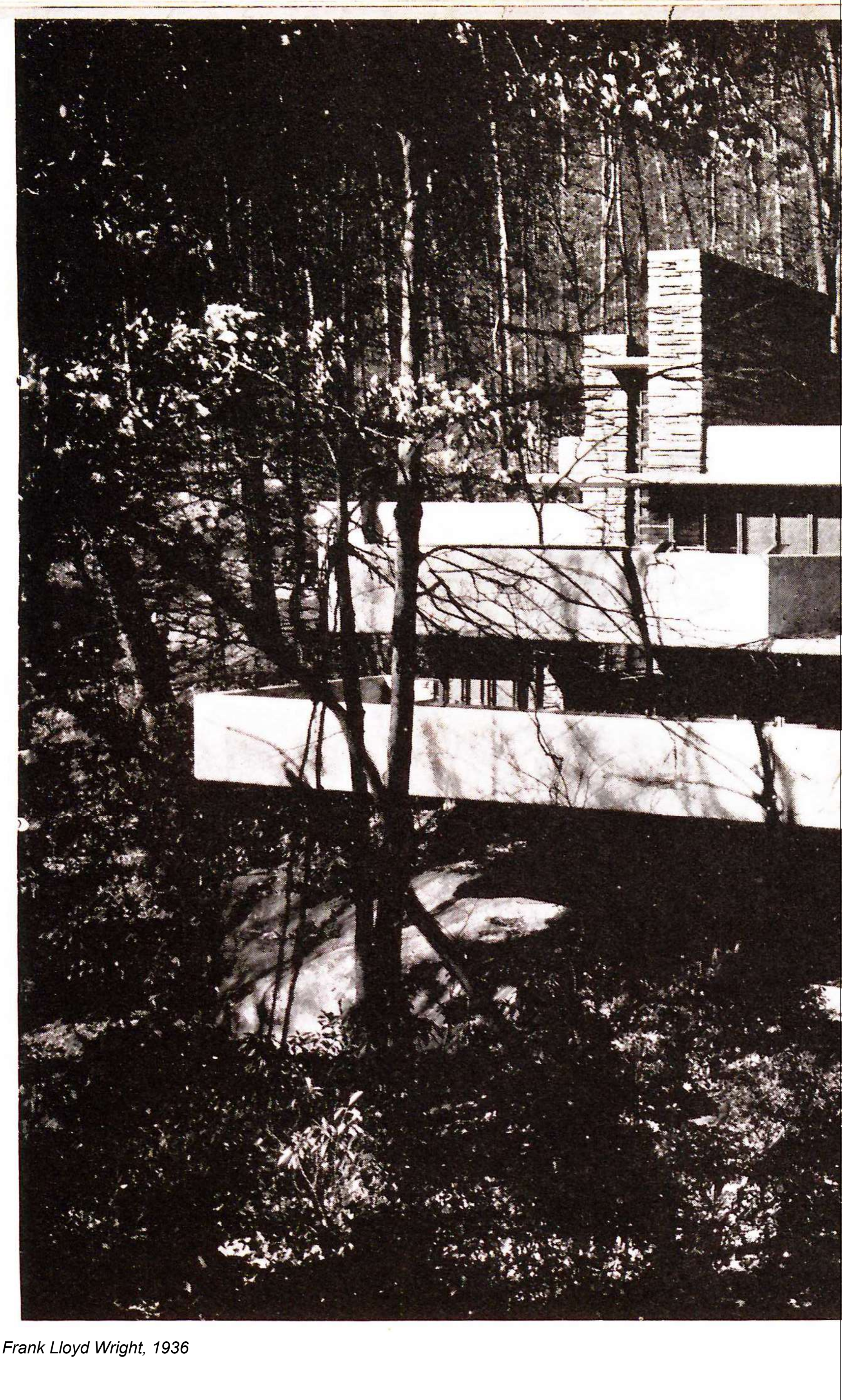



[Img. 6] : Plan Fallingwater, Frank Lloyd Wright, 1936

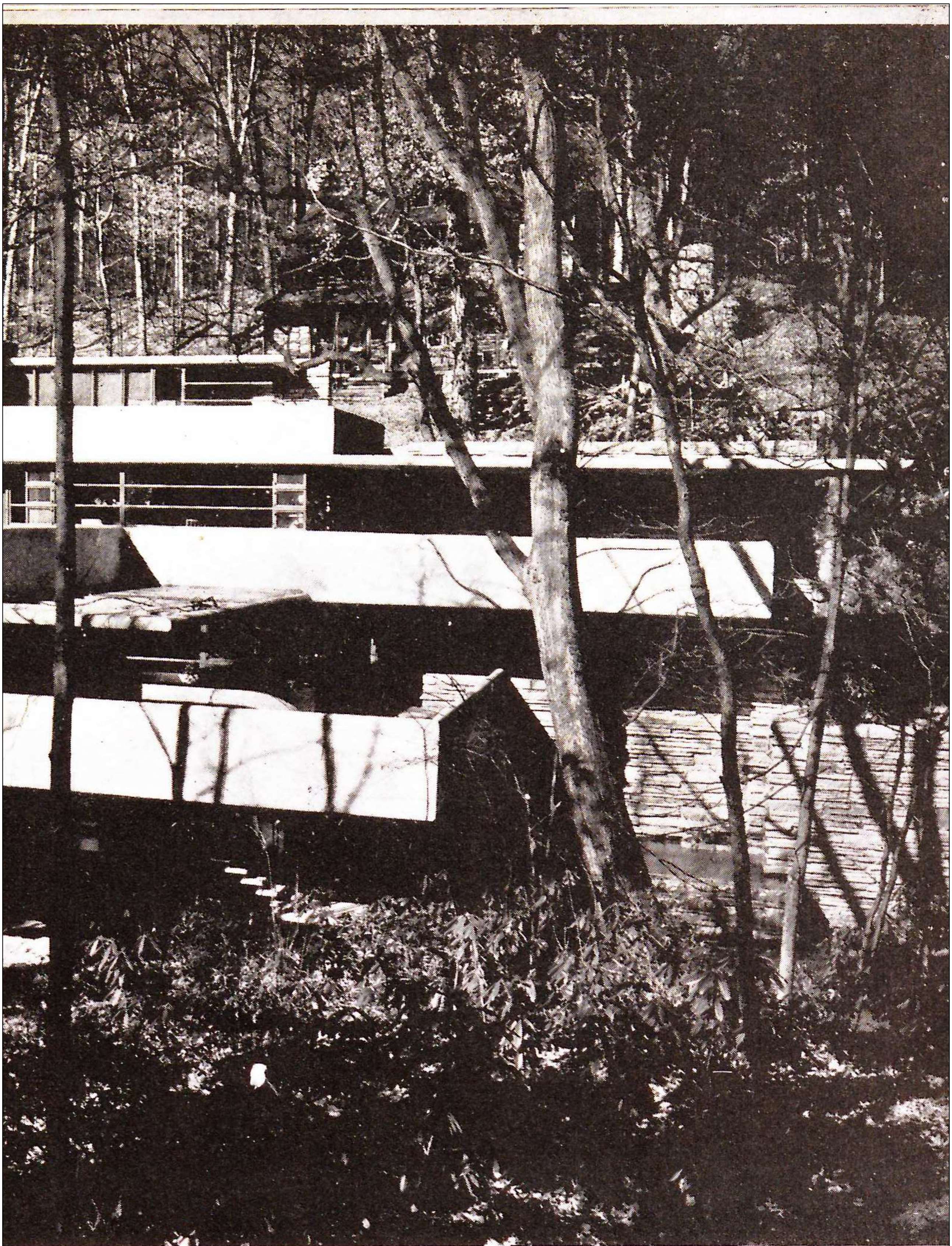

BRIDGE TO FUTURE GUEST HOUSE
SERVANTS & CARPORT ALONGSIDE HIGHWAY ABOVE
ROCK OUTCROP 16' ABOVE DRIVE
DRIVEWAY
LOGGIA
PLUNGE
BEAR
RUN
BRIDGE
ENTRANCE
DRIVEWAY

**Falling Water**

View across glen; bridge entrance out of sight on right.



[Img. 7] : Fallingwater, Frank Lloyd Wright, 1936



## HUGO HÄRING

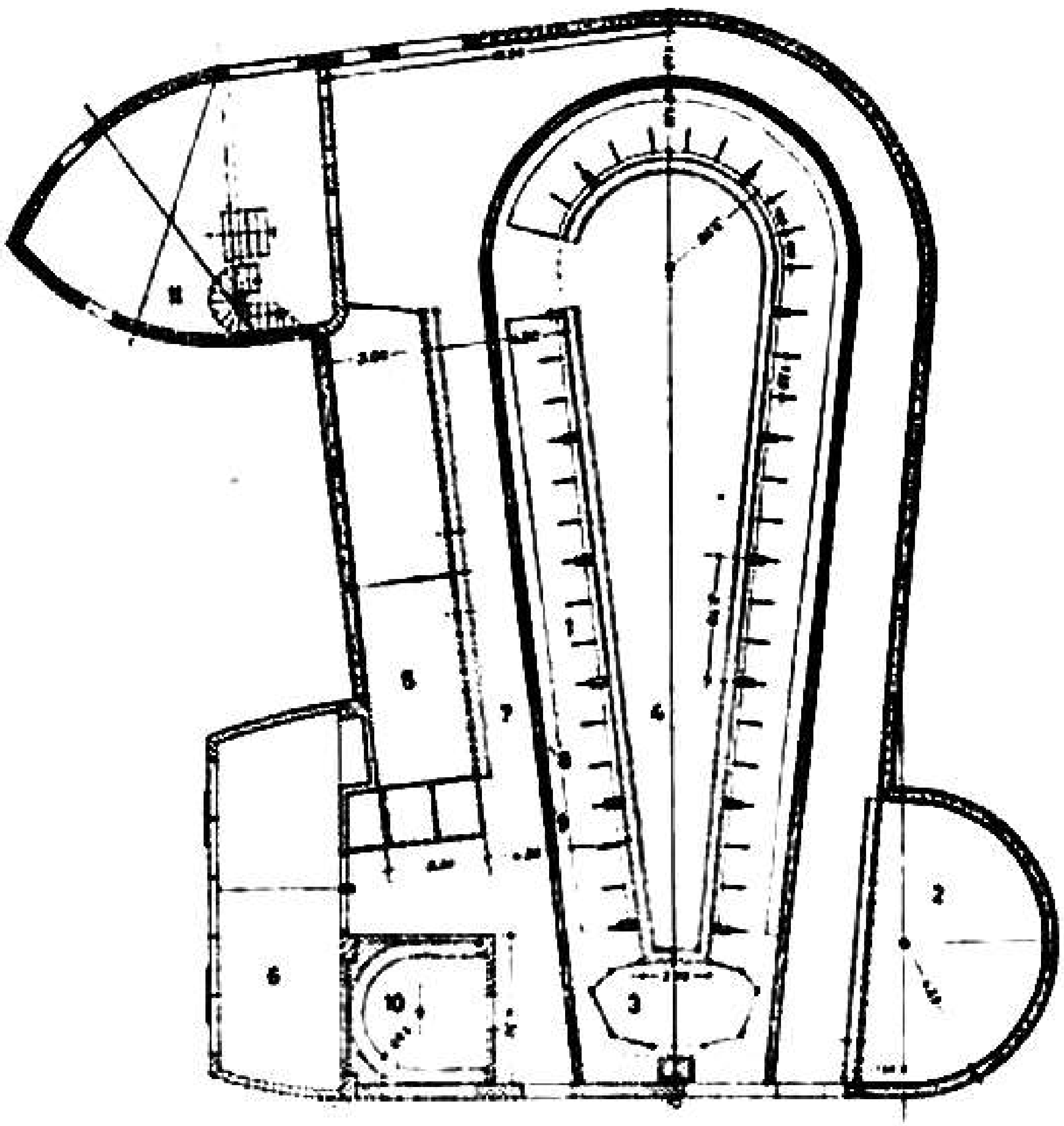
Hugo Häring was one of the early proponents of the “organic“ modernism. His early agricultural and rural projects were skillfully executed, both materially and formally. Sensuous curved plans were the drivers for layered textural skins that both structurally and artistically engaged with the ribbons of glass and concrete lintels slung above patternated brick walls and large doorways and openings.

Häring‘s main architectural work of the twenties, Garkau Estate in Ostholstein, refers to the local tradition in the choice of materials, such as the exposed brick, but uses state-of-the-art constructions and redesigns all the functions of the individual farm buildings. Inside the cow shed, for example, cantilevered concrete girders allow for a free floor plan and uniform illumination by means of continuous high-lying window ribbons. On the outside, the building is clamped by its curves in the road network of the court. The fodder is stored behind the wooden cladding of the upper floor, and the husks that accumulate during threshing are collected in an attached tower-like funnel to be fed directly to the livestock. He also opposed the cubic forms promoted by Gropius and Le Corbusier, which he countered with his notion of organic form-making. (cf. Häring, 1925)

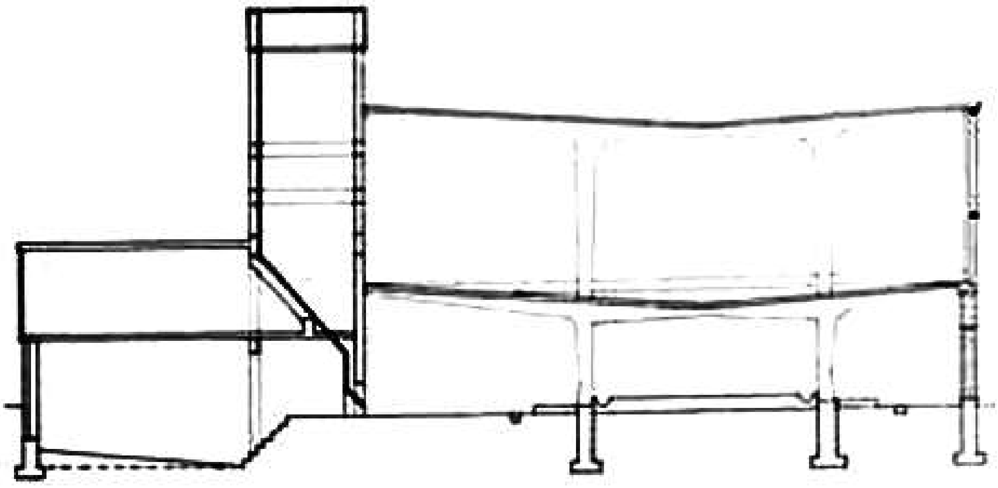
*“We want to seek out things and let their own form unfold. It is wrong to give one form to them, to determine their form from without, to force arbitrary laws on them, to dictate to them. We are wrong when we make them display historical demonstrations; we are likewise wrong when we make them objects of our individual whims. „*
*(Häring, 1925, p. 14)*


[Img. 8] : Cowshed of Gut Garkau, Hugo Häring, 1926

[Img. 9] : Gut Garkau, Hugo Häring, 1926



*[Img. 10] : Plans Gut Garkau, Hugo Häring, 1926*



Notre Dame du Haut in Ronchamp, isn’t an ordinary example for organic architecture. Le Corbusier is known for his sculptural architecture and in the chapel, he reunited painting, sculpture and architecture - three arts that naturally belong together. In this sense it may be defined as three-dimensional rather than one-dimensional organic architecture. It is an architectural sculpture which one can enter, walk through, meditate in, and enjoy.
(cf. Senosiain, 2003)

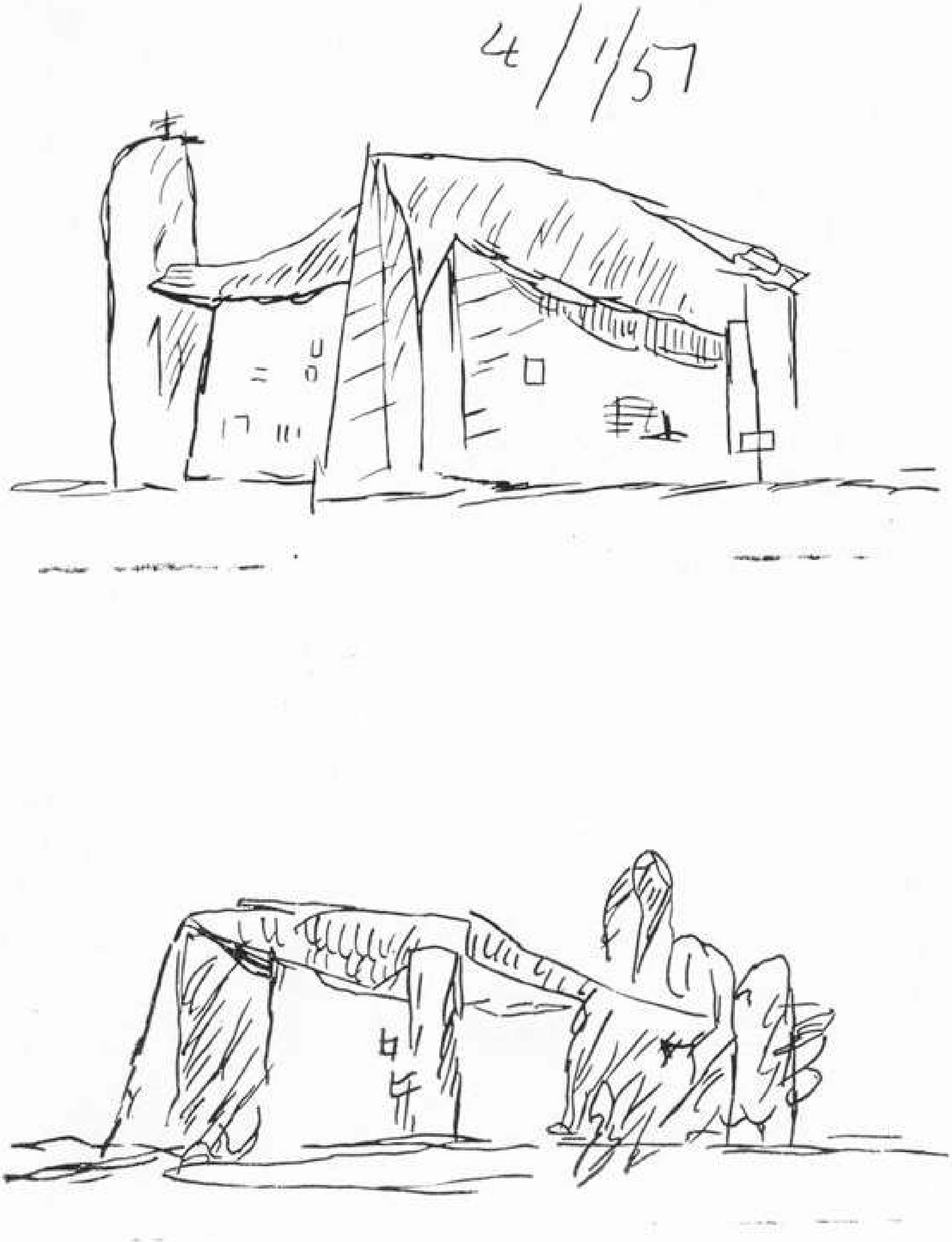
The form of the chapel consists of a sequence of convex and concave surfaces that create the sense of being in a sort of “nest”, a space that embraces its visitors and, at the same time, seems to escape towards the sky. That makes the building, which has a gross floor area of only 756 square meters, look much larger than it is. Le Corbusier obtained such an effect by masterfully combining gently sloped vertical walls with an imposing roof. This large shell-like roof of this chapel is said to be inspired by an empty crab shell, which Le Corbusier found on the beach in Long Island, New York.
(cf. Senosiain, 2003)

Furthermore, the curved shape of the building creates external areas, such as the back choir’s, which extend the chapel’s internal space onto the outdoors, often used for open-air religious events. Such a strict relationship between interior and exterior is further emphasized by the most important religious symbol in the chapel, an 18th-century revolving statue of the Holy Lady located at the back of the altar, which can be turned to aim it either at the indoor or at the outdoor, depending on the situation.
(cf. www.inexhibit.com/mymuseum/notre-dame-du-haut-le-corbusier-ronchamp-chapel/, 17.01.2020)

Located at the top of a hill, the chapel not only becomes part of the existing environment - the walls follow the natural slope from the top of the hill - but is itself built like a living organism.
(cf. Senosiain, 2003)

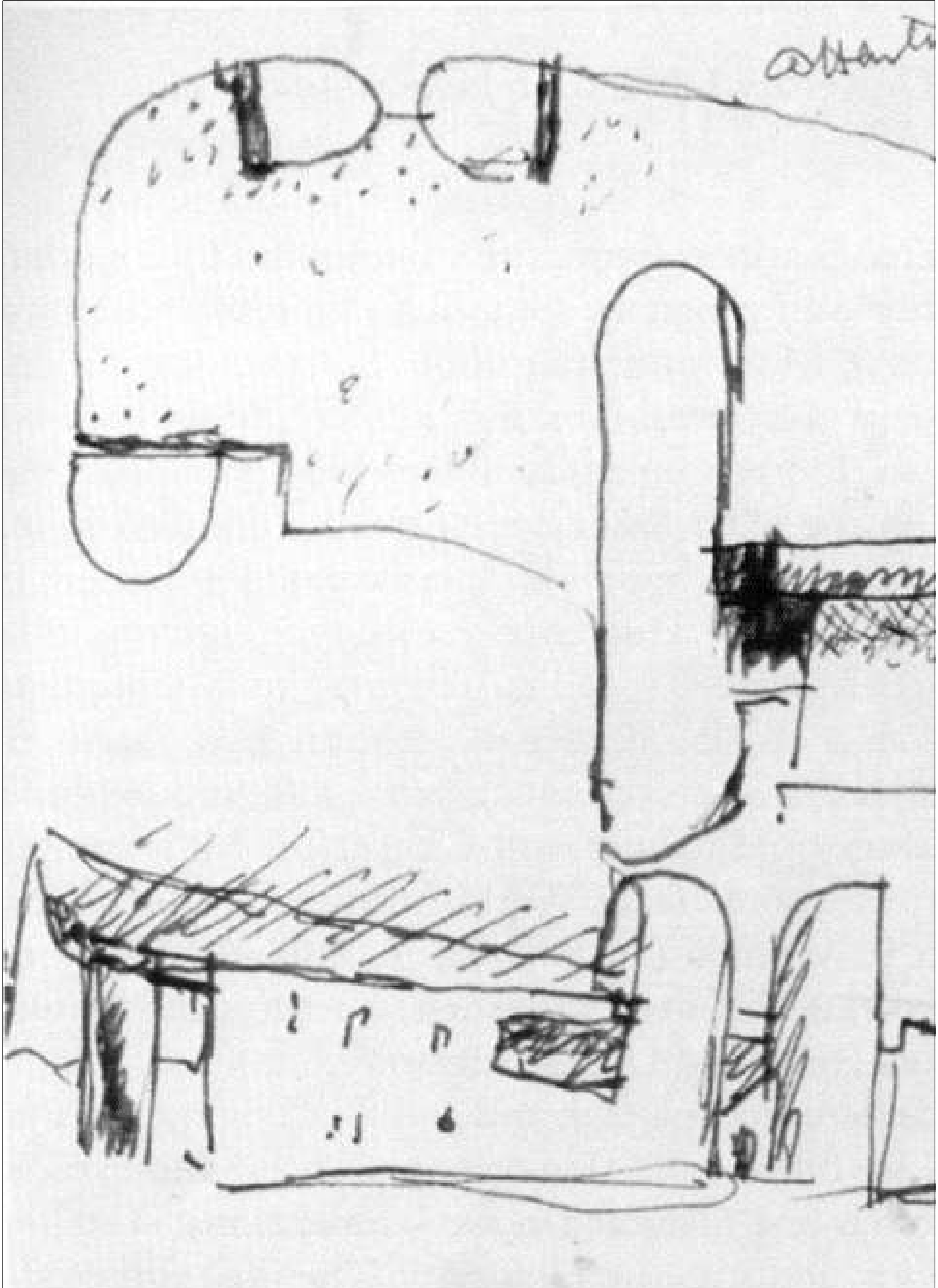
When architects started saying that a design is influenced by nature at that time, they most likely talked about its appearance or its concept: Nature is a good teacher in this regard, but solely being inspired by nature, textures and colors wasn‘t enough for us.

Allthough organic architecture seems to have started the discourse on rethinking the relationship between nature and the built environment, there have been tremendous developments, opening the way for an inquiry into nature‘s principles on far deeper levels.



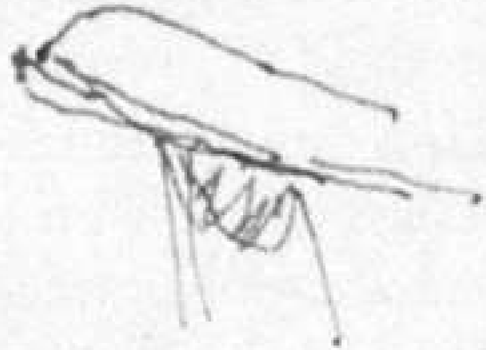

[Img. 11] : Sketch of the Chapel Notre Dame du Haut - Ronchamp, Le Corbusier, 1957


[Img. 12] : Notre Dame du Haut - Ronchamp, Le Corbusier, 1957



[Img. 13] : Notre Dame du Haut - Sketches by Le Corbusier

il faut éviter fissures et
créer fente = f 13



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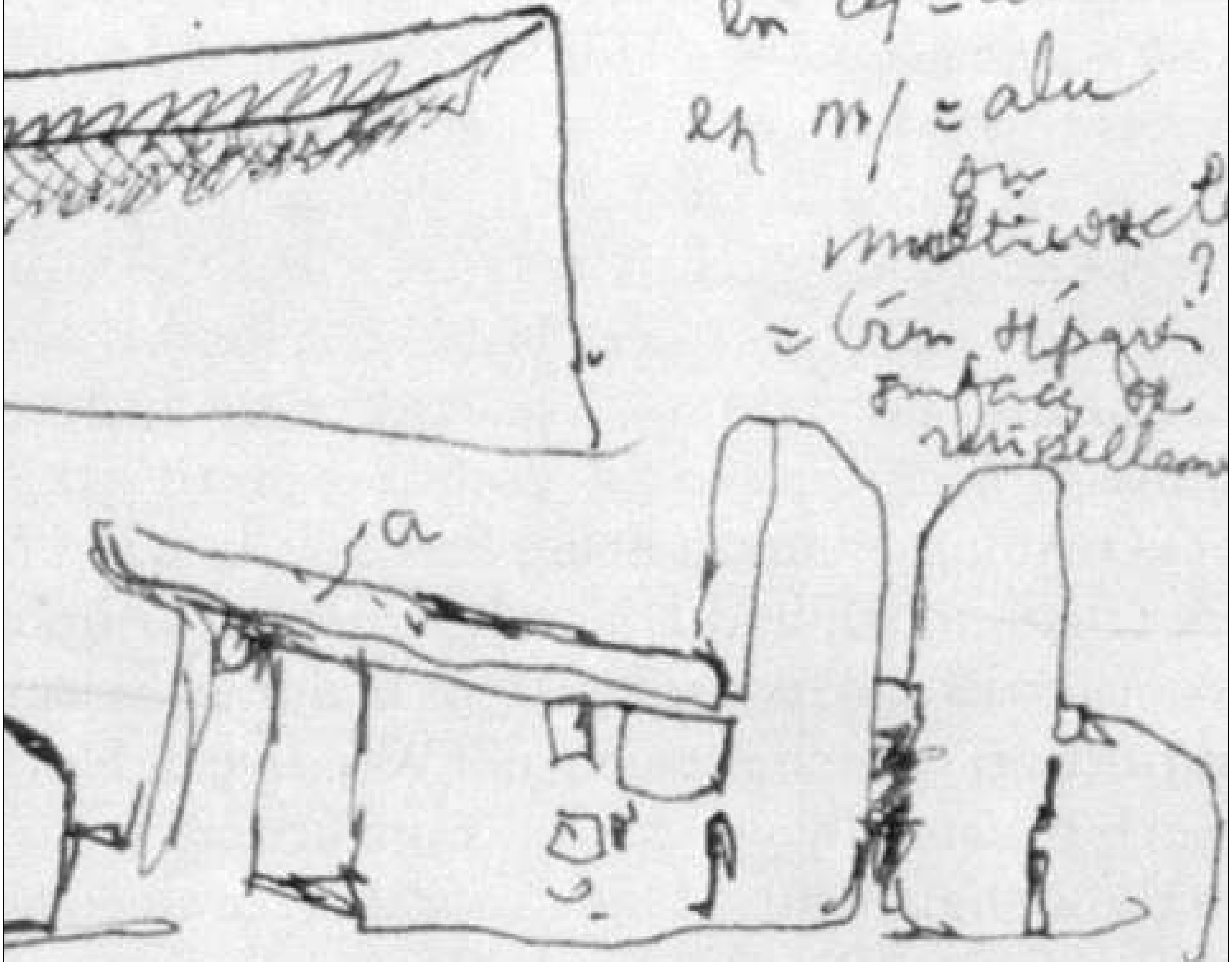
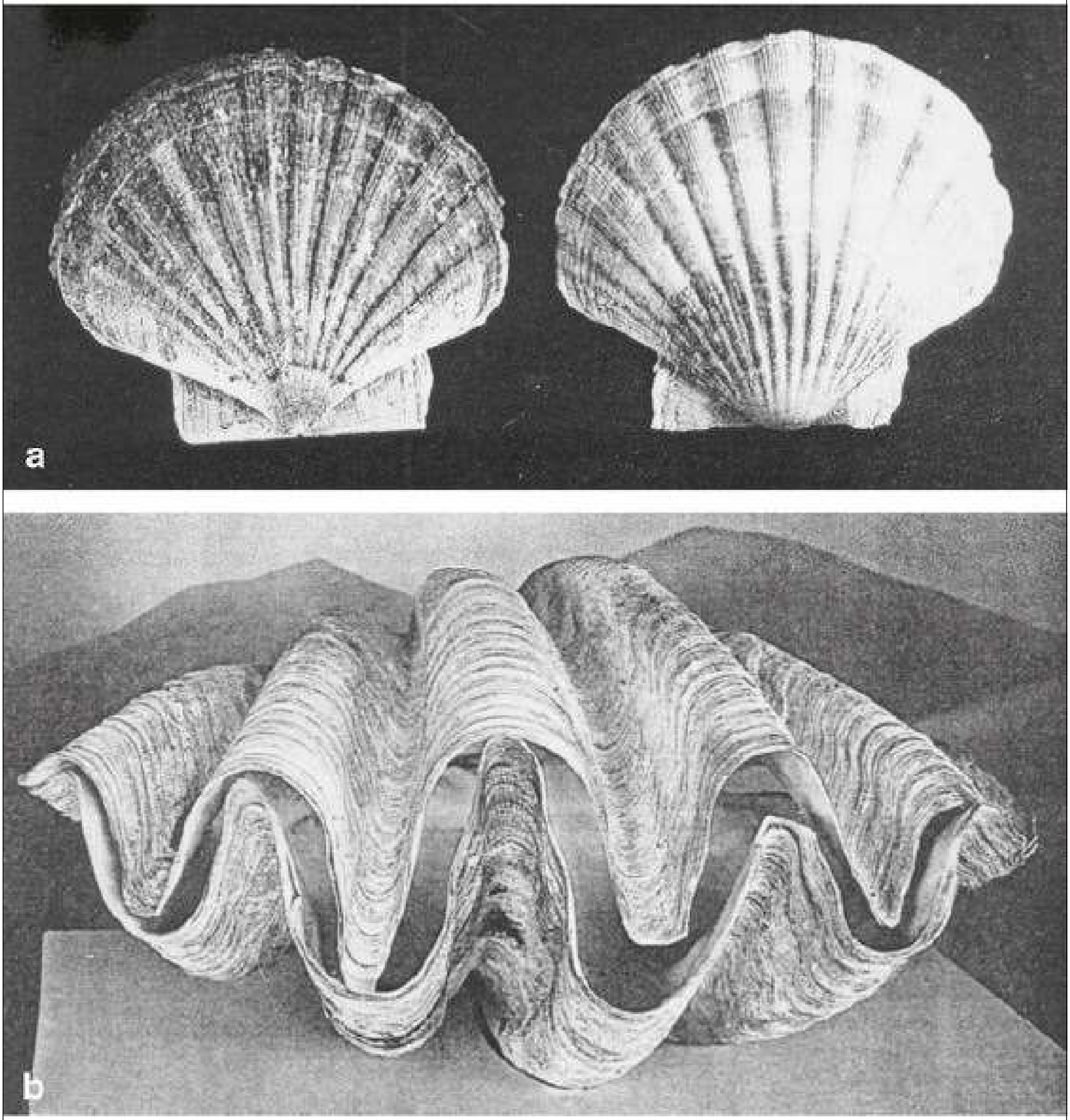
surface de
ressellement



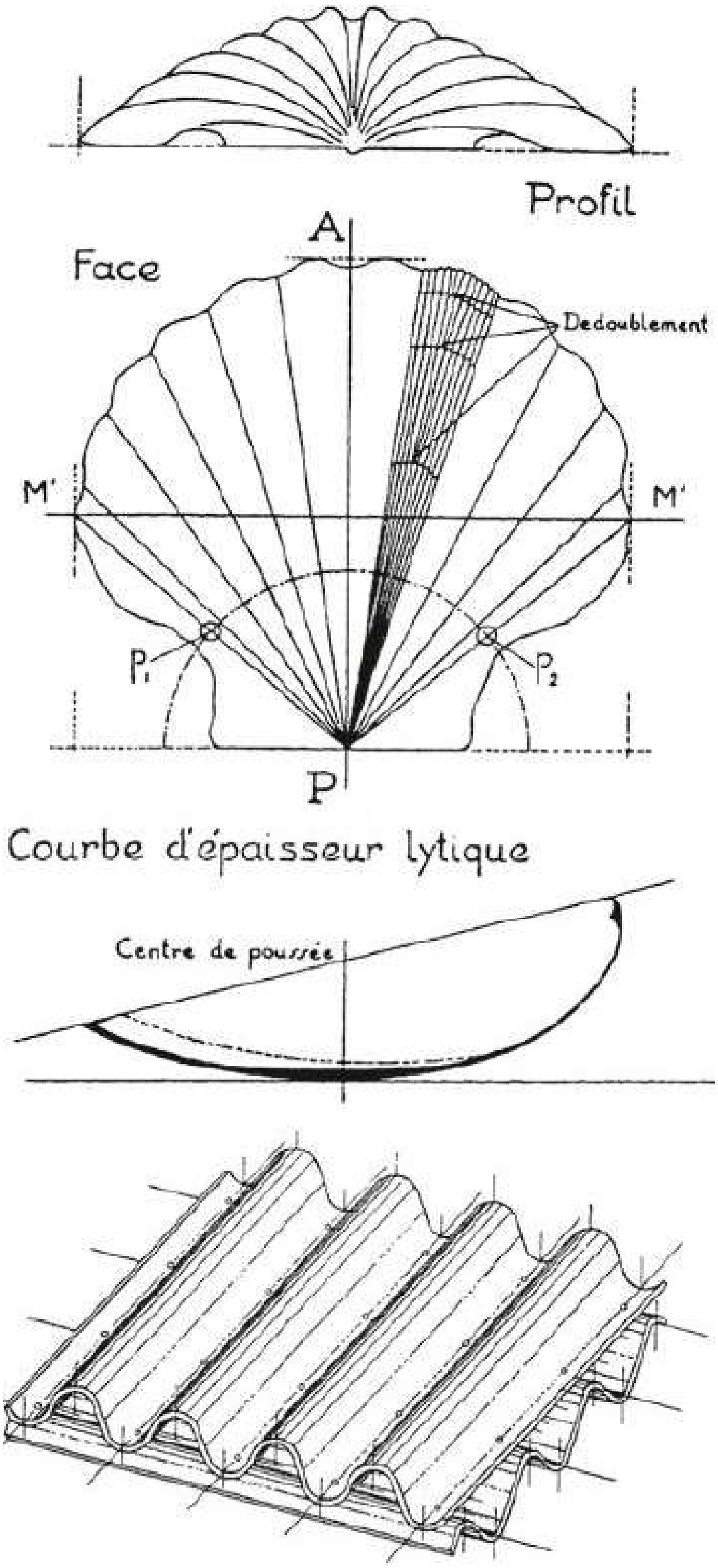



[Img. 14]

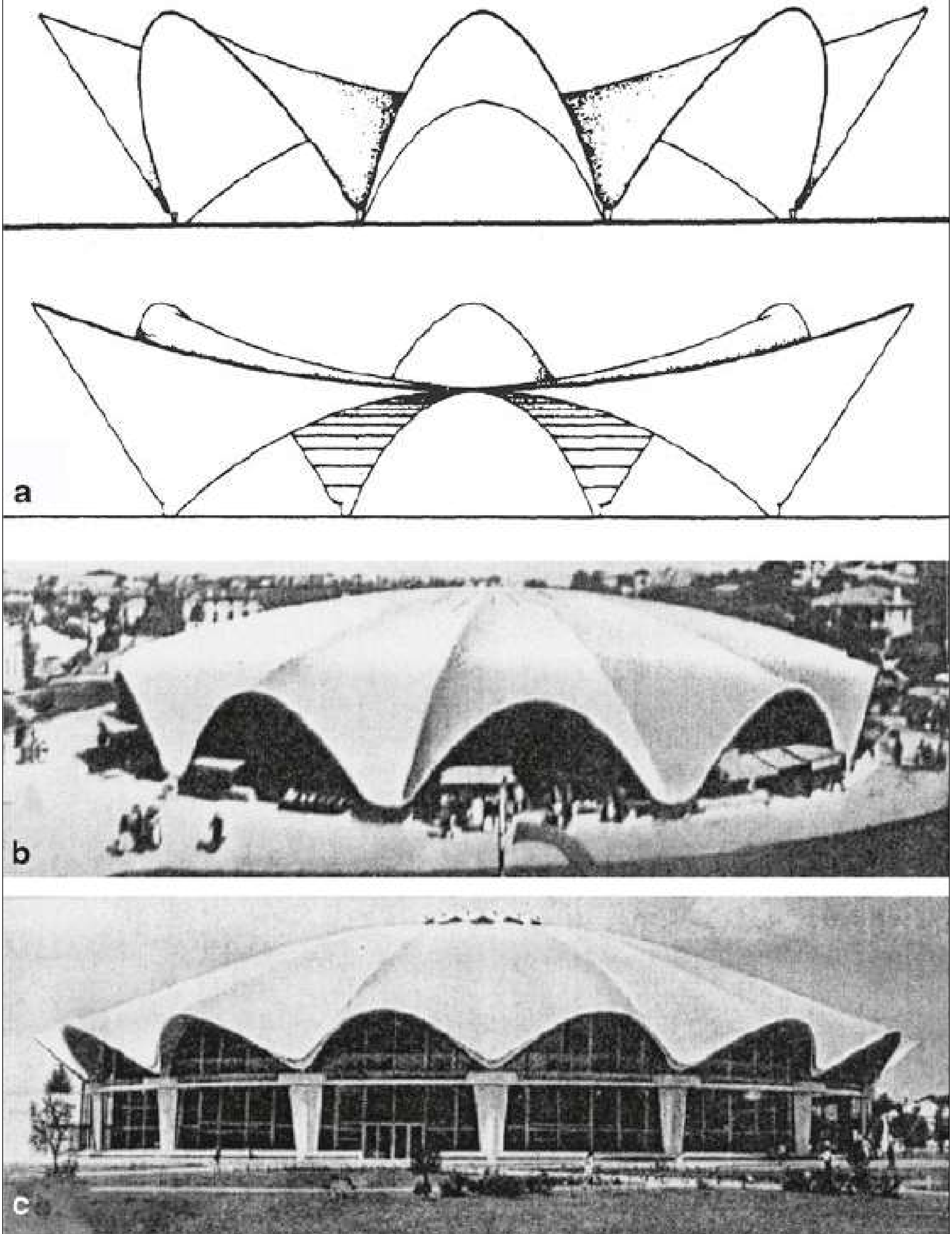
# PRE-BIOMIMICRY

## LAYING THE FOUNDATION FOR BIOMIMICRY

Allthough the technology was already available, it was still not as widely used and sophisticated. Since biomimicry was then not really a widely used term, there are architectural examples from the time between organic architecture and biomimicry, which already suggest somewhat of a biomimetic approach. The projects collected in this chapter show what one might perceive as very primitive, almost naïve approaches. Nevertheless, the projects did lay the groundwork for this field and definitely have validity and their own qualities when we see them in consideration with the methods and technologies used at this time.

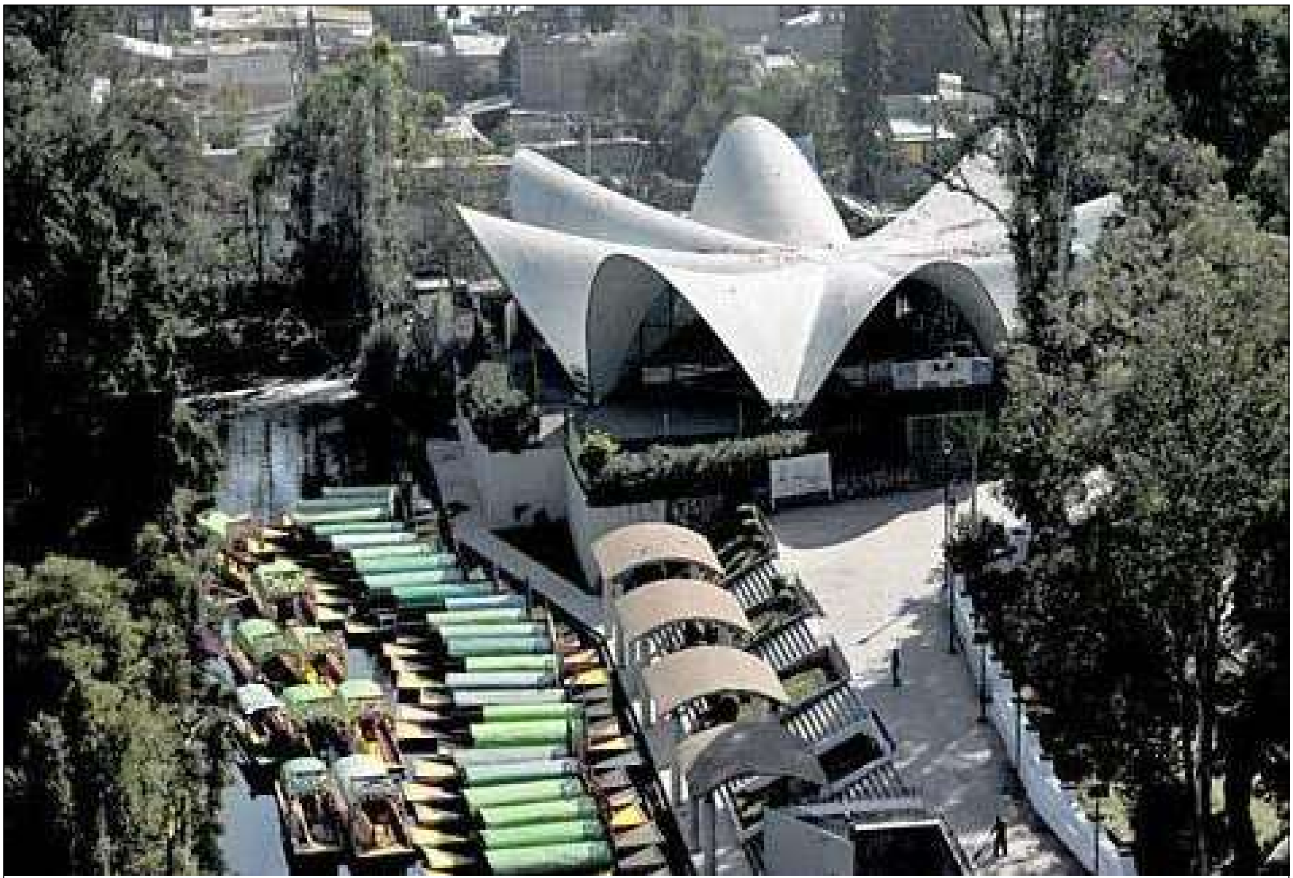

Profil
A
Face
Dedoublement
M'
M'
P1
P2
P
Courbe d'épaisseur lytique
Centre de poussée

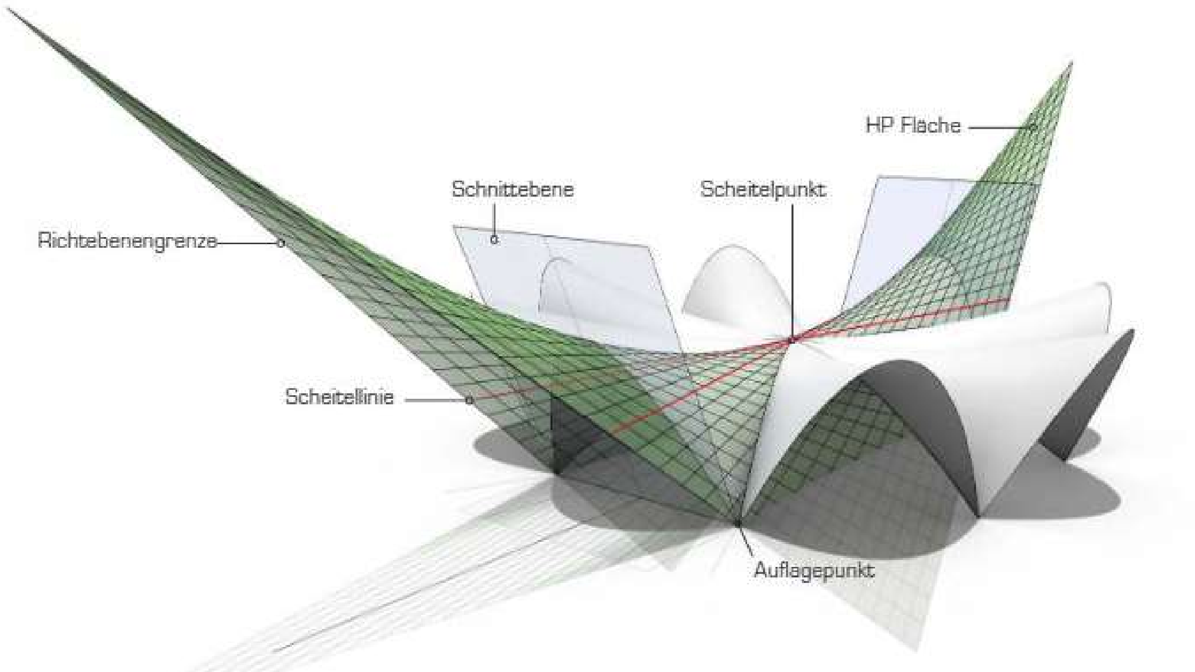
[Img. 15]






*[Img. 16]*


[Img. 17]


HP Fläche
Schnittebene
Scheitelpunkt
Richtebenengrenze
Scheitellinie
Auflagepunkt
[Img. 18]

# LOS MANANTIALES
FELIX CANDELA I 1958 I BUILT

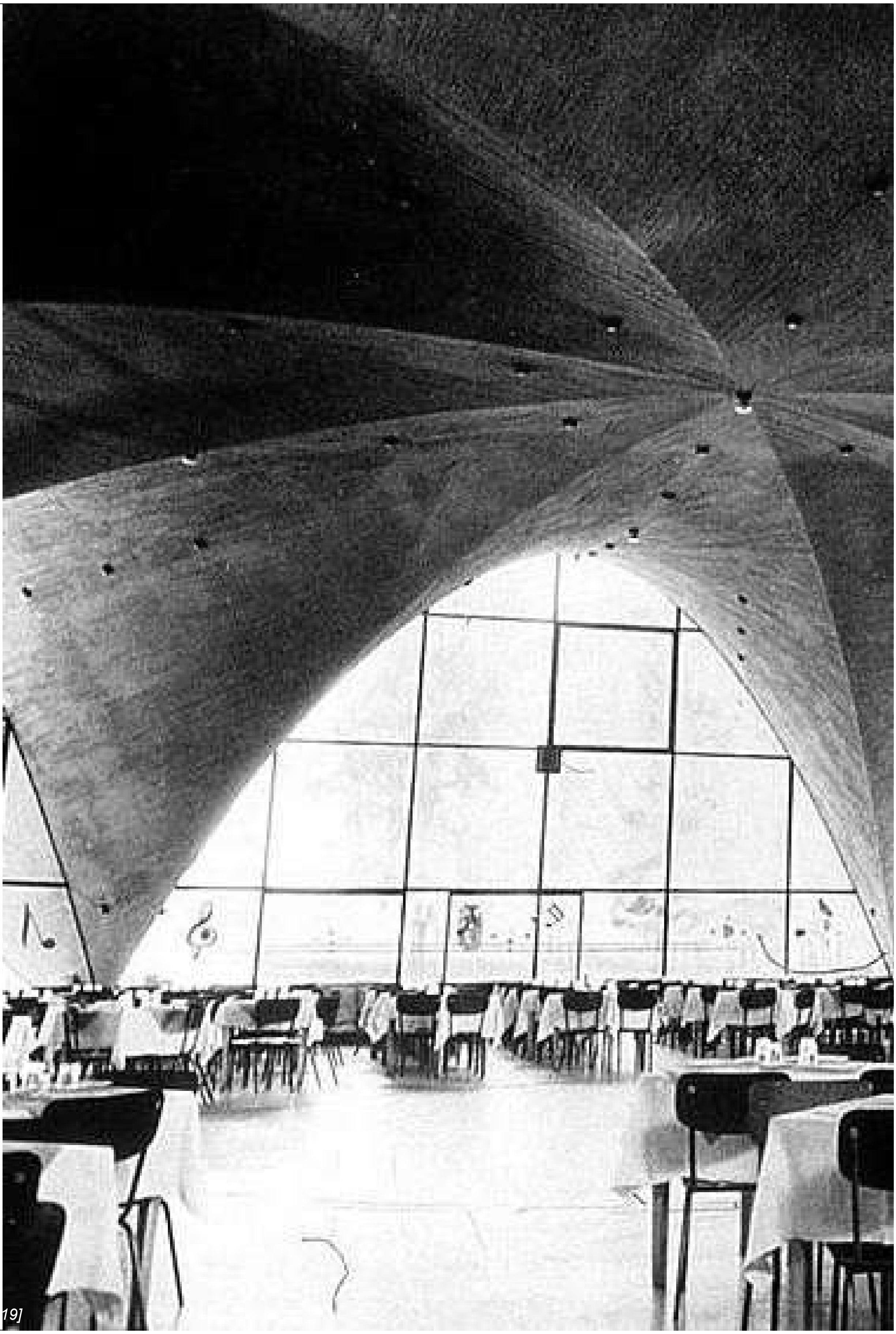
Heinz Isler analyzed the span of shell structures as a result of their thickness and thus their weight. He was of the opinion that concrete shells must be formed in such a way that the supporting network of the prestressed concrete does not deviate from the plane of the self-supporting form by more than a few millimeters. (cf. Nachtigall, Pohl, 2013, p. 125)

An example of a realized object with the biomimetic base being a shell is a restaurant in Mexico, which is a hyperbolic paraboloid with a shell thickness of only 1.5 centimeters. (cf. Nachtigall, Pohl, 2013, p. 125)

This restaurant was built from in 1958. The planning was done by Felix Candela, which is why this building is still called Candela Restaurant today. But the correct name is „Los Manantiales“. The restaurant was built after the old one, which was built of wood, but burned down. It is enthroned on a small peninsula.

In the interior, up to 1000 people can stay. The building has a width of 42 meters. Because of the penetrating hyparene, the original form is sometimes thought to be a lotus blossom. The outwardly protruding thin surfaces open the space to nature and let light and warmth into the interior. In addition, it gives the surroundings a certain lightness and transparency.

The reference to nature has always been a top priority. A form was adapted from nature, which allows people to look even closer to nature and does not exclude it.
(cf. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=2ahUKEwjt8PPZpprnAhXIpYsKHYEjDJUQFjAAegQIBBAB&url=https%3A%2F%2Fmoodle.zhaw.ch%2Fpluginfile.php%2F340153%2Fmod_forum%2Fattachment%2F206116%2FCandela%2520HP%2520Dach%2520kl.pdf&usg=AOvVaw39IGQZan5M3G_7Uc4_oPCn, 15.01.2020)


[Img. 19]


[Img. 20]

# ROYAN MARKET HALL

## LOUIS SIMON & ANDRÈ MORISSEAU I 1956 I BUILT

The Royan market hall in France was built in 1956 in the form of a radial wave roof with a span of 52.4 meters. (cf. Nachtigall, Pohl, 2013)

The architects Louis Simon and André Morisseau were very keen to give people new strength and courage with their architecture, as much seemed lost after the war. All over Royan, a lot of work was done with concrete, so it is not surprising that the architects also used this material.

The only 10 cm thick layer was additionally equipped with small window slits on the dome. It brings a small play of light to the column-free interior. (cf. https://edoc.hu-berlin.de/bitstream/handle/18452/7873/wittmann-englert.pdf, 20.01.2020)


[Img. 21]

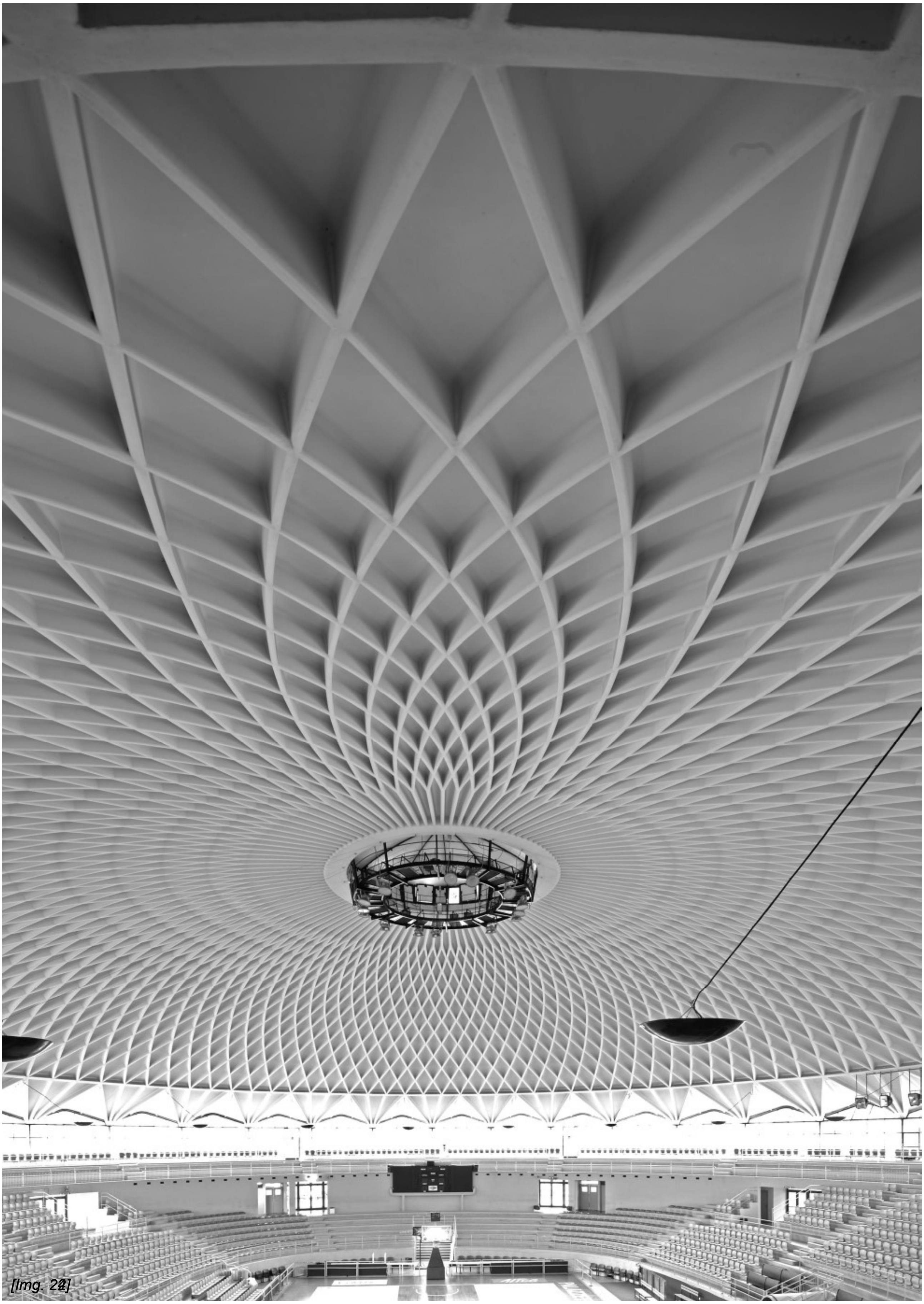
[Img. 22]

# CIRCUL METROPOLITAN
NICOLAE PORUMBESCU I 1961 I BUILT

In Romania a radial wave roof with a span of 66.6 meters was built in 1960. (cf. Nachtigall, Pohl, 2013, p. 125)

It is still known today as the Bucharest State Circus. It is also known as Globus Circus. It offers 1,850 seats in the auditorium. The dome with the lower waves darkens the interior so that a successful revolving stage is created and the show effects are shown to their best advantage. (cf. https://de.qwe.wiki/wiki/Bucharest_Metropolitan_Circus, 20.01.2020)


[Img. 23]



[Img. 24]

# PALLAZETTO DELLO SPORT
## PIER-LUIGI NERVI I 1956 I BUILT

Pier-Luigi Nervi was inspired by the great Amazon water lily and was tempted to create an incredible ceiling construction. The idea of this construction was derived from the structure of the lily and developed further on this basis. The Pallazetto dello Sport was built for the 1956/57 Olympic Games in Rome. The capacity of the spectators is about 5000 people.
(cf. Pawlyn, 2012)

Its construction could only be achieved because the experiments with concrete were already so advanced at that time. He brought a completely new perspective to sports interior design. From the former simple concrete box, as we usually see it, he built a playful meeting place. It has greatly influenced the activity and social coexistence of people through its versatile construction.
(cf. http://www.archidiap.com/opera/palazzetto-dello-sport/, 20.01.2020)

*[Img. 25]*



[Img. 26]

[Img. 27]

# OLYMPIA PARK MUNICH

## OTTO FREI, BEHNISCH & PARTNER | 1972 | BUILT

The trees branch out more and more upwards. They distribute the load of the treetop to the isolated branches, these are mainly loaded by pressure. In comparison, the interweaving of the spider's web also becomes more intensive towards the top, but to strengthen the threads under tension. These two natural phenomena were combined in a well-known project. Otto Frei first presented his idea of an experimental roof in 1967 at the Expo exhibition in Montreal. He used tree-like beams that became thinner and thinner towards the top and branched further down. This measure was aimed at reducing weight. However, the idea remained the same; only the „mass minimum under given load boundary conditions of the load" was valid. The web of the spider, which is laid over the framework of the tree crown. O. Frei himself denied the influence of nature in his model, but the similarity can hardly be overlooked.
(cf. Nachtigall; Pohl, 2013)

The Olympic Park in Munich was a further development in the spirit of Otto Frei. Behnisch und Partner took over the extravagant design and created a completely new landscape and architectural image of Munich. The three square kilometer sports center was built to mark the 20th Olympic Games. It comprises a hilly park landscape, the stadiums with their tent roof construction and the Olympic lake. Four years before the construction project, the Stuttgart architects won the public tender. Prior to this, around 1945, a 60-metre high mountain of rubble had been heaped up from the ruins of the Second World War on the southern edge of the Oberwiesenfeld. The rubble mountain was integrated as today's Olympic mountain - from here you can overlook the Olympic grounds and the city. A park becomes a place of social freedom.
(cf. https://www.muenchen.de/rathaus/Stadtverwaltung/baureferat/freizeit-sport-natur/gruene-oasen/olympiapark.html, 20.01.2020)

The extraordinary shape of the Olympic Park is mainly built with steel poles and Plexiglas. The curved shape of the connected tents stands for a certain lightness, which was only made possible by this combination of materials. The entire construction was built like a spider's web. Steel cables tension the framework like the crown of a tree. The steel poles lift the weight upwards and the plexiglass plates were then attached to the steel net. Through this combination of tension and compression rods, the roof adapts to any weather condition. It bends with the weight of the snow load and swings in the wind. Some of the plexiglass plates were even colored grey to provide sun protection. Due to the processing of the plexiglass, a lot of light gets under the construction. The practical and creative ideal is optimally combined. It protects the room from wind and weather and leaves shady places even on hot summer days. At that time the material combination of steel and plexiglass was the latest innovation.
(cf. Nachtigall; Pohl, 2013)

This project is a milestone in the history of German architecture and stands symbolically for the ephemeral and changeable in our world, as well as for lightness, transparency and openness. With the help of the spider's web and the tree they succeeded in creating this amazing composition. After so many years the Olympia Park is still used as a meeting place for young people and adults. There are concerts and exhibitions, as well as sporting events, which are followed with great interest.

All those projects never called themselves biomimetic, but nevertheless, we get the impression that the techniques used in designing these buildings are essential developments that enabled the emergence of the field of biomimicry, because they already go further than just metaphorically using nature as a reference.

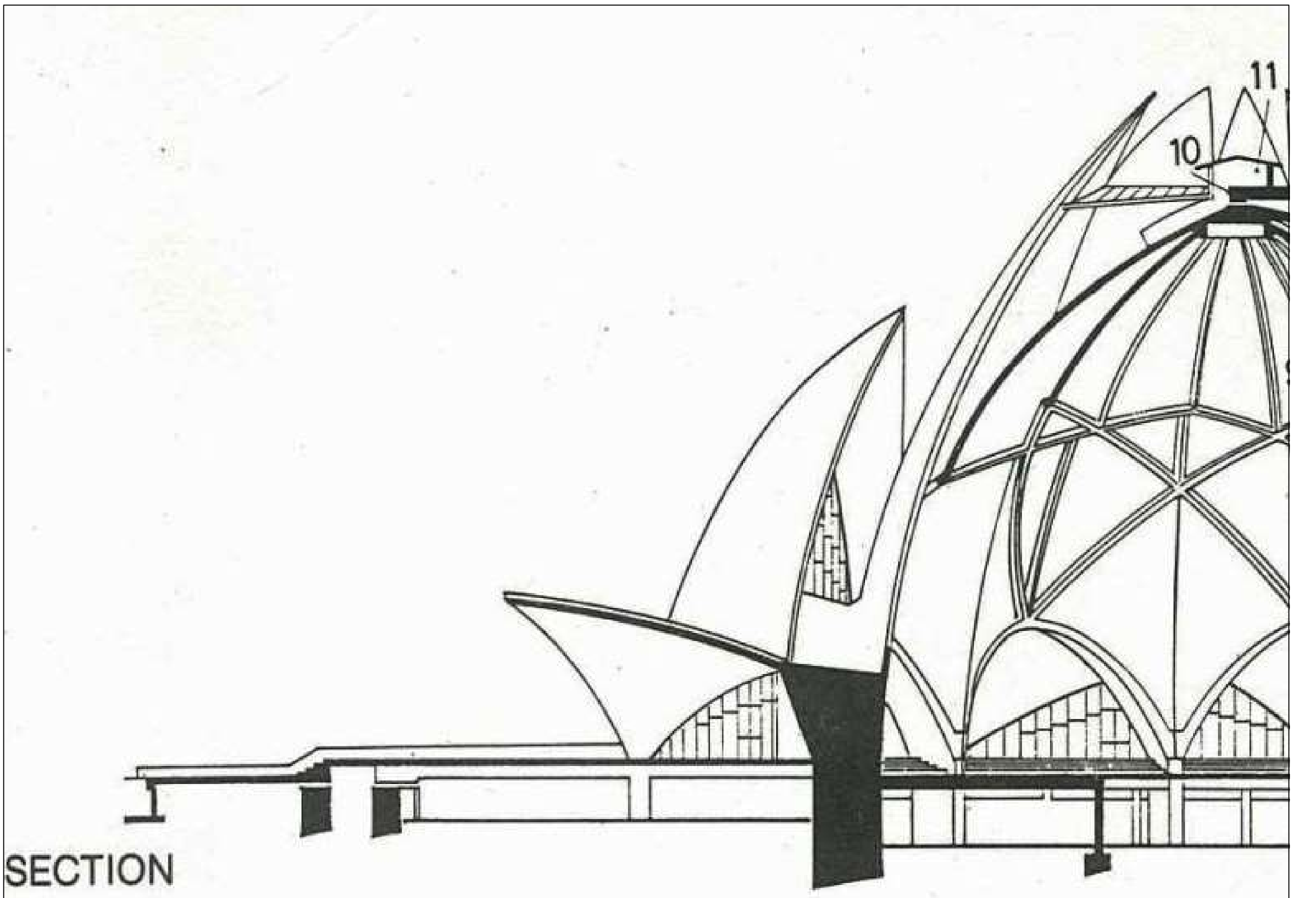
[Img. 28]

# LOTUS TEMPLE
FARIBURZ SABHA | 1979 - 1986 | BUILT

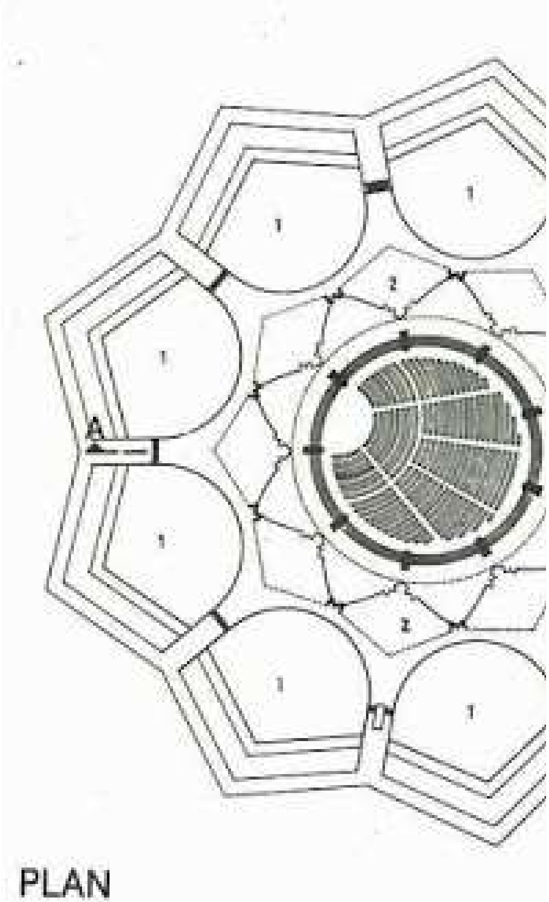
The Lotus Temple is the Bahá'í house of prayer in New Delhi, India. This memorial was completed in 1986. As the name suggests, the architect Fariborz Sahba was inspired by the lotus blossom in his design. In Buddhism the lotus stands for purity and is therefore the ideal interpretation. The temple is open to all religions. It is used as a place of worship, as a meeting place or as a memorial.

The arrangement of the circular structure, with 20 leaves, is based on the Bahá'í script. It is thus a nine-sided structure with a circular floor plan. The marble-clad, free-standing concrete outer leaves are always placed in threes on one of the nine sides.
The spatial planning can be divided into inner leaves, outer leaves and entrance leaves. The inner leaves approach each other in the middle, but do not touch. This approach creates a glass-and-steel element in the interior of the dome, which brings natural light into the main room. It is a repetition of the shape of the lotus blossom. The outer leaves cover the side rooms and storage spaces.

The lotus leaves are made of concrete and covered with Greek marble. The choice of material gives the body a white, clear and pure radiance, which further emphasizes the form choice.
(cf. https://www.archdaily.com/158522/ad-classics-lotus-temple-fariborz-sahba, 24.01.2020)



[Img. 29]



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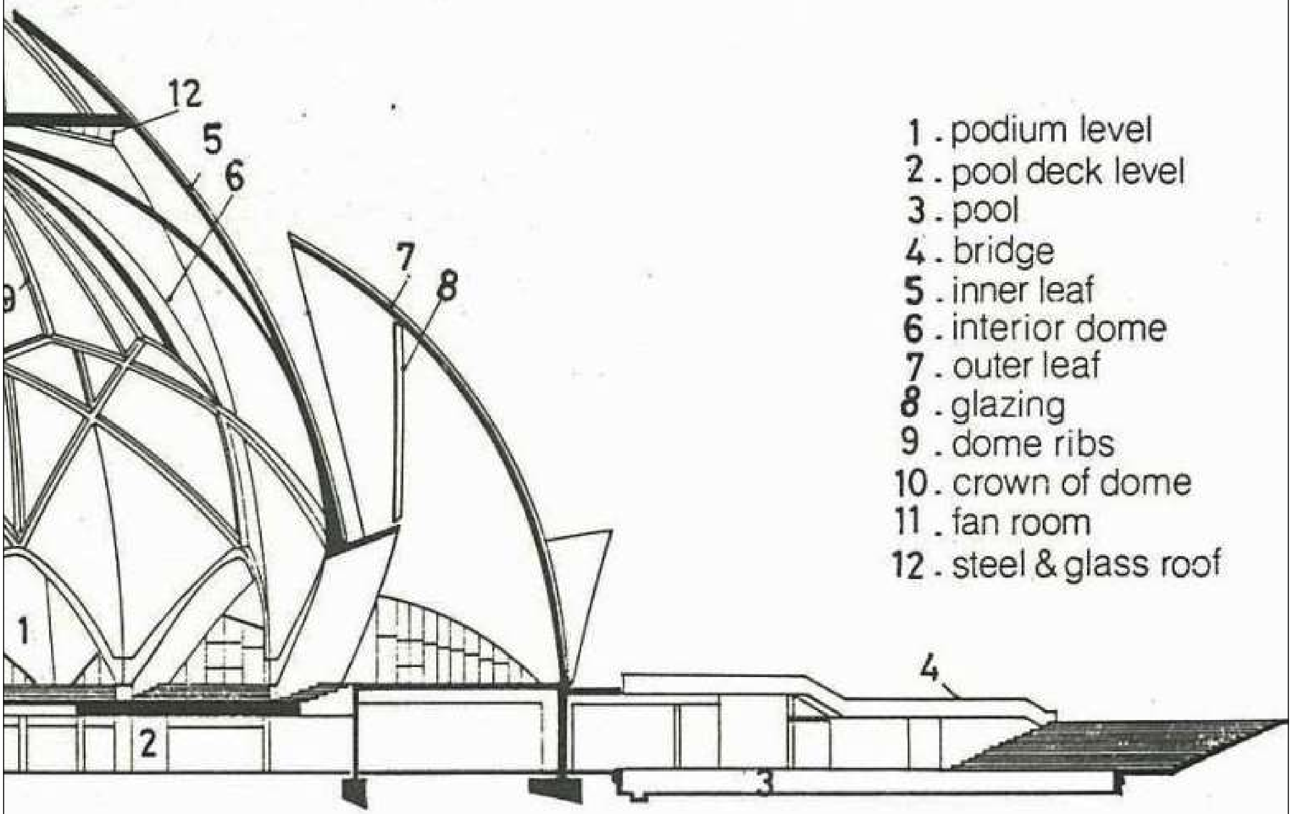
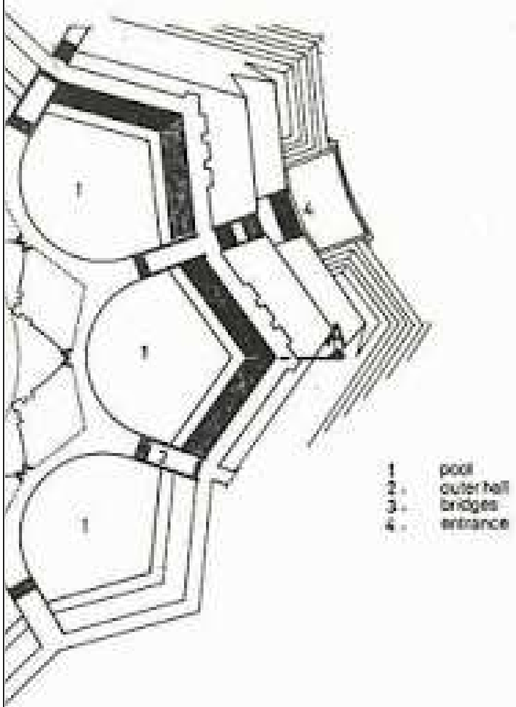
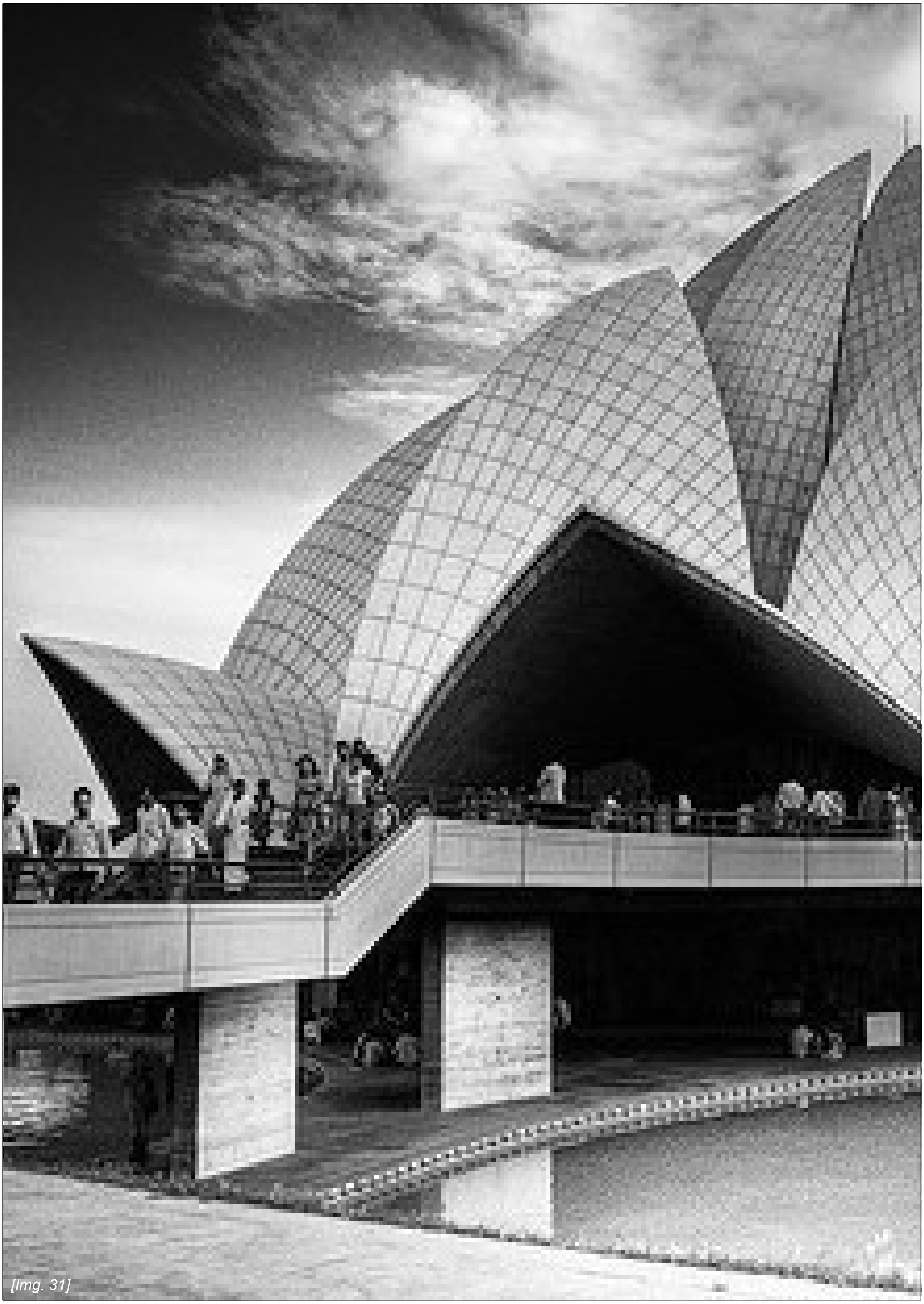
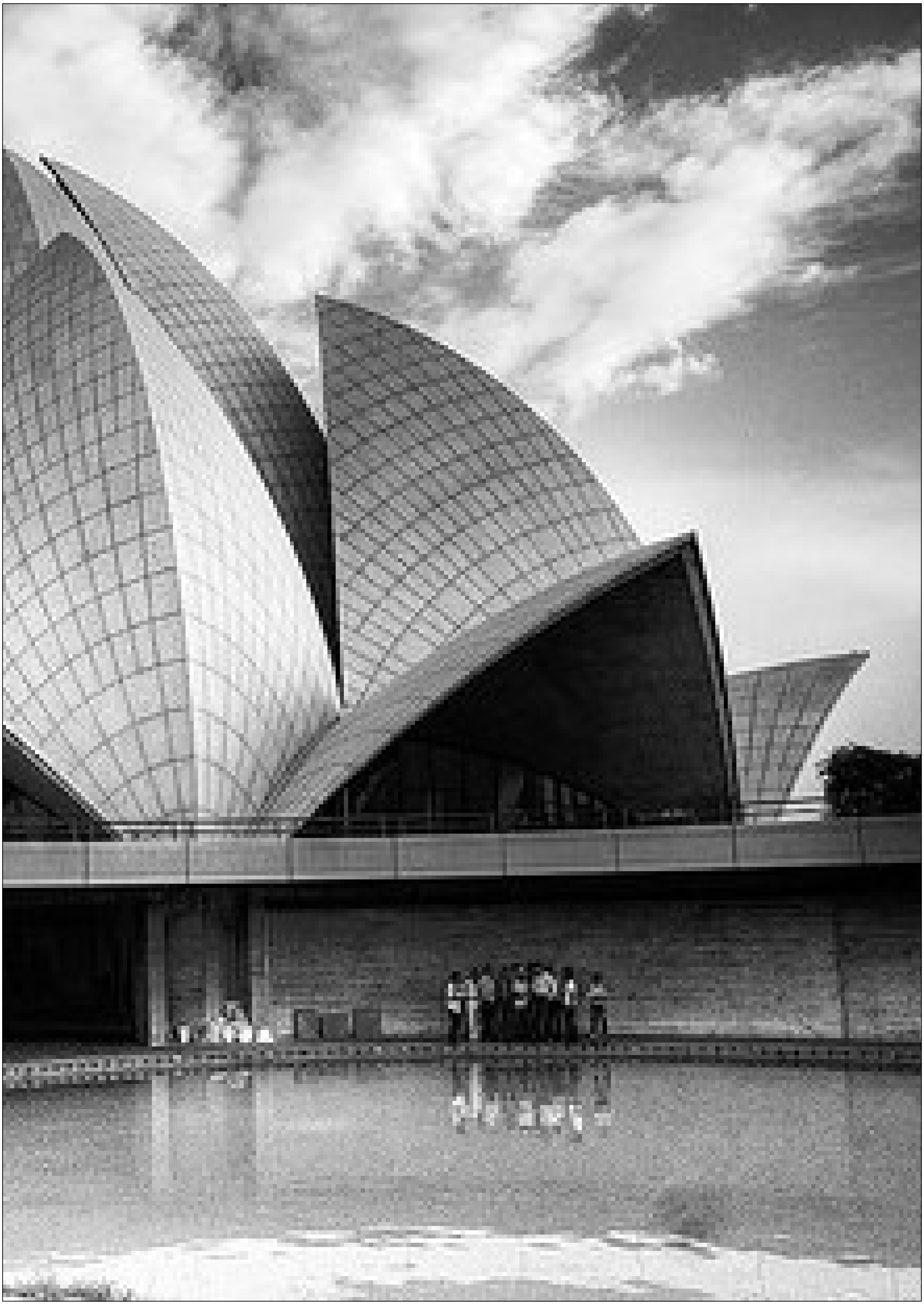
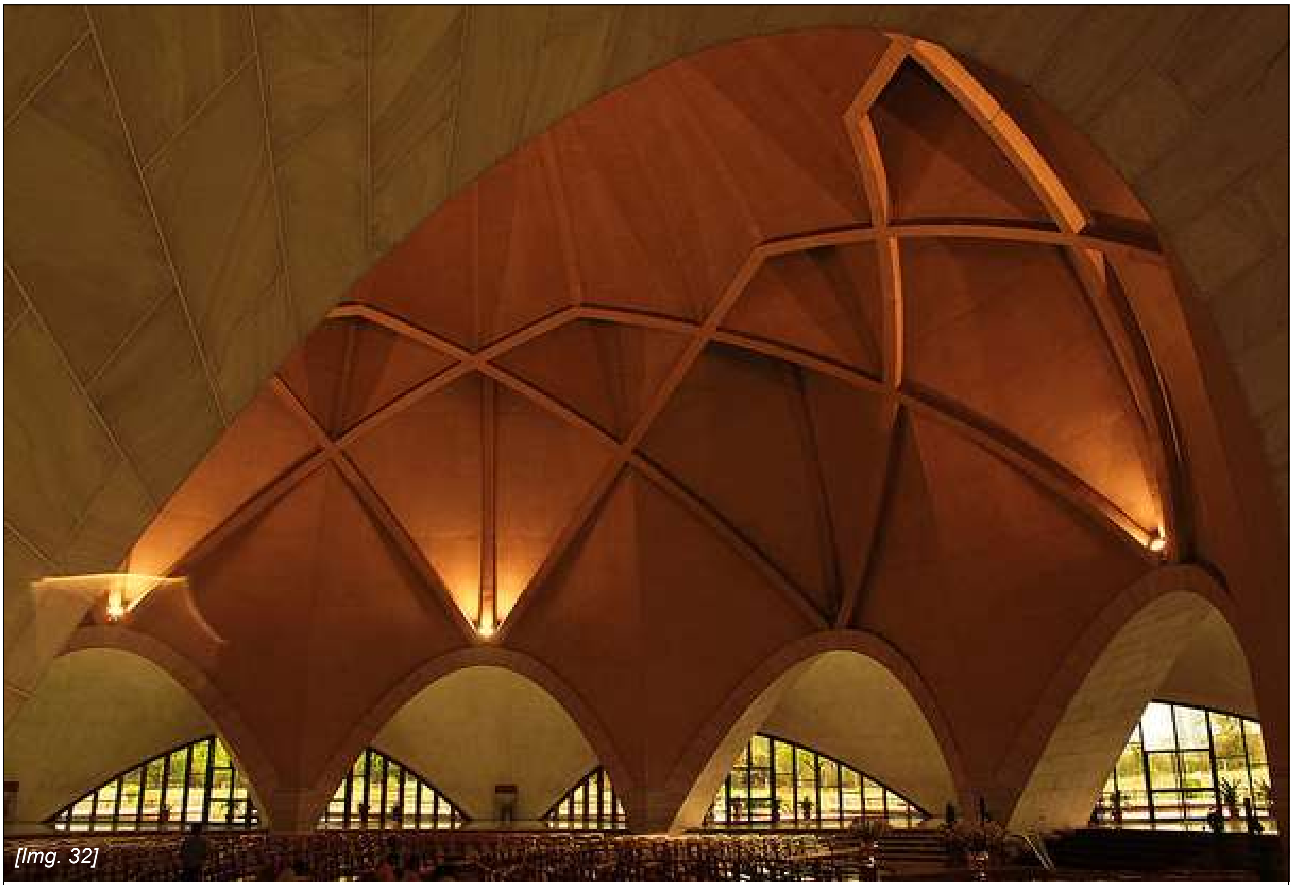
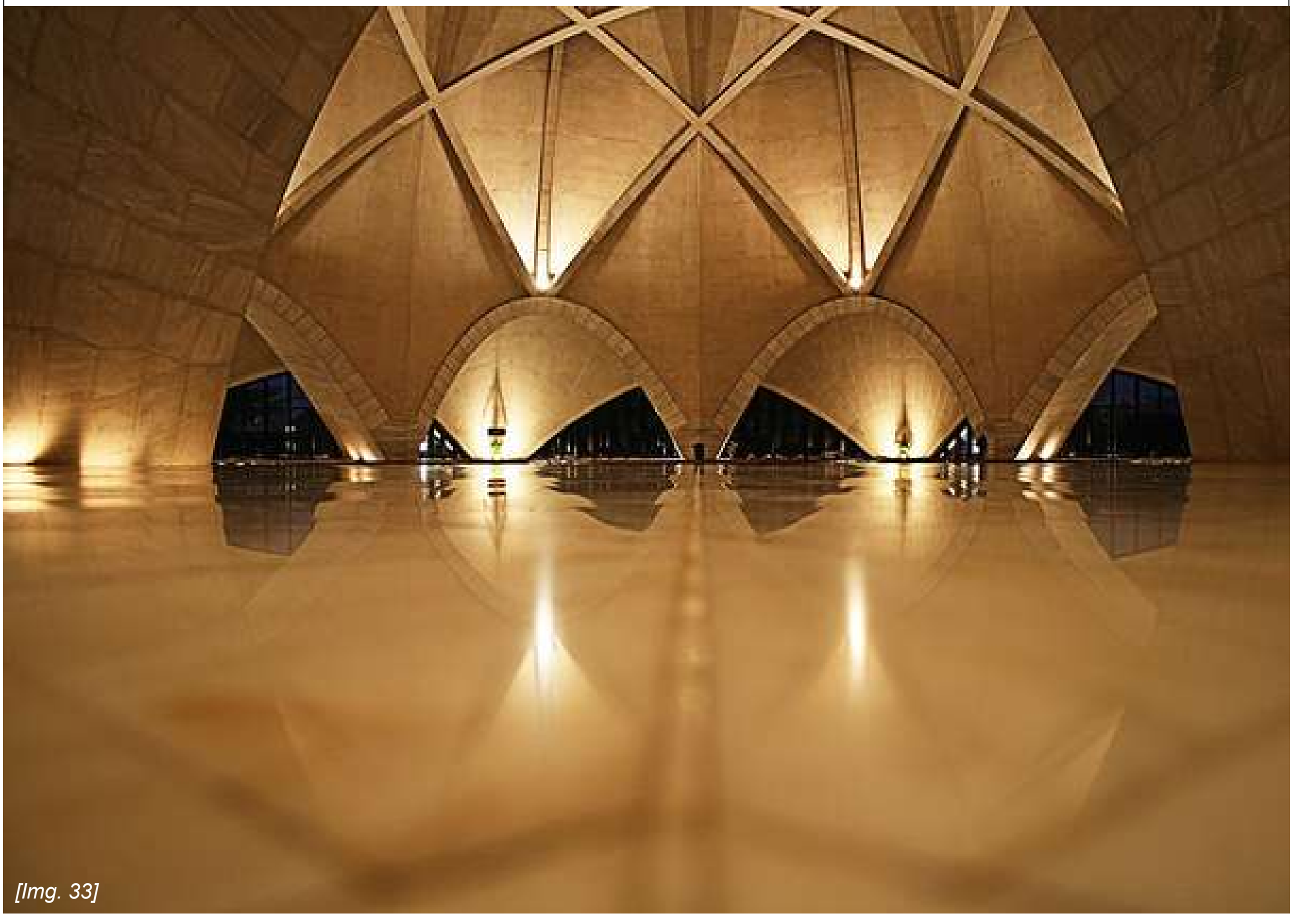

1 . podium level
2 . pool deck level
3 . pool
4 . bridge
5 . inner leaf
6 . interior dome
7 . outer leaf
8 . glazing
9 . dome ribs
10 . crown of dome
11 . fan room
12 . steel & glass roof


1 pool
2 . outer hall
3 . bridges
4 . entrance


[Img. 31]




[Img. 32]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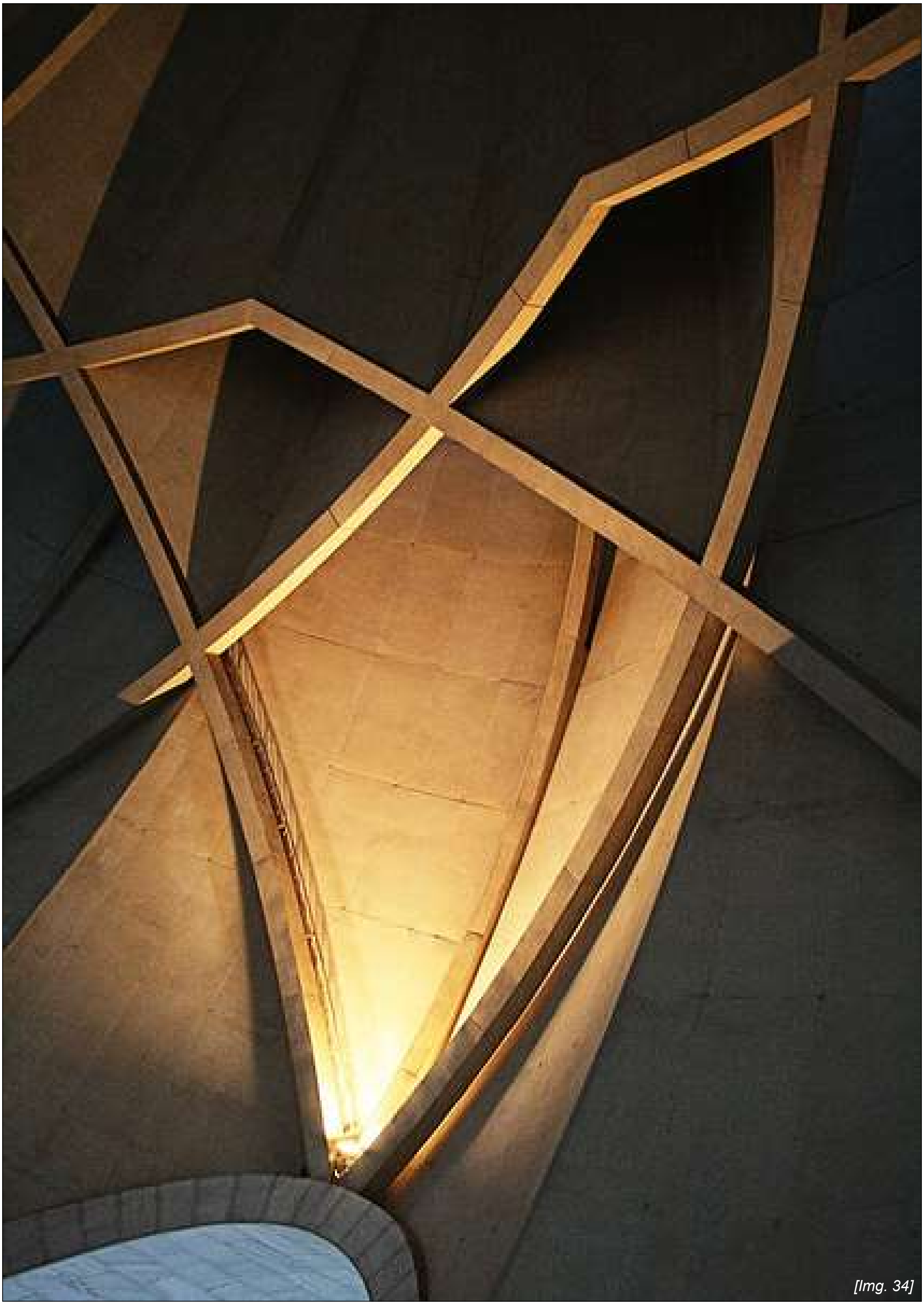
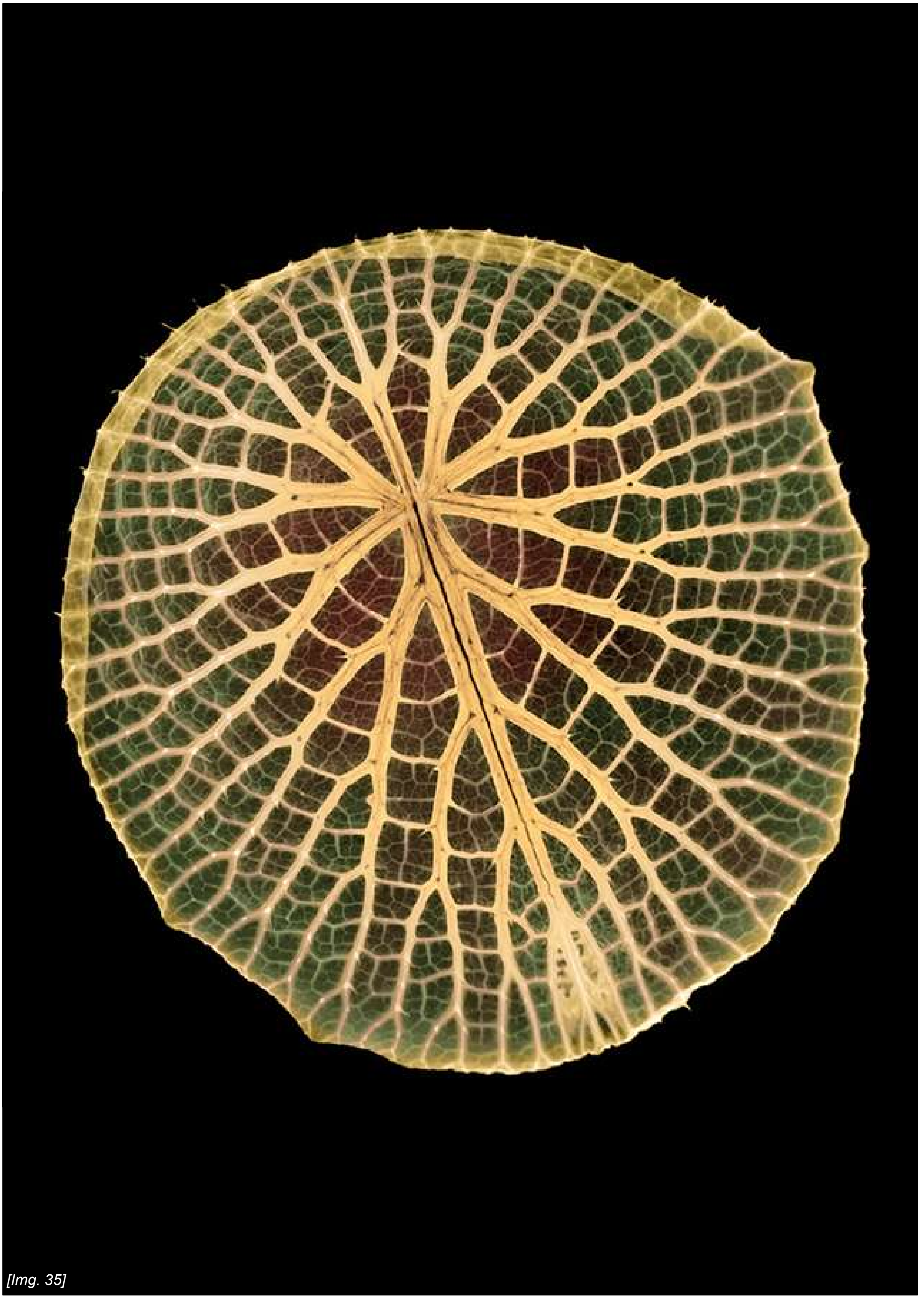


[Img. 34]



[Img. 35]

# NEW POSSIBILITIES

## WHAT IS BIOMIMICRY?

*„BI - O - MIM - IC - RY*
*[From the Greek bios, life, and mimesis, imitation]“*
(Benyus, 1997)

*„1. Nature as model. Biomimicry is a new science that studies nature‘s models and then imitates or takes inspiration from these designs and processes to solve human problems, e.g., a solar cell inspired by a leaf.“* (Benyus, 1997)

*„2. Nature as measure. Biomimicry uses an ecological standard to judge the „rightness“ of our innovations. After 3.8 billion years of evolution, nature has learned: What works. What is appropriate. What lasts.“* (Benyus, 1997)

*„3. Nature as mentor. Biomimicry is a new way of viewing and valuing nature. It introduces an era based not on what we can extract from the natural world, but on what we can learn from it.“* (Benyus, 1997)

As the contemporary human, called “Homo industrialis” by Benyus – the first person to write about Biomimicry -, is slowly recognizing how it has reached the limits of nature’s tolerance, the fact that soon humankind might be just another extinct species, just as all the other species that humans themselves eradicated from earth, becomes more and more a possibility. To counter this, biomimicry is proposing to look at all the organisms that have evolved, adapted and learned from nature throughout the last 3.8 billion years.

As we always want to dominate or improve nature, biomimicry is a new approach of trying to imitate nature in a respectful way in order to integrate into the natural world and thus be accepted by this whole ecosystem, just like the species that managed to live in somewhat of a harmony with nature for billions of years before us. (cf. Benyus, 1997)

*“In seeing how seamlessly animals fit into theirs homes, I began to see how separate we managers had become from ours. Despite the fact that we face the same physical challenges that all living beings face – the struggle for food, water, space, and shelter in a finite habitat – we were trying too meet those challenges through human cleverness alone. The lessons inherent in the natural world, strategies sculpted and burnished over billions of years, remained scientific curiosities, divorce from the business of our live.”* (Benyus, 1997, p. 4)

“*Though it seems perfectly sensible to echo our biological ancestors, we have been traveling in just the opposite direction, driven to gain our independence. Our journey began ten thousand years gap with the Agricultural Revolution, when we broke free from the vicissitudes of hunting and gathering and learned to stock our own pantries. It accelerated with the Scientific Revolution, when we learned, in Francis Bacon’s words, to “torture nature for her secrets.” Finally, when the afterburners of the Industrial Revolution kicked in, machines replaced muscles and we learned to rock the world.*

*But these revolutions were only a warm-up for our real break from Earthly orbit – the Petrochemical and Genetic Engineering Revolutions. Now that we can synthesize what we need and rearrange the genetic alphabet to our liking, we have gained what we think of as autonomy. Strapped to our juggernaut of technology, we fancy ourselves as gods, very far from home indeed.*

*In reality, we haven't escaped the gravity of life at all. We are still beholden to ecological laws, the same as any other life-form. The most irrevocable of these laws says that a species cannot occupy a niche that appropriates all resources – there has to be some sharing. Any species that ignores this law winds up destroying its community to support its own expansion. Tragically, this has been our path. We began as a small population in a very large world and have expanded in number and territory until we are bursting the seams of that world. There are too many of us, and our habits are unsustainable.*

*But I believe, as many have before me, that this is just the storm before the calm. The new sciences of chaos and complexity tell us that a system that is far from stable Is a system ripe for change. Evolution itself is believed to have occurred in fits and starts, plateauing for millions of years and then leaping to a whole new level of creativity after crisis.*

*Reaching our limits, then, if we choose to admit them to ourselves, may be an opportunity for us to leap to a new phase of coping, in which we adapt to the Earth rather than the other way around. The changes we make now, no matter how incremental they seem, may be the nucleus for this new reality. When we emerge from the fog, my hope is that we'll have turned this juggernaut around, and instead of fleeing the Earth, we'll be homeward bound, letting nature lead us to our landing, as the orchid leads the bee."* (Benyus, 1997, p. 5f)

So instead of chasing the idea, that someday humankind will be completely independent of it's natural habitat, instead of treating the earth and therefore nature as a temporary means to an end, biomimicry want's to remind us, that nature is the fundament of our life's and therefore we will never be completely independent from it. So instead of escaping nature, we should work with it and learn from it.

Even more so that now we have technologies that allow us to see structures in nature and natural processes in various depths, from an intercellular to an interstellar perspective. And through those different perspectives, we can see, that our inventions, as spectacular as they might seem, appear in nature in a far more elegant and sustainable way:

*"When we stare this deeply into nature's eyes, it takes our breath away, and in a good way, it bursts our bubble. We realize that all our inventions have already appeared in nature in am ore elegant form and at a lot less cost to the planet. Our most clever architectural struts and beams are already featured in lily pads and bamboo stems. Our central heating and air-conditioning are bested by the termite tower's steady 86 degrees F. Our most stealthy radar is hard of hearing compared to the bat's multifrequency transmission. And our new "smart materials" can't hold a candle to the dolphin's skin or the butterfly's proboscis. Even the wheel, which we always took to be a uniquely human creation, has been found in the tiny rotary motor that propels the flagellum of the world's most ancient bacteria."* (Benyus, 1997, p. 6)

So, to transcend this constant chase of the idea of independently human achievements and inventions – which are part of destroying our own species and others alike -, we might have to stop and look at nature's intertwined systems of sustainability and co-existence. To do so, Benyus notes a "canon of nature's laws":

> *"Nature runs on sunlight.*
> *Nature uses only the energy it needs.*
> *Nature first form to function.*
> *Nature recycles everything.*
> *Nature rewards cooperation.*
> *Nature banks on diversity.*
> *Nature demands local expertise.*
> *Nature curbs excesses from within.*
> *Nature taps the power of limits."*
> (Benyus, 1997, p.7)

Finally, one could say that biomimicry is not only a notion of how to do things, but also a very philosophical approach. Because it want's *"us as a culture to walk in the forest again. Once we see nature as a mentor, our relationship with the living world changes… This time, we come not to learn about nature so that we might circumvent or control her, but to learn from nature, so that we might fit in, at last and for good, on the Earth from which we sprang."* (Benyus, 1997, p.9)

## BIOMIMICRY IN AN ARCHITECTURAL CONTEXT

*"The process of evolution and the resulting adaptations have allowed life to sustain itself for millennia. But the increased pace and scale of human activities has unknown consequences for the balance of systems that allow all species, including our own, to thrive. Sustainable design is a way for us to begin to harmonize man-made structures with the natural environment. Biomimicry can help us change our perception by looking to nature as a source of functional and aesthetic solutions rather than as a source of obstacles to overcome."* (Mazzoleni; Price, 2013, p. 3f)

*"What has been commonly called „The Industrial Revolution" (but could also be referred to as „The Fossil Fuel Age") could now be seen as a diversion from the kind of ingenuity that we once had in common with nature's evolved solutions. The ubiquity and convenience of fossil fuels has allowed extreme inefficiency to develop, and has effectively undermined resourcefulness. The lessons from nature which informed many vernacular approaches to design and manufacturing were therefore abandoned and largely lost from our collective memory. Now that the folly of releasing many millennia of stored carbon is becoming increasingly apparent, there is an opportunity to explore the incredible effectiveness of the responses that natural organisms have evolved. For virtually every problem that we currently face - whether it is producing energy, finding fresh water or manufacturing benign materials - there will be numerous examples in nature that we could benefit from studying. While fascination with nature undoubtedly goes back as long as human existence itself, now we have an opportunity to revisit the idea of learning from biology with massive advantages of scientific knowledge, better tools and aesthetic sensibilities unconstrained by historical dogma. There are few times when designers have been presented with such an opportunity... The intention is therefore to transcend the mimicking of natural forms and attempt to understand the principles that lie behind those forms and systems. Then we can look for opportunities to create works of architecture that are celebratory as well as being radically more efficient."* (Pawlyn, 2012, p. 1f)

Basically, technology has made it possible for humans to live in disharmony with nature through a border that seemed impenetrable, but the current situation – namely global warming and the climate crisis – shows that the effect of humans on earth, specifically since this complete detachment from a somewhat give and take relationship to a position where the human seemingly doesn't depend on nature, with all the resource depletion and pollution, is screaming for a new solution, either the extinction of humankind or a new way to think the relationship.

What biomimicry offers is exactly a way to think this new relationship. To gain back perspective on how to integrate humankind back into its very own ecosystem earth, biomimicry is proposing to take nature as an example and implement its closed-loop-circle like approach to architecture:

*"Just as animals have systems, such as skeletal, circulatory, immune, digestive, communication, and sensory, so too do buildings have systems of structure, circulation, protection, energy and water use, communication, and thermal regulation. Viewed as a network of internal systems interacting with its surrounding environment, which is in turn part of a larger global network of systems, the building can find inspiration from an animal's interactions with its ecological realm."* (Mazzoleni; Price, 2013, p. 4)

So through seeing architecture in this new context, it could become something dynamic, flexible and reactive, something incorporated into the whole ecosystem, which in turn would make it integral to preserve this ecosystem and thus nature and maybe even restore it.

Up until now nature was used as a formal reference, whereas biomimicry wants to overcome this superficial way of thinking by thinking about solutions that make it possible to have a co-existence of the natural and the built environment without exploitation.

*"Architecture has always inserted itself into and interacted with the natural environment. Essentially, architecture provides shelter in nature to protect its inhabitants from nature…By embracing bioinspired design processes, opportunities arise to help us develop man-made environments in harmony with nature, beginning to eliminate the separation between the built and the living realms."* (Mazzoleni; Price, 2013, p. 6f)

So the objective of biomimicry could be summarized as thinking the built environment as a biological organism, therefore embedding it into the ecosystem earth

and thus making it impossible to exploit.
This approach of taking nature's concepts and implementing them in an architectural context already exists in architecture with all the different movements around ORGANICISM, especially with Frank Lloyd Wright, Alvar Aalto, Buckminster Fuller, Frei Otto and some more, as already explored in the previous chapters.

But with the new possibilities of technology, biomimicry is a field that needs to be explored in an architectural context in order to be able to fully reach the potential of implementing nature into the built environment.
(cf. Mazzoleni; Price, 2013)

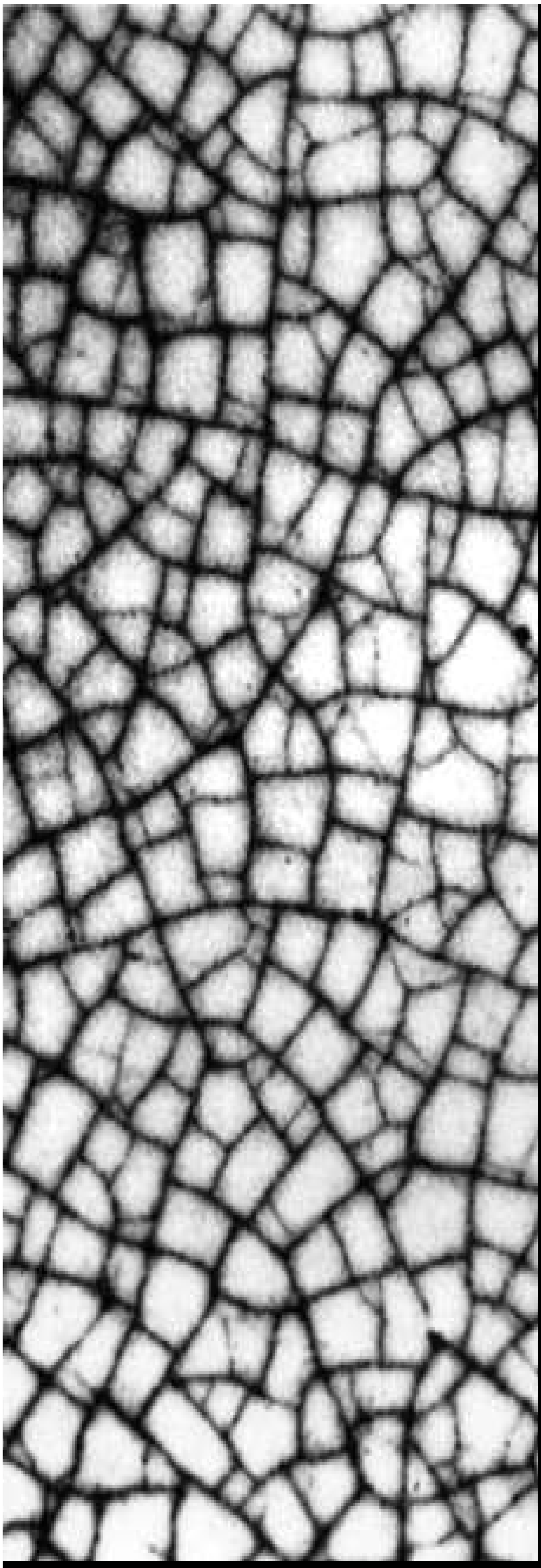
In contrast to organic architecture, biomimicry aims to take a quite literal approach, similar to the „per-biomimetic" projects in the previous chapter to integrate natural principles into architecture. Appearing at a time where technology has already developed quite a bit, more information is available in this field than there was almost a century ago. Furthermore, the methods for implementation have changed. There are a lot of new materials that can be used and machines are becoming more and more sophisticated.

## CONTEMPORARY CONTEXT

"By 2050 two thirds of the world's population will live in cities, which will also be where most of the world's pollution is produced. We are already faced with metropolitan sizes of nearly 40 million inhabitants. As a consequence we are confronted with a problematic decrease in elementary resources such as clean air and water, and the challenges of massive waste production, and at the same time urbanization contributes to climate change. In this situation sustainability, renewable energy, alternative building techniques, refined materials and interacting digital systems all play an important role." (Imhof; Gruber, 2016, p. 17)

In this time of an uncertain future, catastrophes and tall the problems we are facing, biomimicry is exploring nature as more than just an aesthetic or structural inspiration but rather as nature being something that has proven itself over an unimaginable length of time and therefore appreciating this knowledge and respectfully incorporating it into our built environment.

*[Img. 36] Pollution pods by Michael Pinsky:*
*Five interconnected geodesic domes let visitors experience the pollution in big cities.*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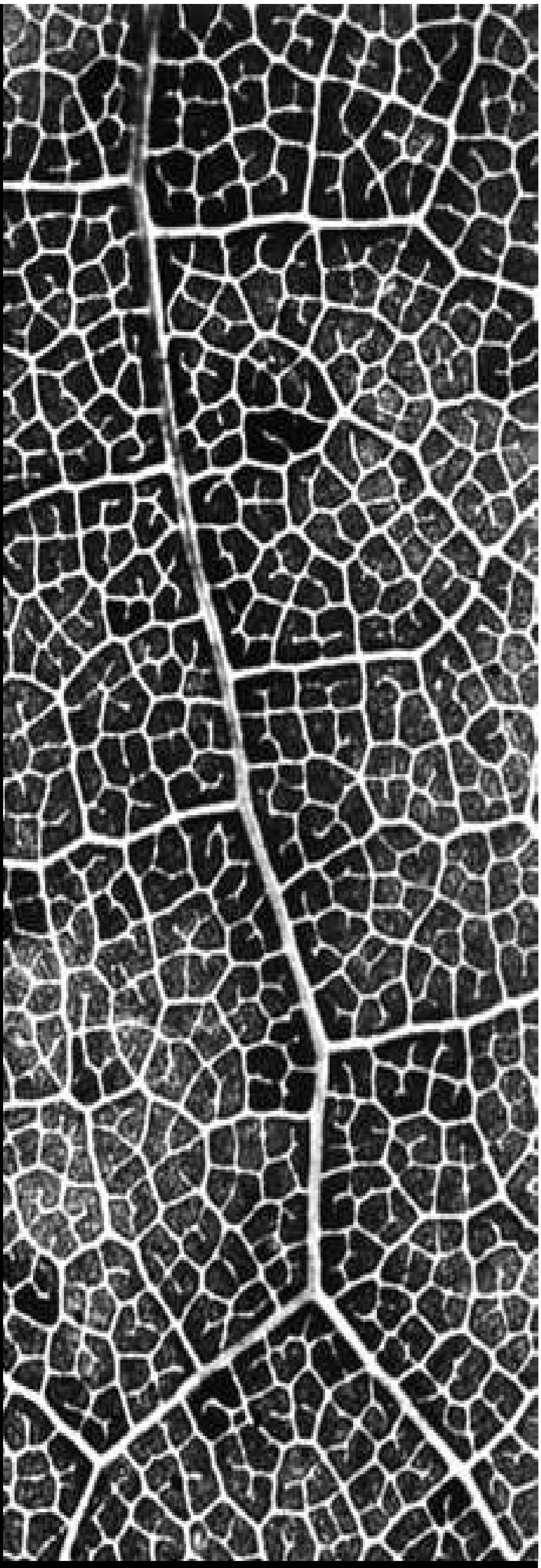

[Img. 38]

# BIOMIMETIC METHODOLOGY

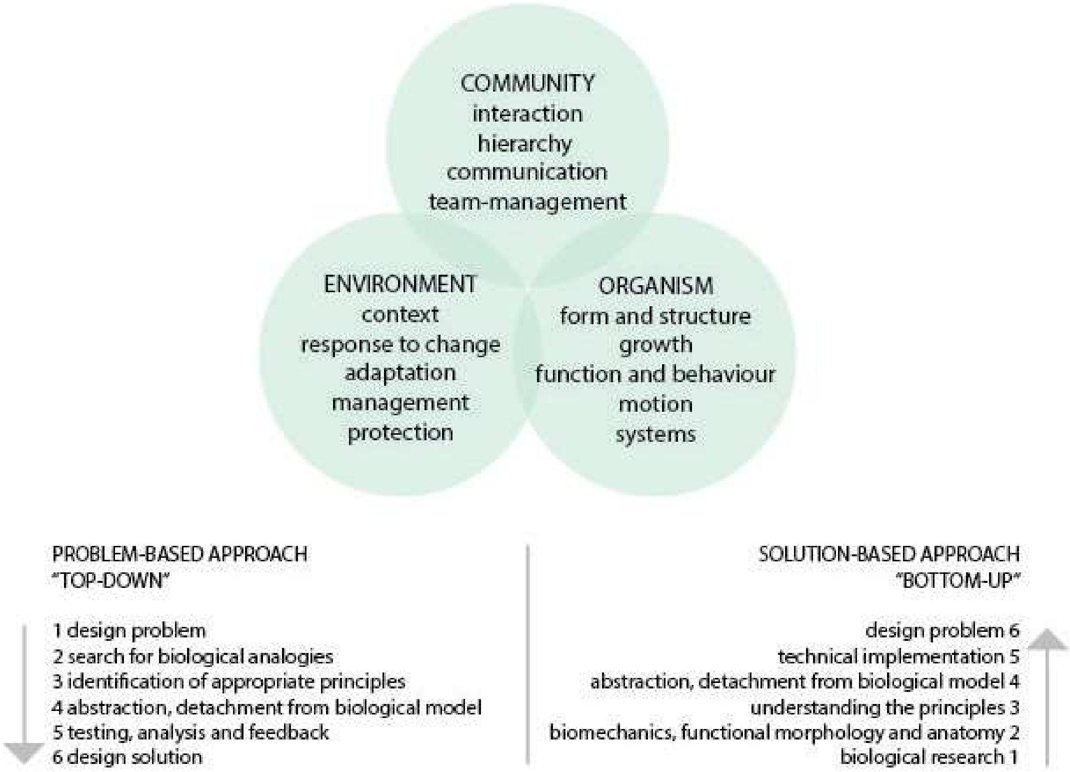
Biomimicry is an applied science that derives inspiration for solutions to human problems from the study of natural designs, processes and systems. The widespread and practical application of biomimicry as a design method remains unrealized; architecture commonly uses biology as a library of shapes, but this alone is not biomimetics; in order to classify as truly biomimetic, the architecture has to have some biology in it. The paper „Biomimicry as a Problem Solving Methodology in Interior Architecture“ by Rasha Mahmoud Ali El-Zeiny reviews key points and case studies of applications of biomimicry in interior architecture. Out of those studies two methods can be extracted:

A problem-based approach (Top-down approach) and a solution-based approach (Bottom-up approach).

These solutions always rely on different levels of biomimetic information:

The information embedded in each organism can be found in many levels, possible features that can be concluded from an organism and its biomimicry are analyzed using three levels:

*1. Organism features*
(Features of the organism itself)
*2. Organism-Community relationship*
(The organism‘s relationship to its community of similar organisms as well as other creatures that it may deal with)
*3. Organism-Environment relationship*
(How an organism fits in its biome and environment)




*[Img. 39]*

*PROBLEM – BASED APPROACH*

In this approach, designers look to the living world for solutions, which requires designers to identify problems and biologists to then match these to organisms that have solved similar issues. This approach is effectively led by designers identifying initial goals and parameters for the design. (cf. Perdersen, 2007)

The pattern of a problem-based approach follows a progression of steps which, in practice, are nonlinear and dynamic in the sense that output from later stages frequently influences previous stages, providing iterative feedback and refinement loops. (cf. Helms; Swaroop; Ashok, 2009)

Also, McDonough stated that this approach might be a way to begin the transition of the built environment from an unsustainable to an effective paradigm (McDonough, 2002).

*SOLUTION- BASED APPROACH*

When biological knowledge influences human design, the collaborative design process is dependent on people having knowledge of relevant biological or ecological research, rather than on determined human design problems.

An advantage of this approach is that biology may influence humans in ways that, as it is conceived outside of a predetermined design problem, result in previously unthought of technologies, systems or even approaches to design solutions.

A disadvantage of this approach, from a design point of view, is that biological research must be conducted and then identified as relevant to a design context.

Biologists and ecologists must therefore be able to know the potential of the research in the innovation of ingenious application.

### ***Levels of Biomimetics Information***

The information embedded in each organism can be found in many levels, possible features that can be concluded from an organism and its biomimicry are analyzed using three levels:

*1. Organism features*
(Features of the organism itself)

*2. Organism-Community relationship*
(The organism‘s relationship to its community of similar organisms as well as other creatures that it may deal with)

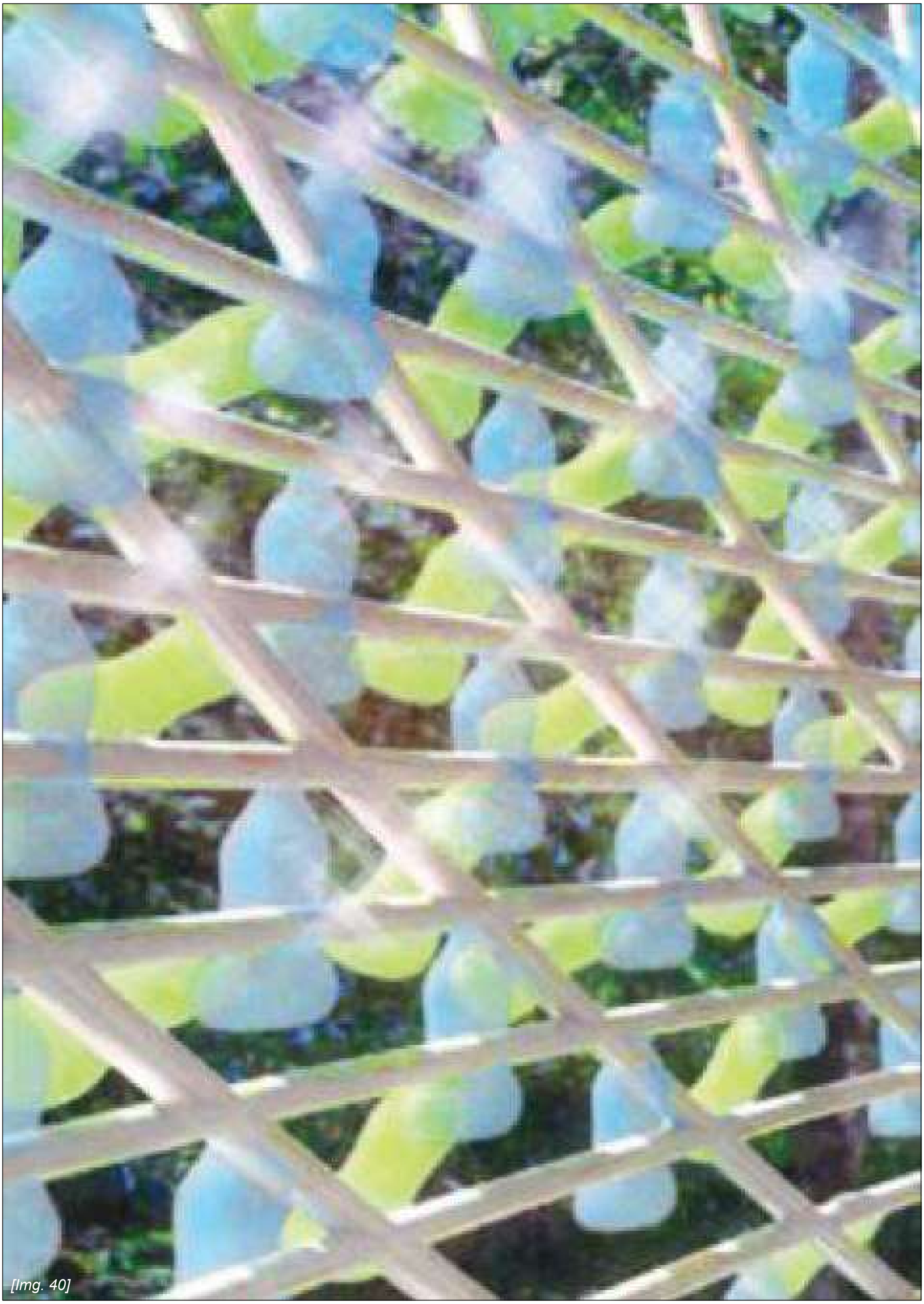
*3. Organism-Environment relationship*
(How an organism fits in its biome and environment)

Each level is concerned with a layer of the design of an organism. The first includes aspects and properties of a creature as a whole unit. The second includes other features that focus on the relationships between an organism and its living community. The third level highlights systems and ecosolutions that can be concluded from relationships between an organism and its context/environment.

# THE EARLY YEARS OF BIOMIMETIC ARCHITECTURE

Like every field, biomimicry developed from something theorethical and experimental into something that has established itself within the context of architecture. But to really understand the development it had to go through, we took a look at examples stamming from a very early interpretation of biomimicry. On the following pages it becomes clear, that this field started its development in a time where technology was already used and computers already existed.

Nevertheless, the illustrations and implementation techniques used show that the technological development for a believable concept was still just evolving into what this field needed.



[Img. 40]

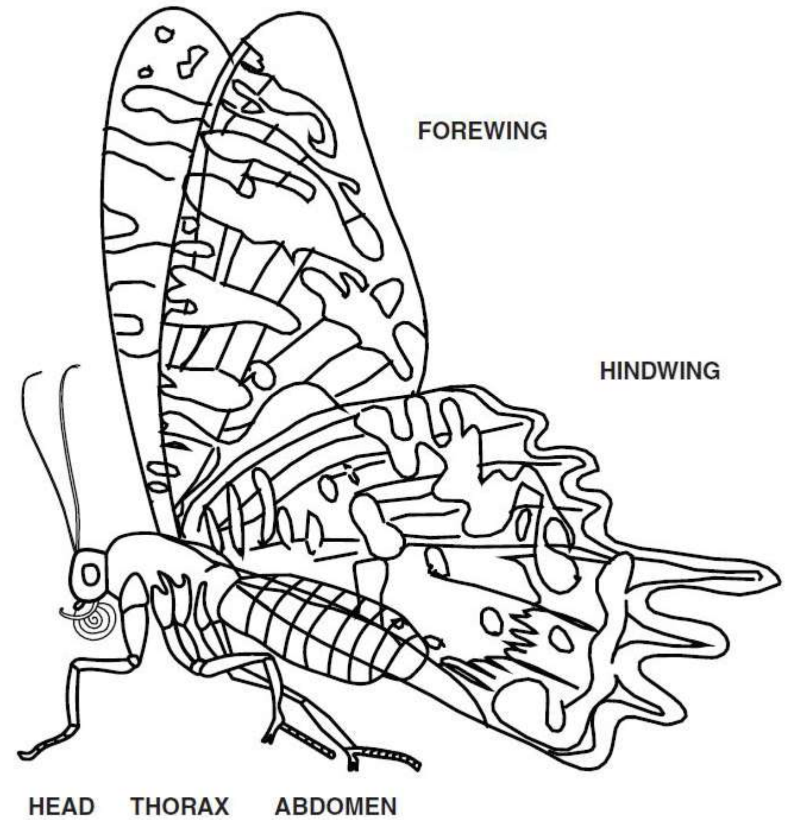
# URANIA MOTH

## CLAIMS TO BE BUILT, BUT NO EVIDENCE OF A REAL-LIFE IMPLEMENTATION

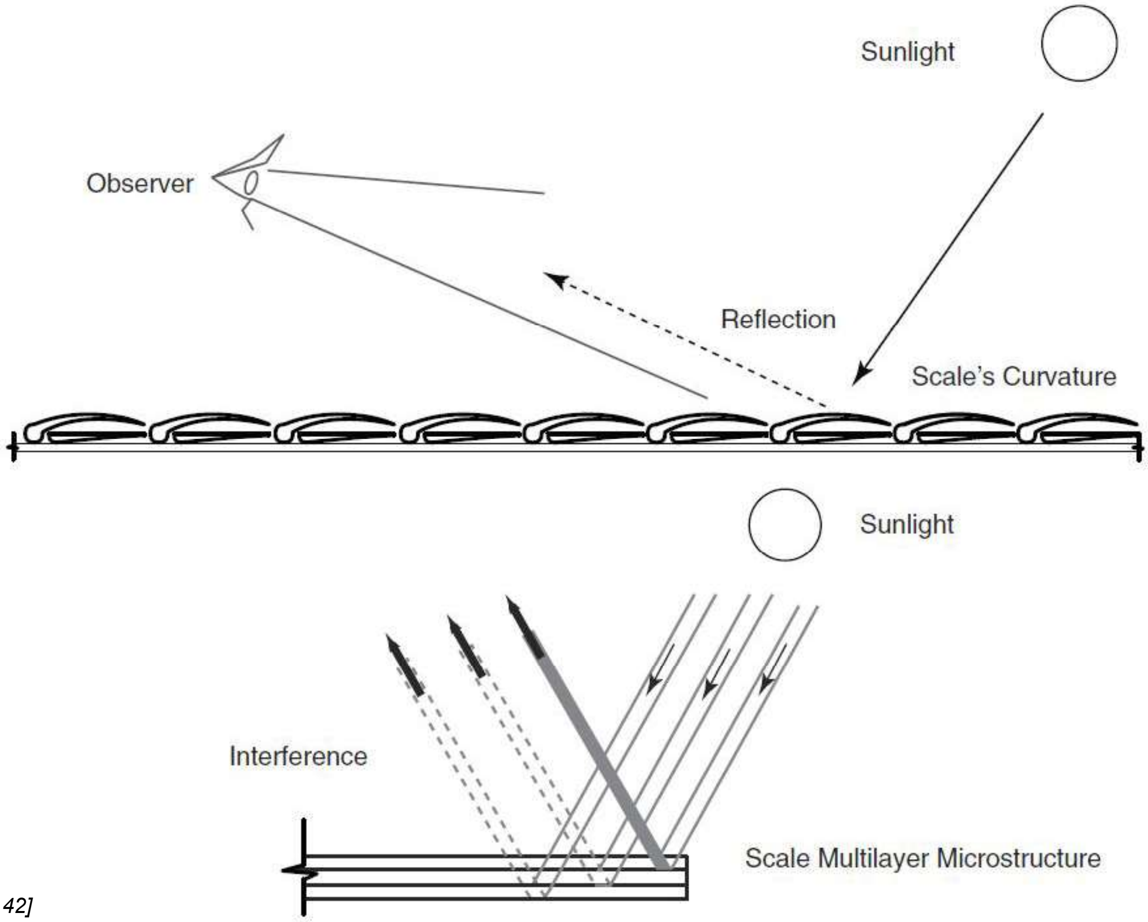
The Urania moth is a very colorful and striking moth. Due to its large color spectrum it is hardly to be confused. It lives in the forests of western Madagascar. Unusual for its species is its daily activity. Its appearance should warn other animals of the poison with which they come into contact as caterpillars. This moth has a multiform wing structure. This creates shimmering surfaces that can change color depending on the incidence of light and the angle of vision. These colors are also known as textured colors. The wing consists of many small overlapping scales. Depending on the absorption or reflection of the individual scales, the moth shimmers in a new light. Each scale has its own pigmentation and reflects it back. (cf. Mazzoleni; Price, 2013)

A project relating to the moth‘s play of colors is located in western Madagascar. This city has a very dry climate, which makes clean drinking water very difficult to obtain. Therefore, a building was constructed which collects the rainwater in a collecting basin above the actual building and then fills it into colored bottles through a grid created as a filter. The entire facade consists of colored bottles that behave differently depending on the amount of water. If no contents can be displayed, the bottles are horizontal, otherwise vertical. Due to the many-sided painted bottles and their reaction to the water, the building always shines in different colors, like the sunset moth.
This play with the sun is called among other things a kaleidoscopic effect. (cf. Mazzoleni; Price, 2013)

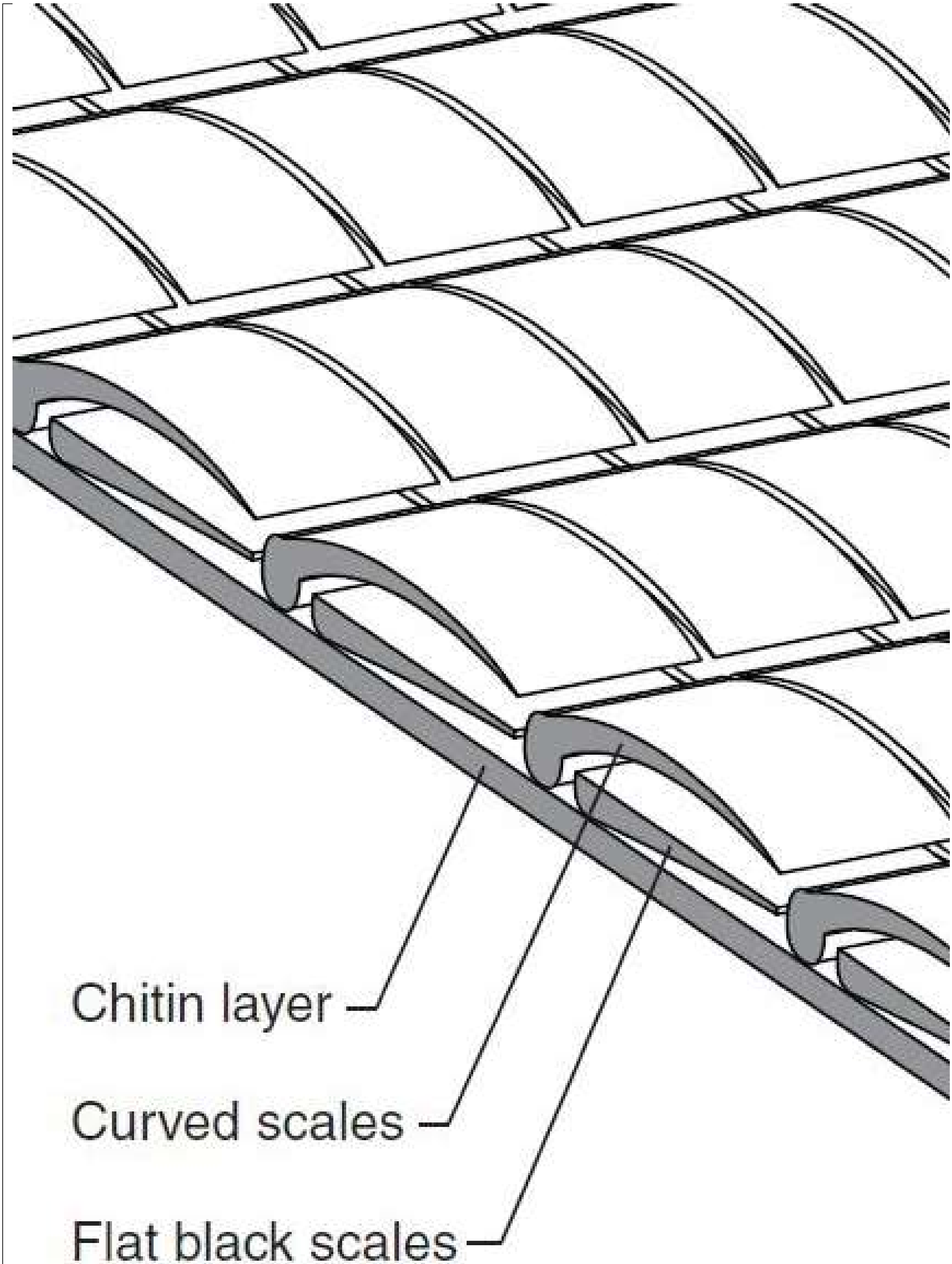
The principle of storing water to save people from dying of thirst is understandable. Many dry countries are confronted with this problem. Deriving the solution from nature is unusual but feasible. There would certainly be simpler solutions that would aim for the same practical result, but then it would probably have been thought through too superficially. Which is why this example is difficult to integrate, whether it belongs to a type of biomimicry or not: the actual derivation consists only of the overall visual picture, which does not clearly emphasize the connection between nature, architecture and technology.


FOREWING
HINDWING
HEAD
THORAX
ABDOMEN

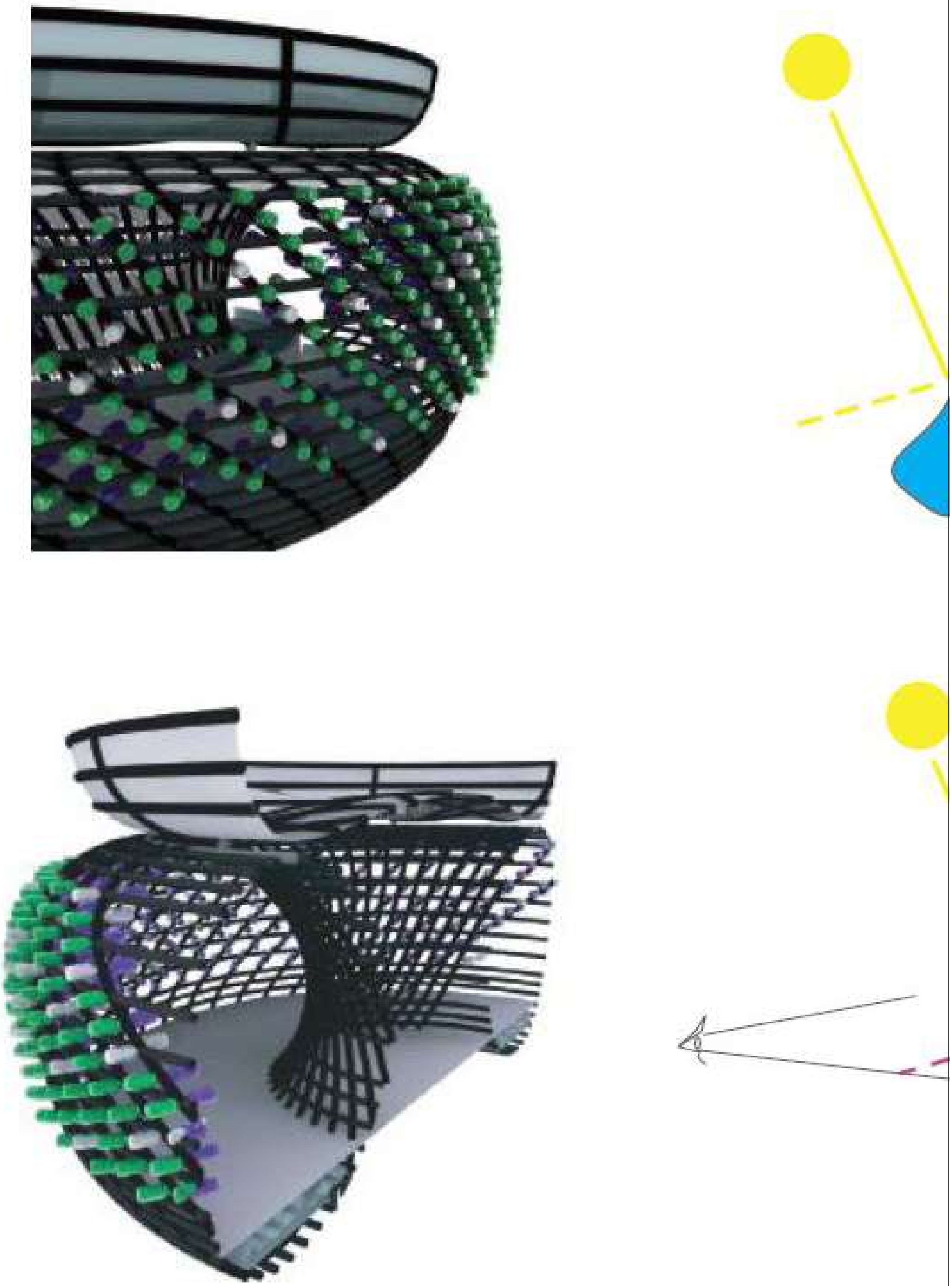
[Img. 41]


Sunlight
Observer
Reflection
Scale's Curvature
Sunlight
Interference
Scale Multilayer Microstructure

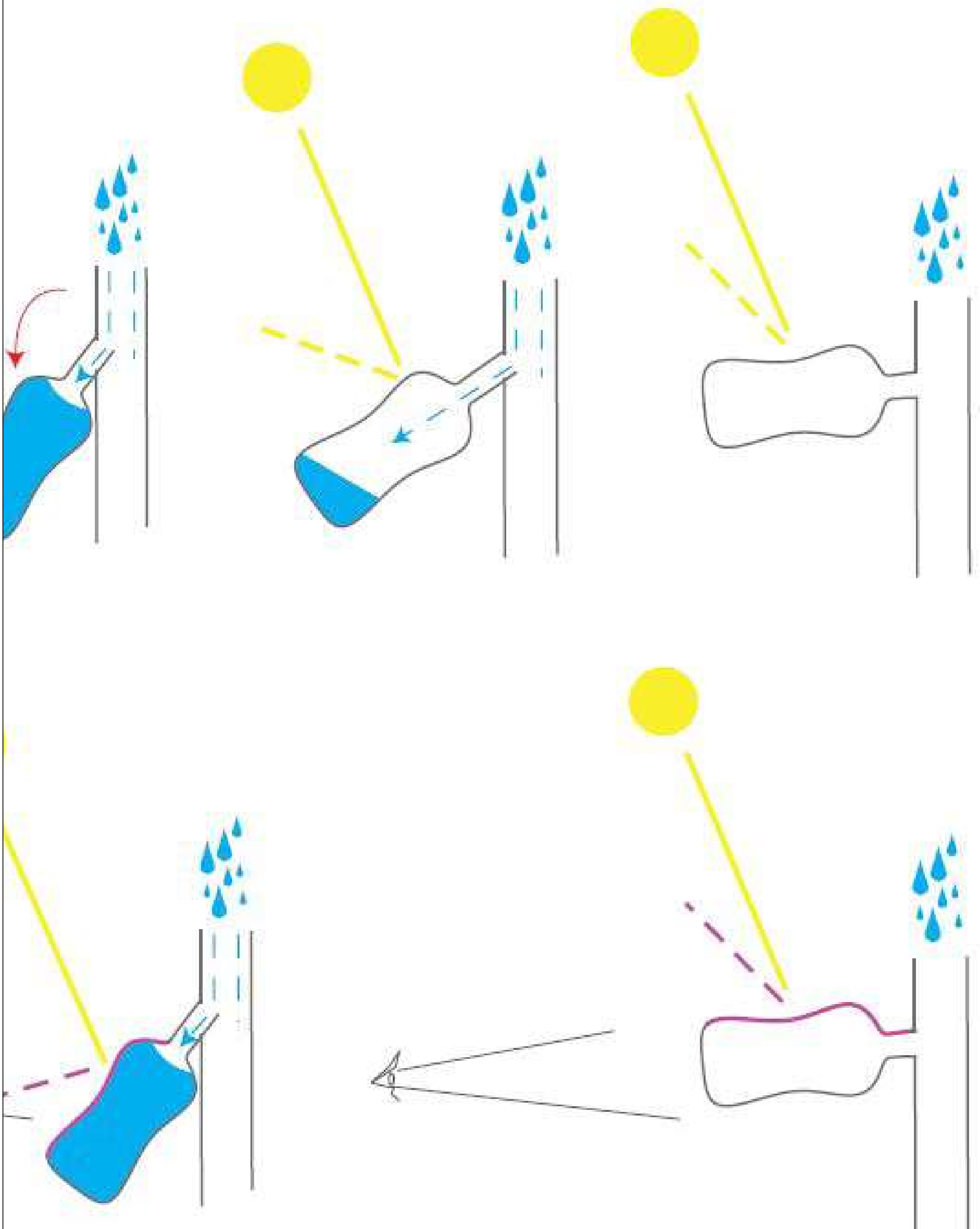
[Img. 42]

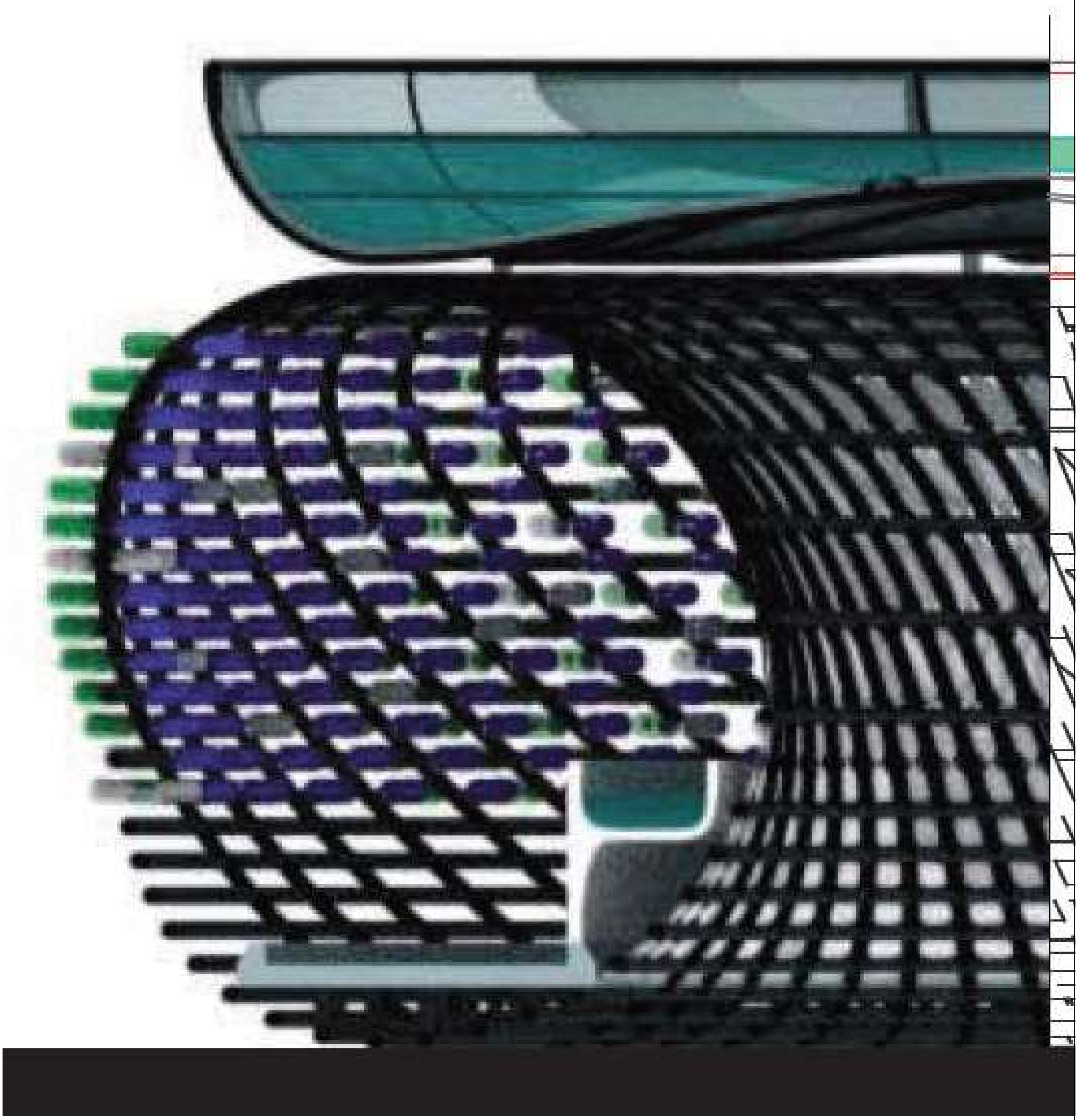



[Img. 43]

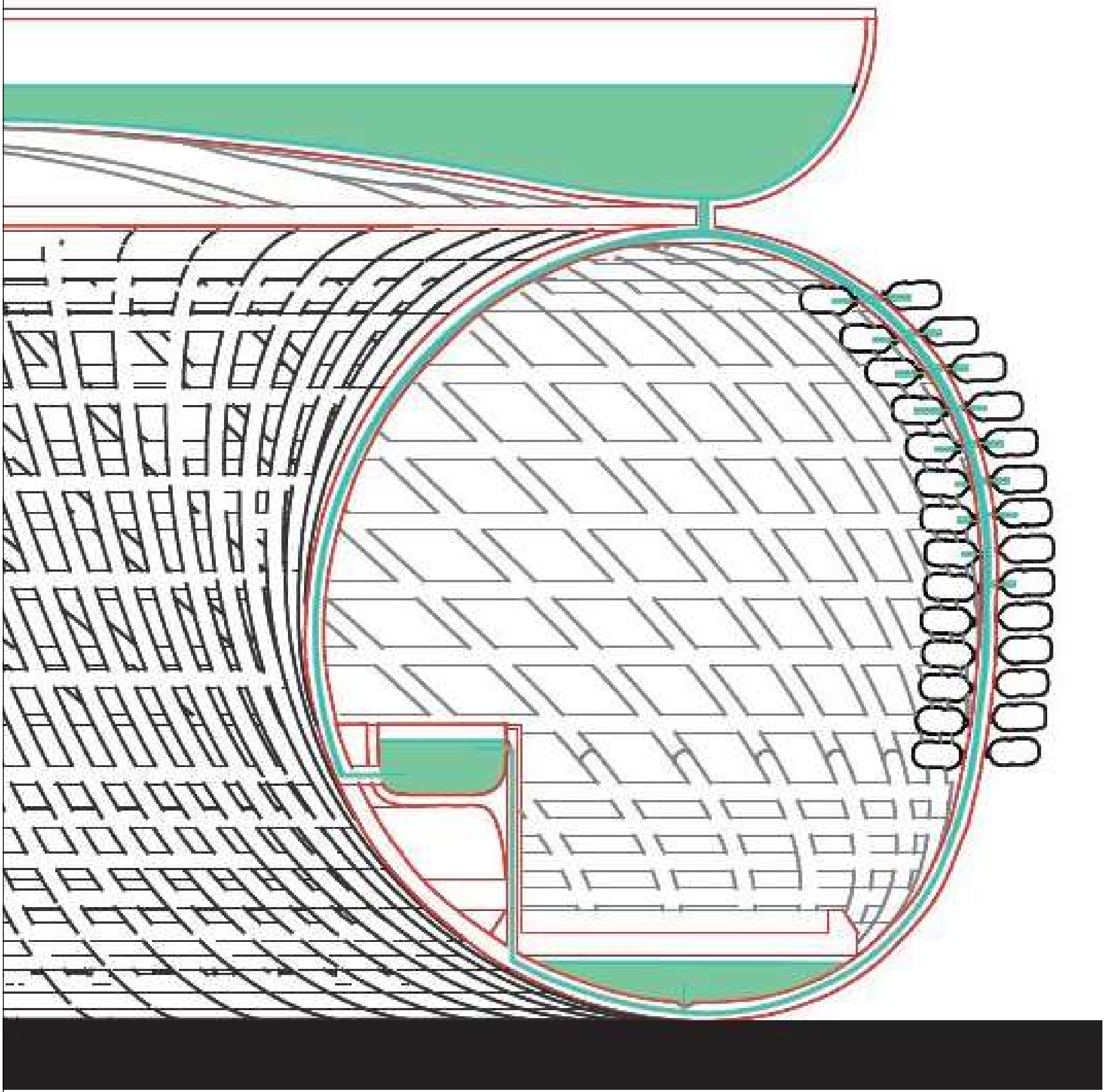


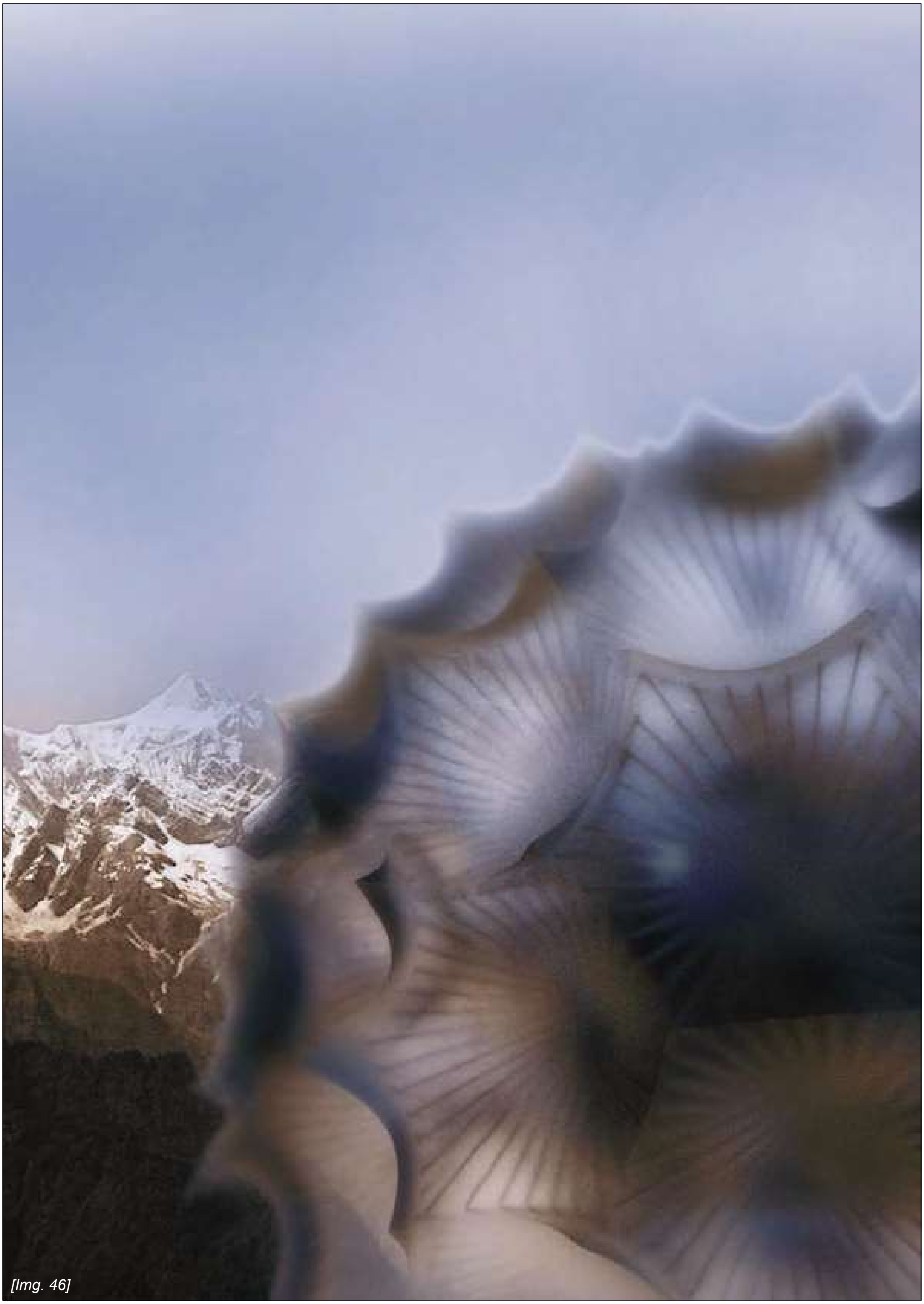
[Img. 44]





[Img. 45]



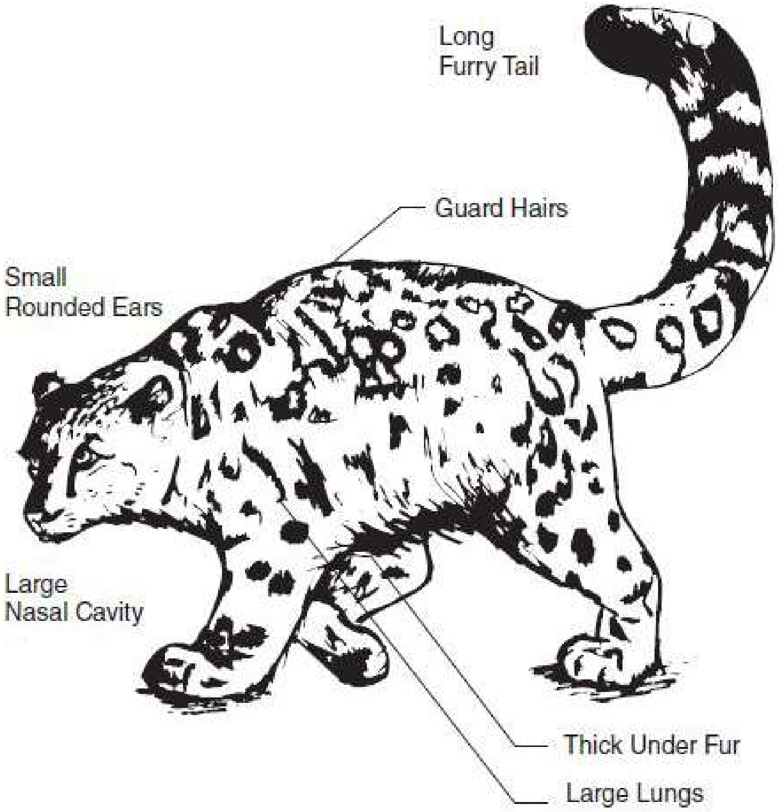


[Img. 46]

# SNOW LEOPARD
NOT BUILT

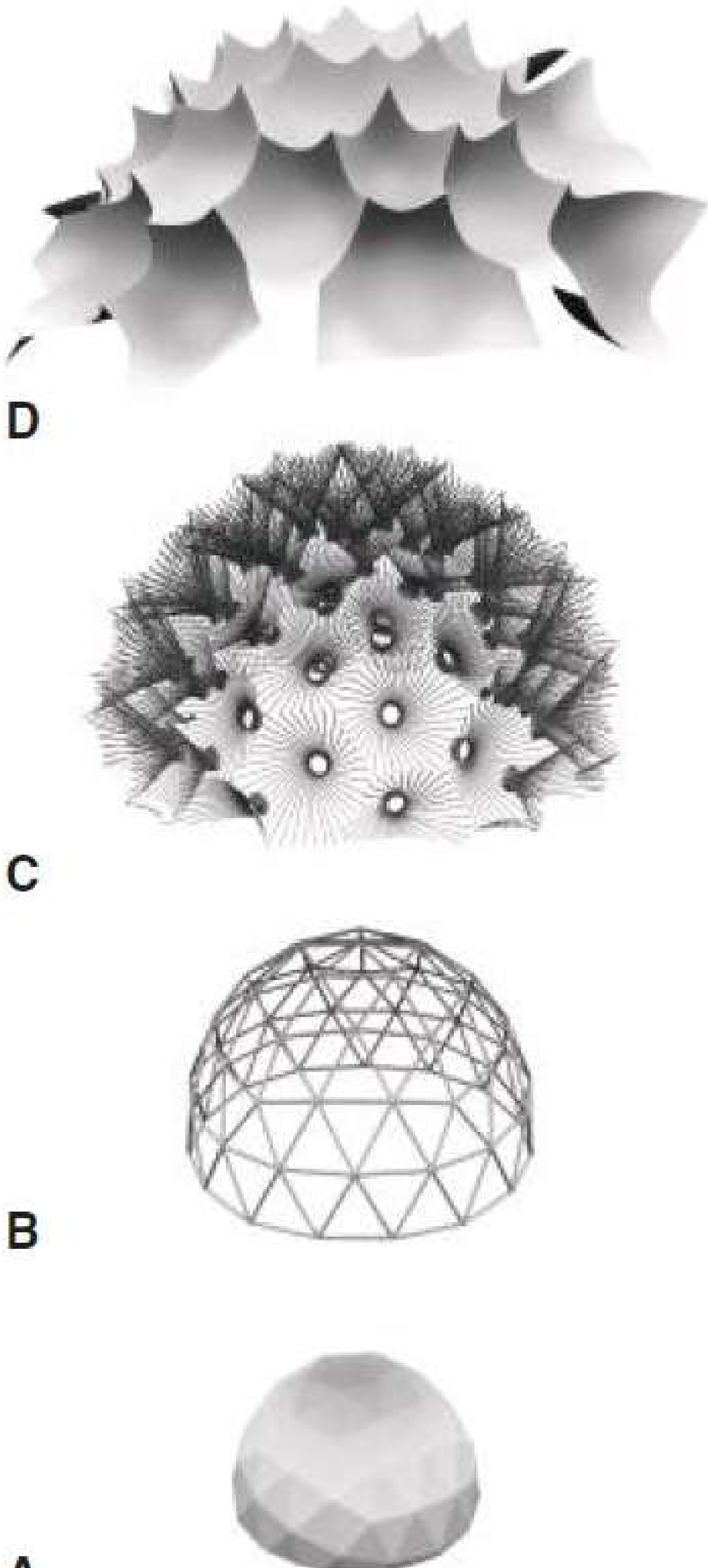
The snow leopard lives in very cold areas, far up in the mountains. The air becomes thinner and thinner and very dry. We humans would have to prepare ourselves especially well for such environmental influences. The snow leopard is one of the few animals that has not been well researched yet due to their habitat. They like to stay on steep slopes. Their habitat is usually at an altitude of 3.000 meters to 4.5000 meters above sea level. The veil which at the moment still hides the life of the animals and the interaction of nature will soon be lifted. At the moment, the architects are working on a kind of building which should make our stay more comfortable and bring us closer to the leopards.
(cf. Mazzoleni; Price, 2013)

There is the idea of a ball in the slope, which consists of many rods that tension a membrane. A vacuum insulation layer is installed. Depending on the weather, this membrane is either contracted or stretched. The result is a geodesic dome that can expand and contract pneumatically. It also has movable joints that make these movements possible in the first place. The high solar radiation warms the air underneath. This idea was inspired by the breathability of the leopard. The leopard uses its muscle-covered nasal concha bones to control the incoming and outgoing air. Excess energy and moisture can be captured and regained when breathing out.
(cf. Mazzoleni; Price, 2013)

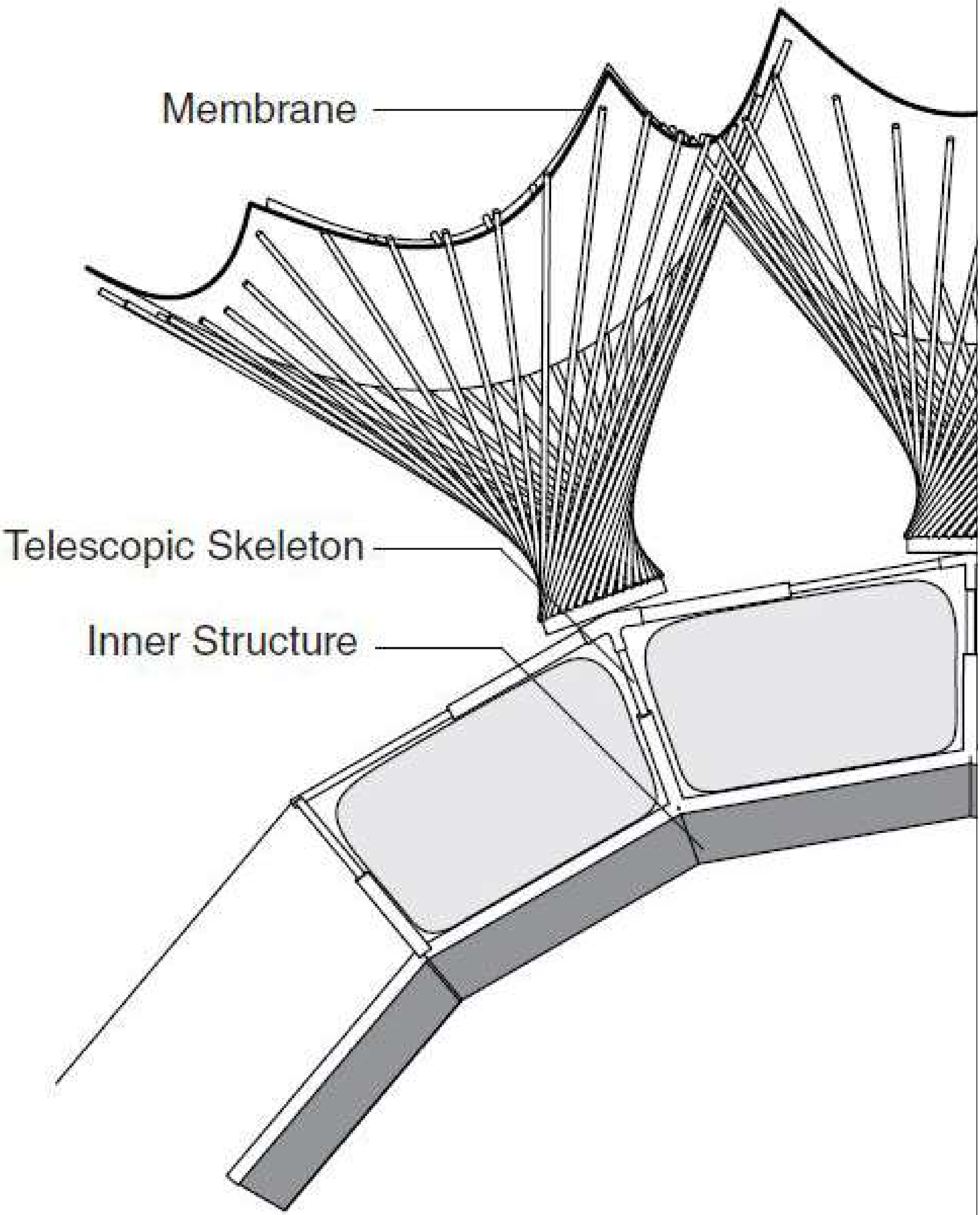

Long
Furry Tail
Guard Hairs
Small
Rounded Ears
Large
Nasal Cavity
Thick Under Fur
Large Lungs

*[Img. 47]*

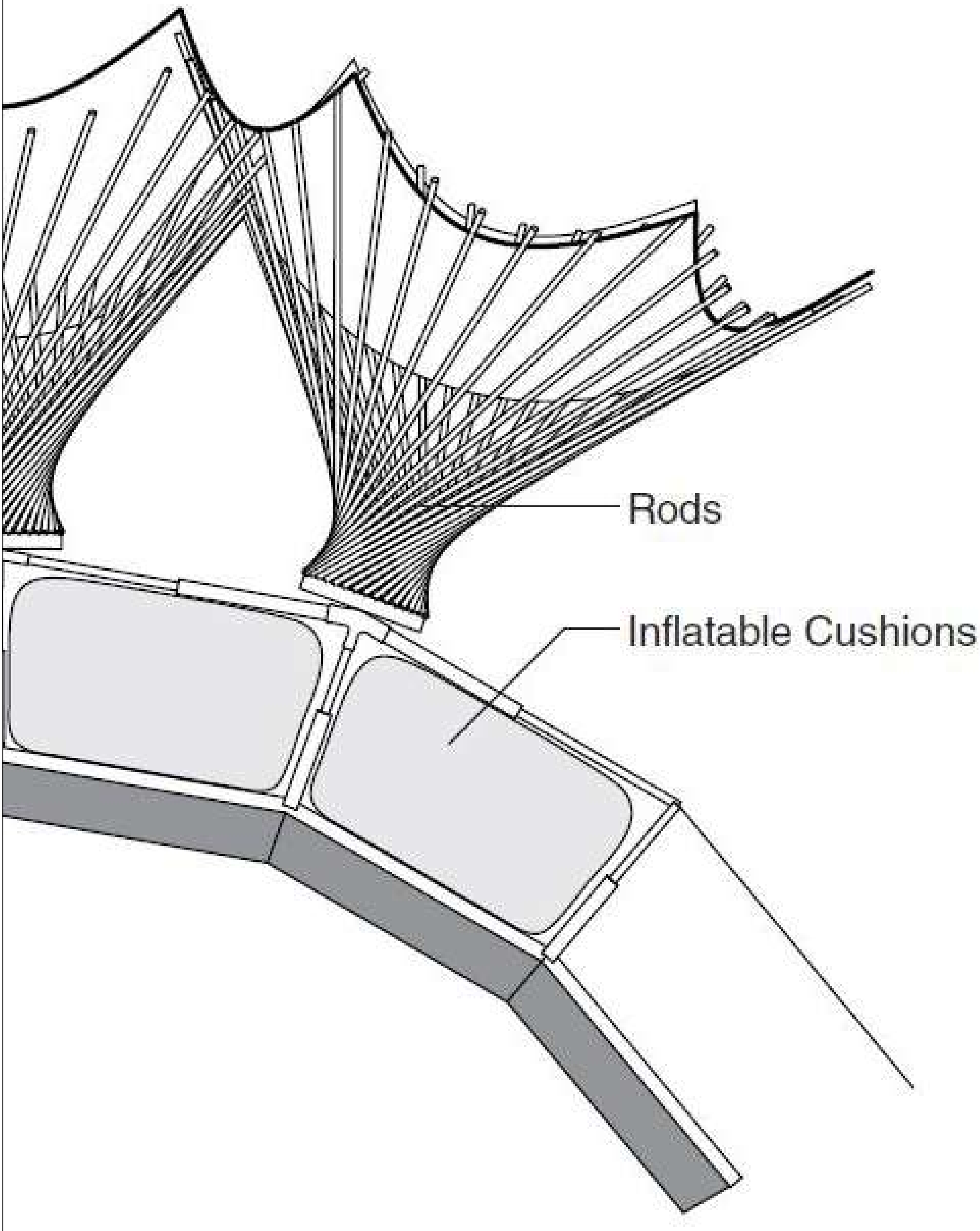
*[Img. 48]*

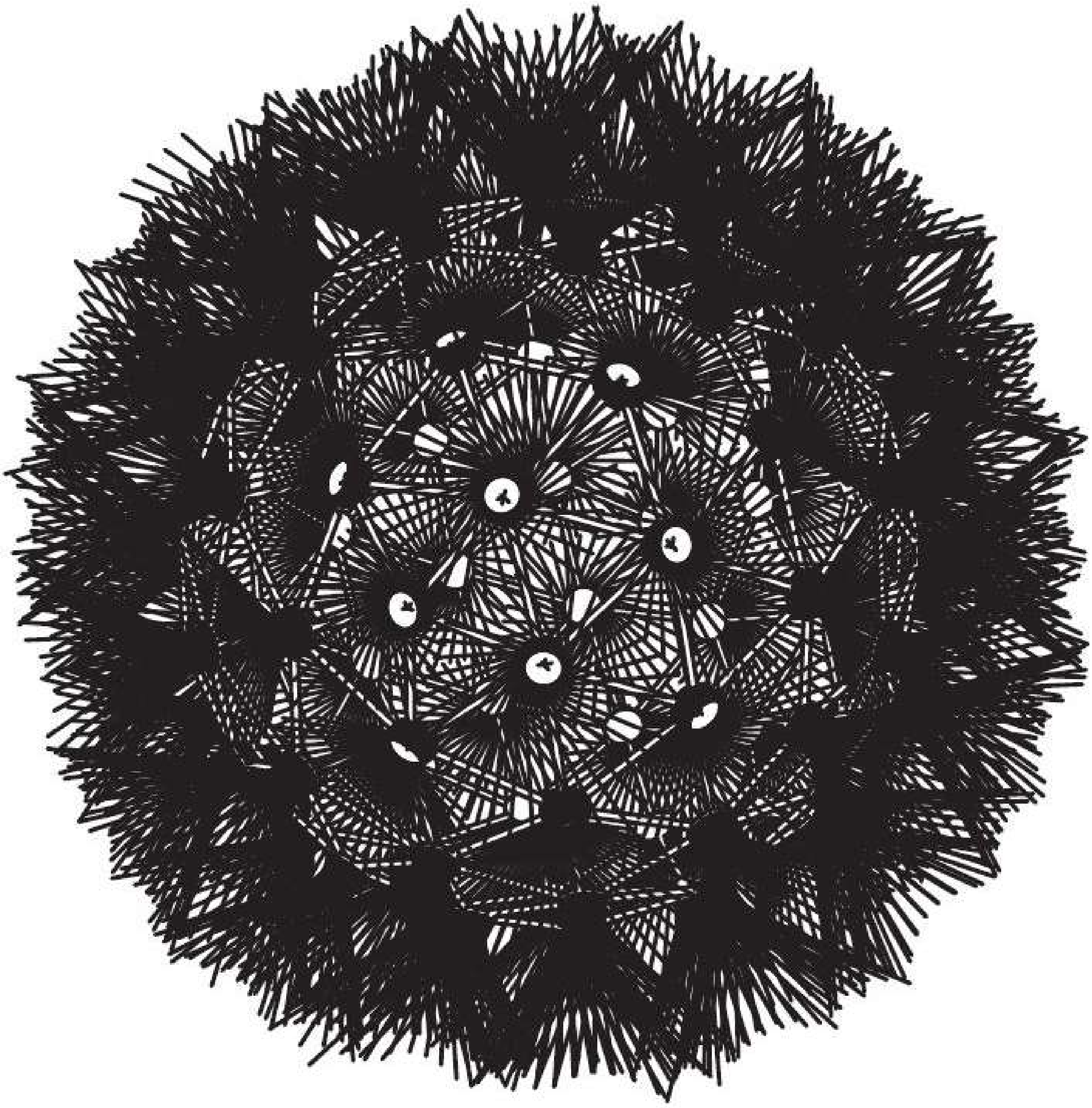



*[Img. 49]*



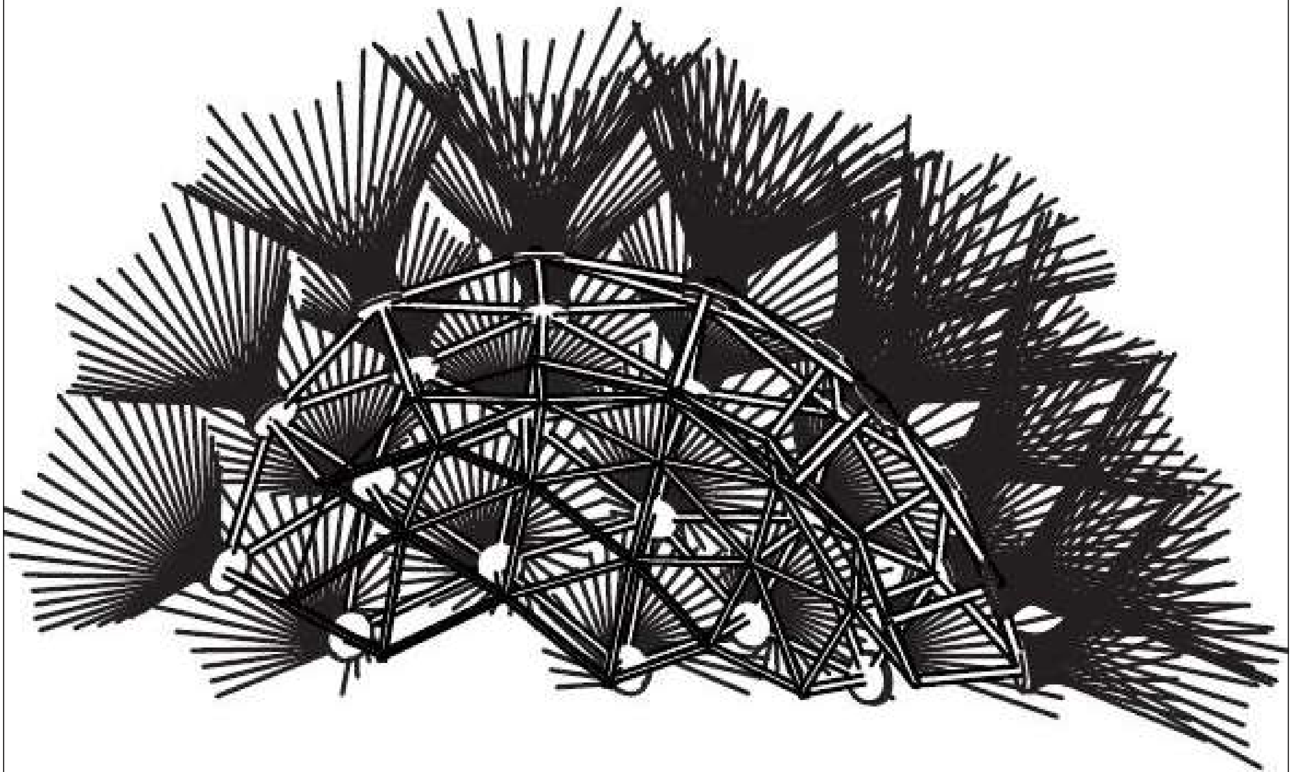

[Img. 50]


Rods
Inflatable Cushions



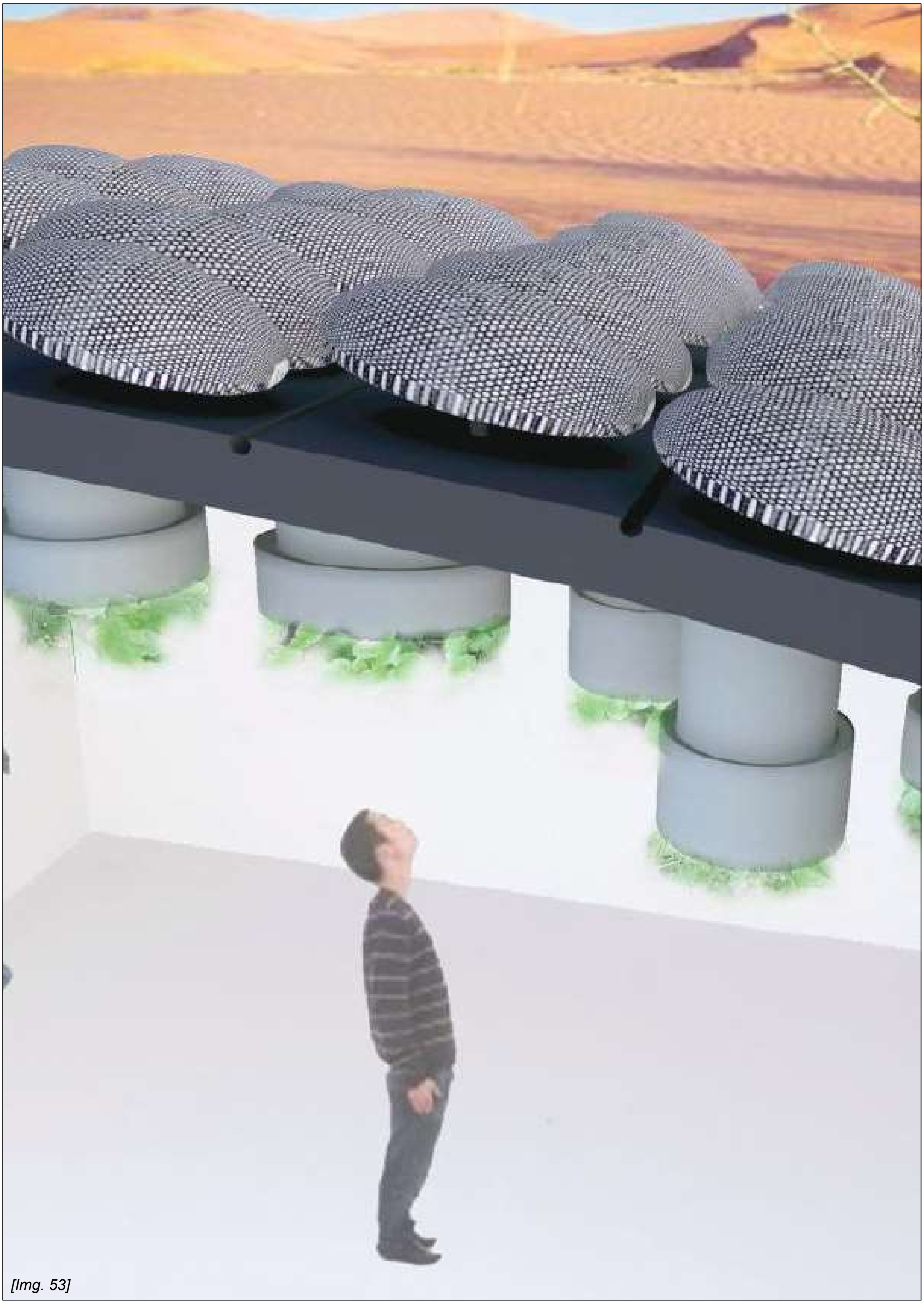


[Img. 51]





[Img. 52]



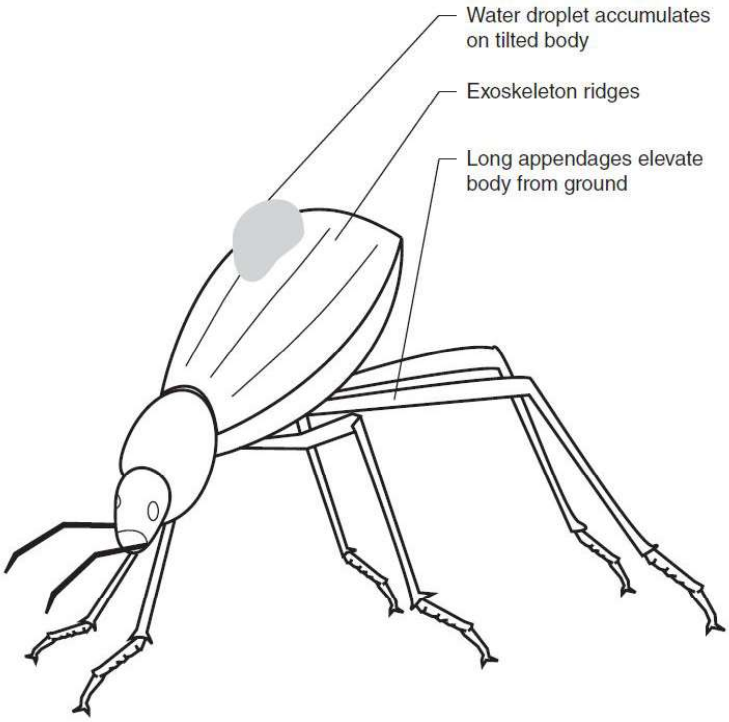
[Img. 53]

# BEETLE
## CLAIMS TO BE BUILT, BUT NO EVIDENCE OF A REAL-LIFE IMPLEMENTATION

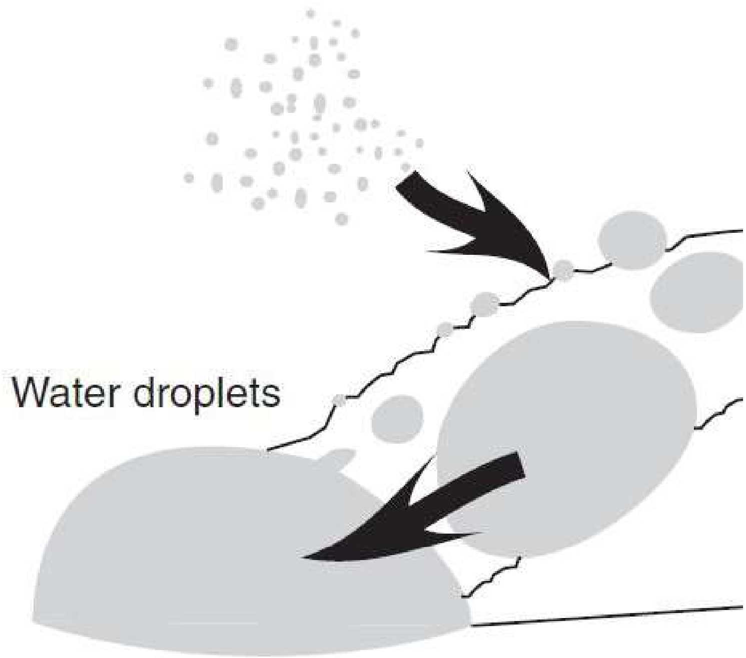
The beetles are at home in the Namib desert. They are used to a very hot and dry environment. Due to their special way of obtaining water, survival in the desert is possible for them at all. The beetles are able to store the dew from the fog on their body. They get their water from fog. Through a certain technique and movement the condensation water then reaches their mouth.
(cf. Mazzoleni; Price, 2013)

The architectural implementation took this idea from the beetle. A building was constructed with the longer sloping side of the roof facing the ocean. From there the morning dew comes. The moisture is absorbed by the outer facade. The condensation water is led into the interior of the building. In this way a new habitat with small plants is created. The curved surfaces slope towards the openings in the ceiling, so that the water flows directly into the interior of the building. However, there will never be enough water to permanently supply many living creatures. There is usually not much abundance in these areas, so multiplying the project would be too expensive.
(cf. Mazzoleni; Price, 2013)

The view of this building is astonishing. Water is channeled into the interior of the building through flexible, mushroom-shaped heads, without which it can immediately evaporate again. It is almost identical to the characteristic of the beetle. A surface was chosen which can bind the dew just as quickly. The project comes very close to the idea of biomimicry.

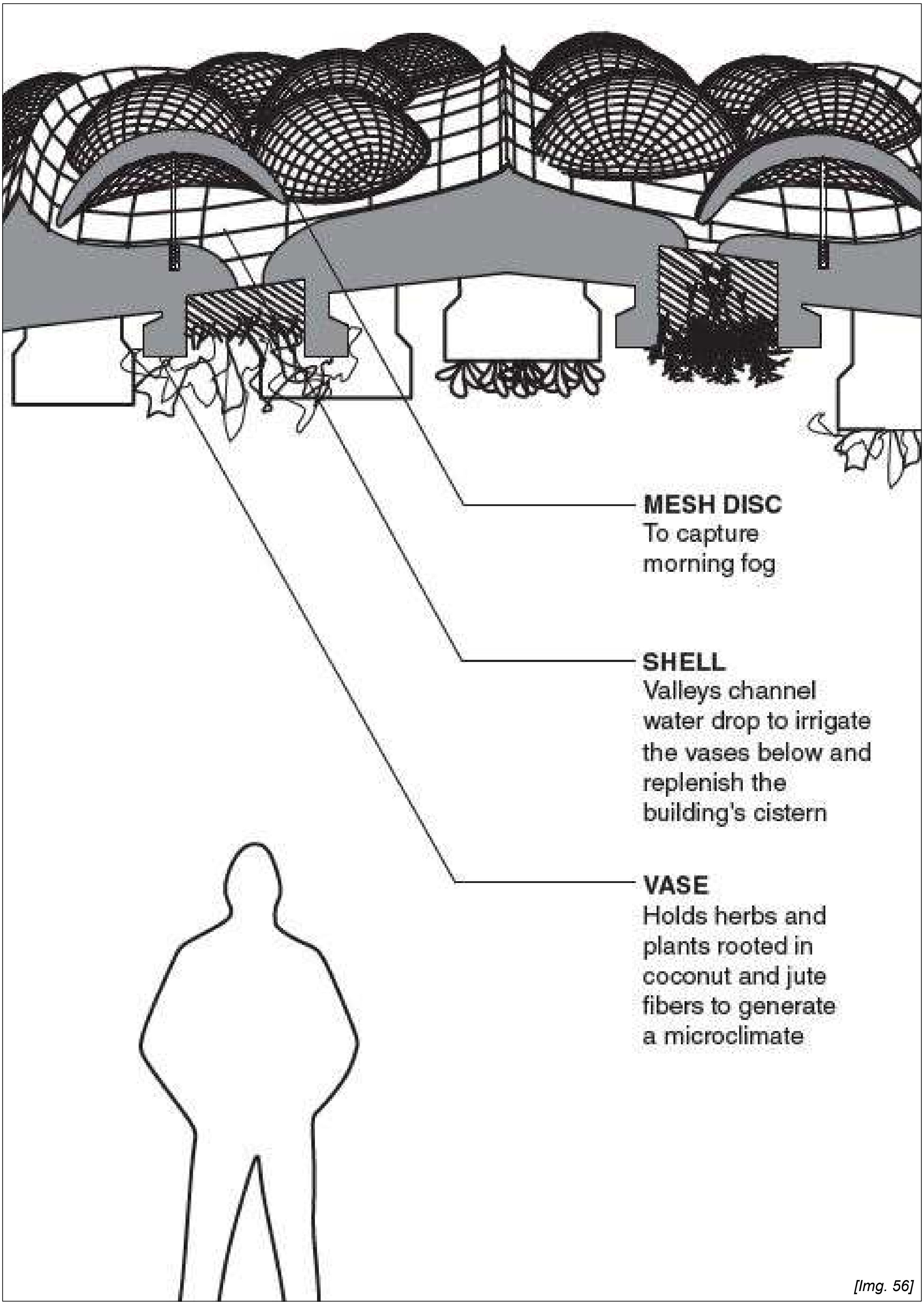

Water droplet accumulates
on tilted body
Exoskeleton ridges
Long appendages elevate
body from ground

*[Img. 54]*


Water droplets



*[Img. 55]*


MESH DISC
To capture morning fog
SHELL
Valleys channel water drop to irrigate the vases below and replenish the building's cistern
VASE
Holds herbs and plants rooted in coconut and jute fibers to generate a microclimate
[Img. 56]



[Img. 57]


[Img. 58] Poster for the exhibition "Insects: Models for Design" at 21_21 DESIGN SIGHT TOKYO 2019

# SMALL DETOUR -

## SEEING MORE

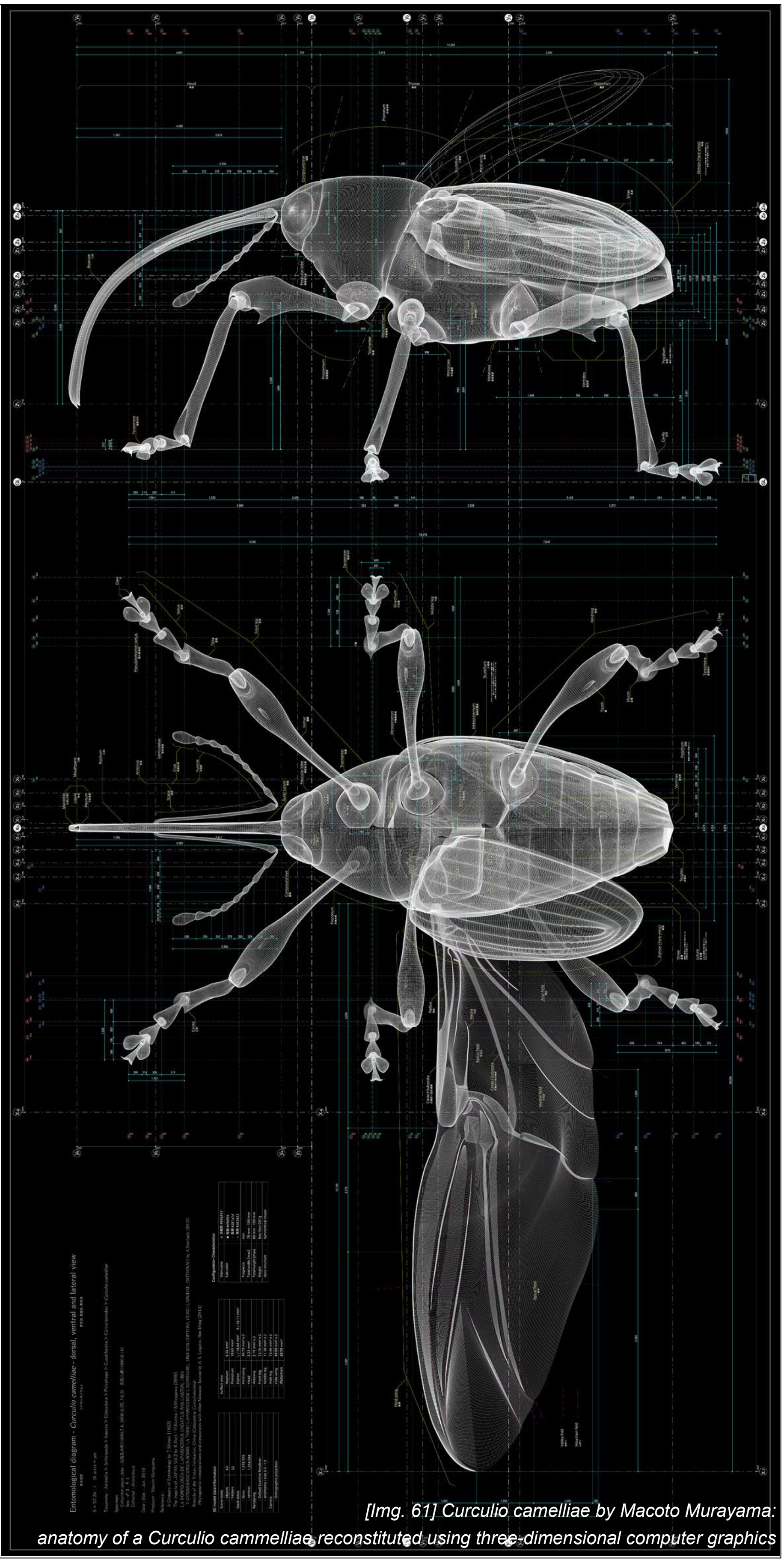
Although humankind is yet to know everything about all the various organisms living on this planet with it, it has made quite huge developments over its existence and especially in the recent decades or centuries. To get a picture of how much is known and can be illustrated through technology as of now, 21_21 Design Sight offered a very rich exhibition capturing insects in various, novel ways in 2019: „INSECTS: MODELS FOR DESIGN“

*“Insects are reflections of the natural world. Although they are always close to us, many facets of their lives remain unknown. Their richness of color, physiological qualities, structures and habits all offer us unseen worlds barely imagined. Insects have evolved over much longer period than humans, and by observing their diversity we will discover new creative possibilities. This exhibition seeks to view the mysterious world of insects as ‚models for design.‘ Designers, architects, structural engineers and artists exhibit work inspired by insects. Some have used their tiny skeletal systems to produce artificial objects, others have studied the skillful way they fold their wings and applied this to robots, others again have learned from the structure of larva nest how to generate human architecture. Astonishing ingenuity is found in every aspects of insects, from mouths and eyes to legs. We also found the interesting rules that lie behind the way we named insects through the relationships with them. The exhibition offers creators and visitors an opportunity to learn from insects and to reconsider their relationships with us.**
(http://www.2121designsight.jp/en/program/insects/index.html, 07.12.2019)

The following pages are therefore a display of how deep and how small humankind is able to see now.

*[Img. 59] Caddisfly Nest by Kenji Kohiyama:*

*[Img. 60] Weevil Legs by Taku Satoh:*
*the middle leg of a weevil at 700-times magnification*



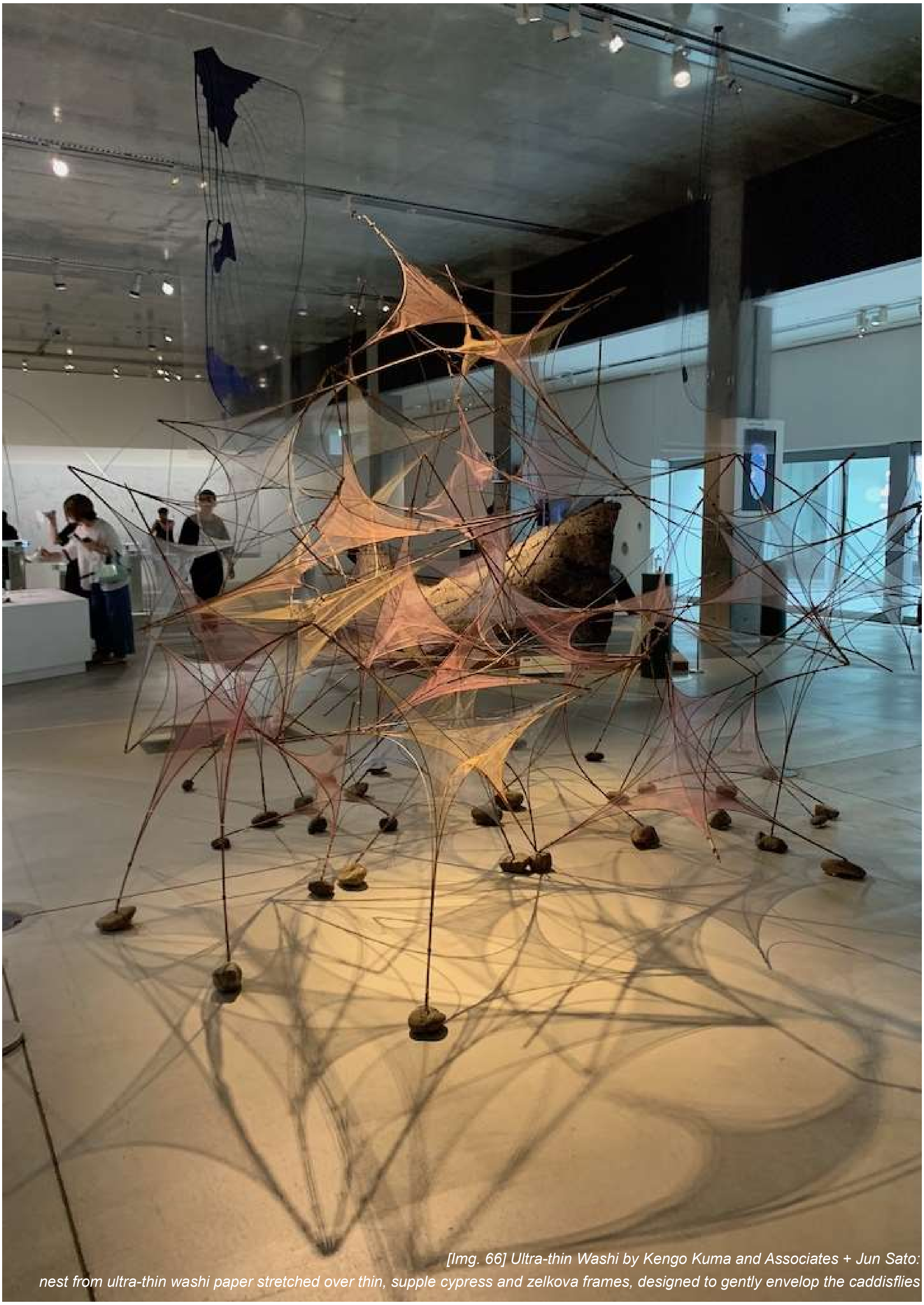
[Img. 61] Curculio camelliae by Macoto Murayama:
anatomy of a Curculio cammelliae reconstituted using three-dimensional computer graphics

*[Img. 62] Amenbo Dome by Yoshiizumi Satoshi:*
*the dome floats on water in the manner of an amenbo water boatman (water-dwelling insect)*

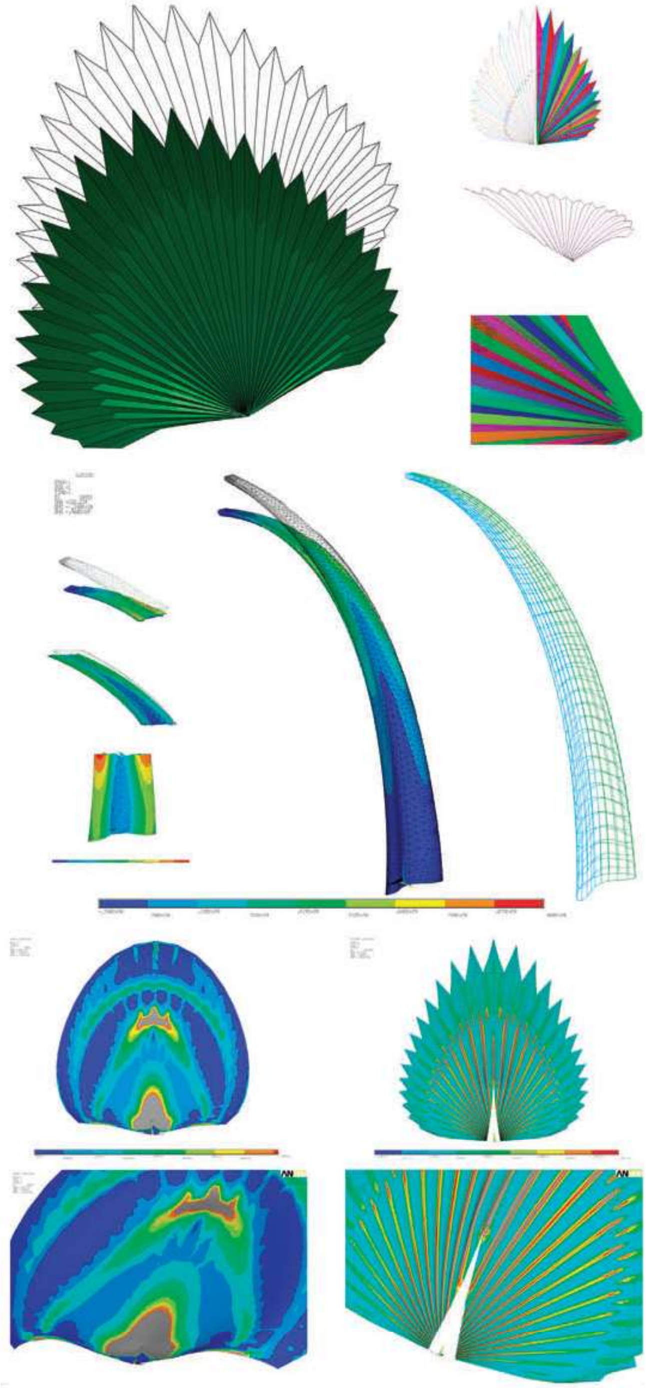
*[Img. 63] Specimen Case of Tools Keita Suzuki:*
*“Ladybird Sneakers“ inspired by ladybird’s feet, which are covered with hairs that they use to cling on to and catch objects*

[Img. 64] Beetle Anatomy

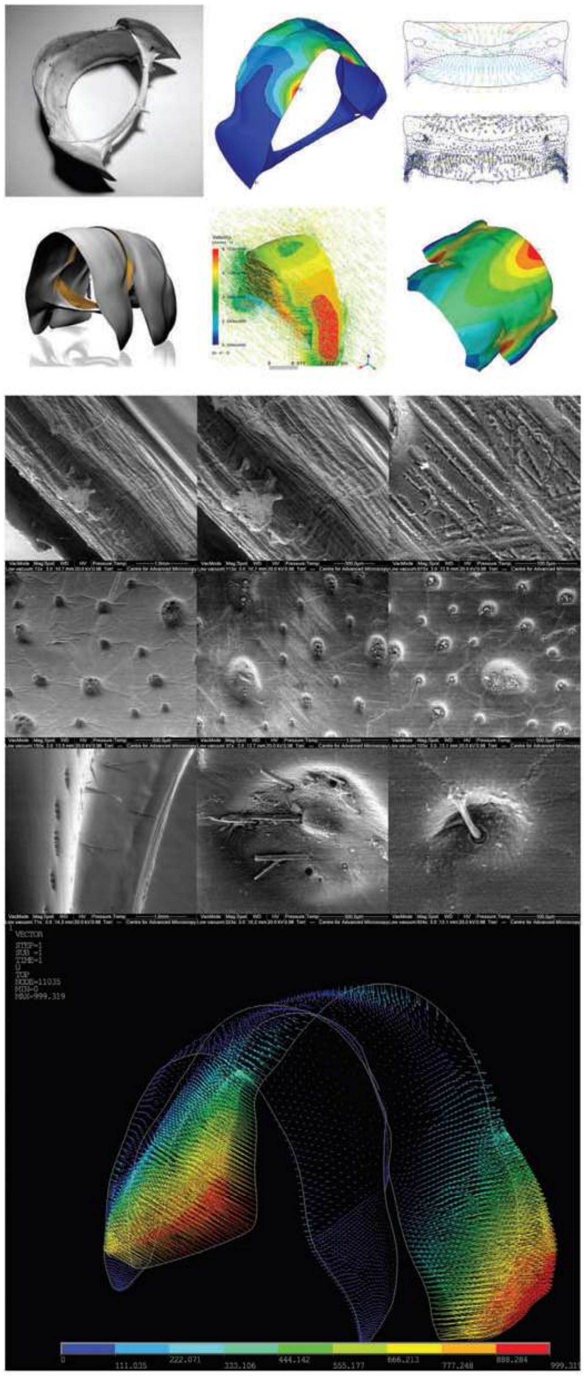
*[Img. 65] Hair Nest by Kengo Kuma and Assiociates + Alan Burden:*
*creating a new material for the nest by combining two items of everyday organic waste - human hair and nut shells*



[Img. 66] Ultra-thin Washi by Kengo Kuma and Associates + Jun Sato:
nest from ultra-thin washi paper stretched over thin, supple cypress and zelkova frames, designed to gently envelop the caddisflies



[Img. 67]


VECTOR
STEP=1
SUB =1
TIME=1
TOP
NODE=11035
MIN=0
MAX=999.319
0
111.035
222.071
333.106
444.142
555.177
666.213
777.248
888.284
999.31

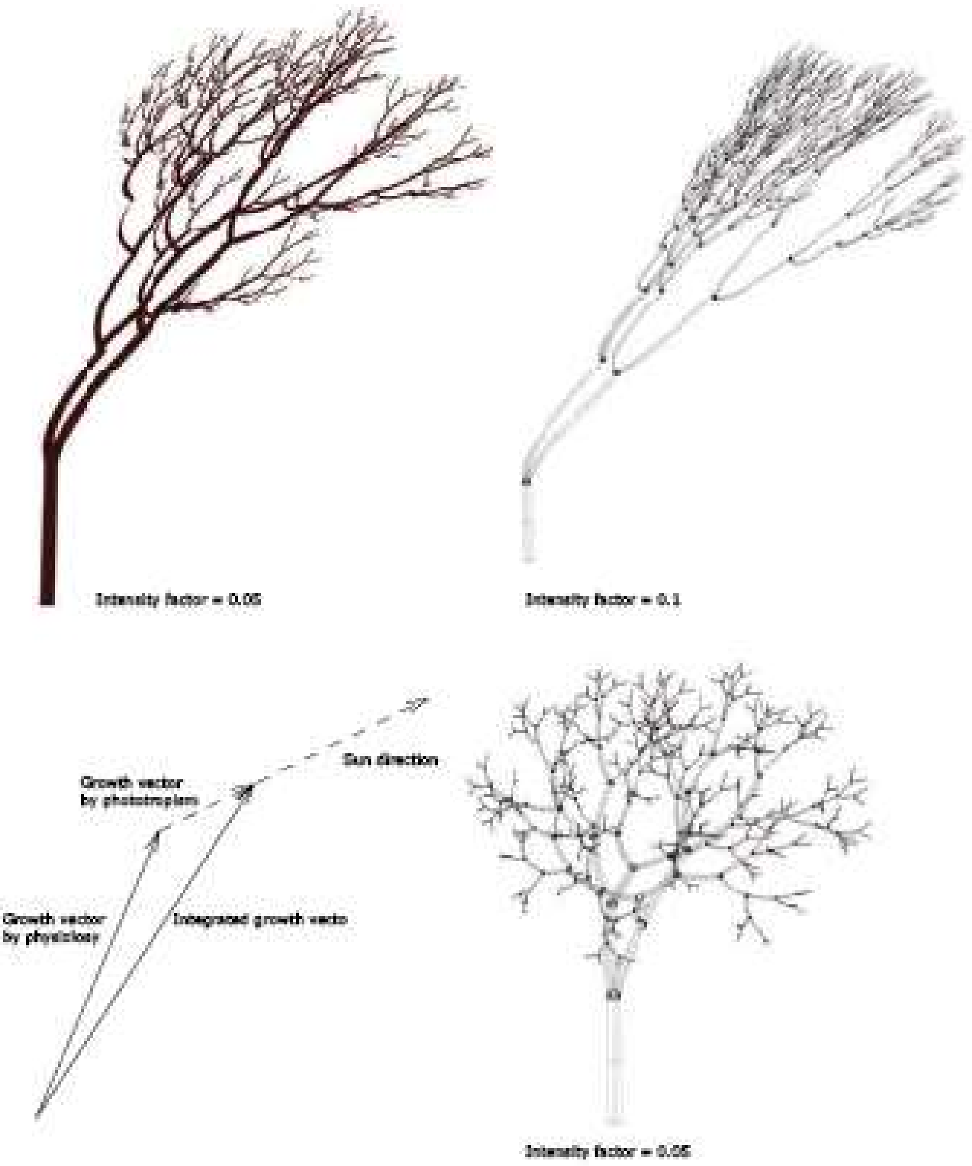
[Img. 68]

# EMERGENT TECHNOLOGIES

Different technologies open up a lot new possibilities in the context of taking inspiration from nature. To see the concept of those various new technologies this chapter focuses on the algorithmic use of nature and natural principles and some other new technol.

[Img. 67] "Natural systems analysis: palm tree. For the investigation of the palm tree's exceptional capacity to respond to very high dynamic loading, the morphology of both the leaf (top) and the stem were accurately modelled. The analysis of the bending stresses occurring at different section of the palm stem (centre) shows different local bending stresses, indicating the global relationship of bending and torsional stiffness resulting from the locally differentiated cross section. The structural performance of the leaf was investigated by means of comparing the stress patterns developing over the leaf (bottom right) due to wind pressure with the stresses that would occur in a leaf with no folds (bottom left) under the same loading conditions. EmTech Natural Systems Module, Zoe Saric, Biraj Ruvala, Michel da Costa Goncalves and Jennifer Boheim, 2005.“
(Hensel, Menges, Weinstock, 2010)

[Img. 68] "Natural systems analysis: lobster shell. An abdominal shell of a lobster was digitally modelled in order to analyse its capacity to bear different directional loads. Finite element analysis served to deduce loads and loading directions to be subsequently compared with the intrinsic directional material make-up of the shell segment (top). The electron microscopic imaging undertaken at the Centre for Biomimetic Engineering at the University of Reading shows that there are two different types of fibre organisations. Fibres and pore channels are oriented to best cope with the constant mechanical stresses and strains acting on them (centre). The findings of the research enabled the building of a precise analytical model of the upper part of the shell (bottom). EmTech Natural Systems Module, Maria Bessa, Christina Doumpioti, Karola Dierichs and Defne Sungurog˘lu, 2006.“
(Hensel, Menges, Weinstock, 2010)


Intensity factor = 0.05
Intensity factor = 0.1
Sun direction
Growth vector
by phototropism
Growth vector
by physiology
Integrated growth vecto
Intensity factor = 0.05

[Img. 69]

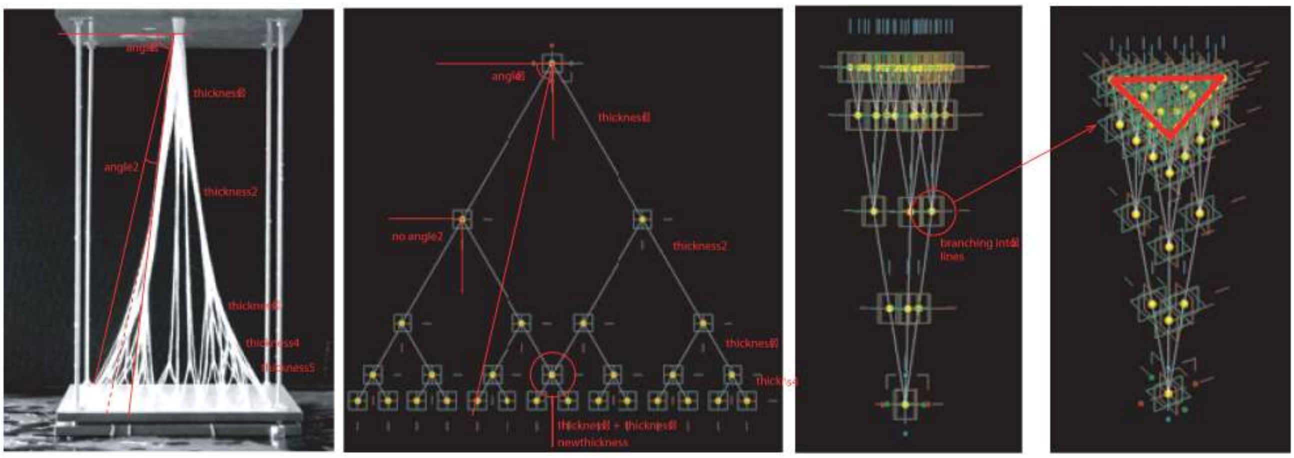
# BRANCHING ALGORITHM

## PAVEL HLADIK | 2010 | DIGITAL MODEL

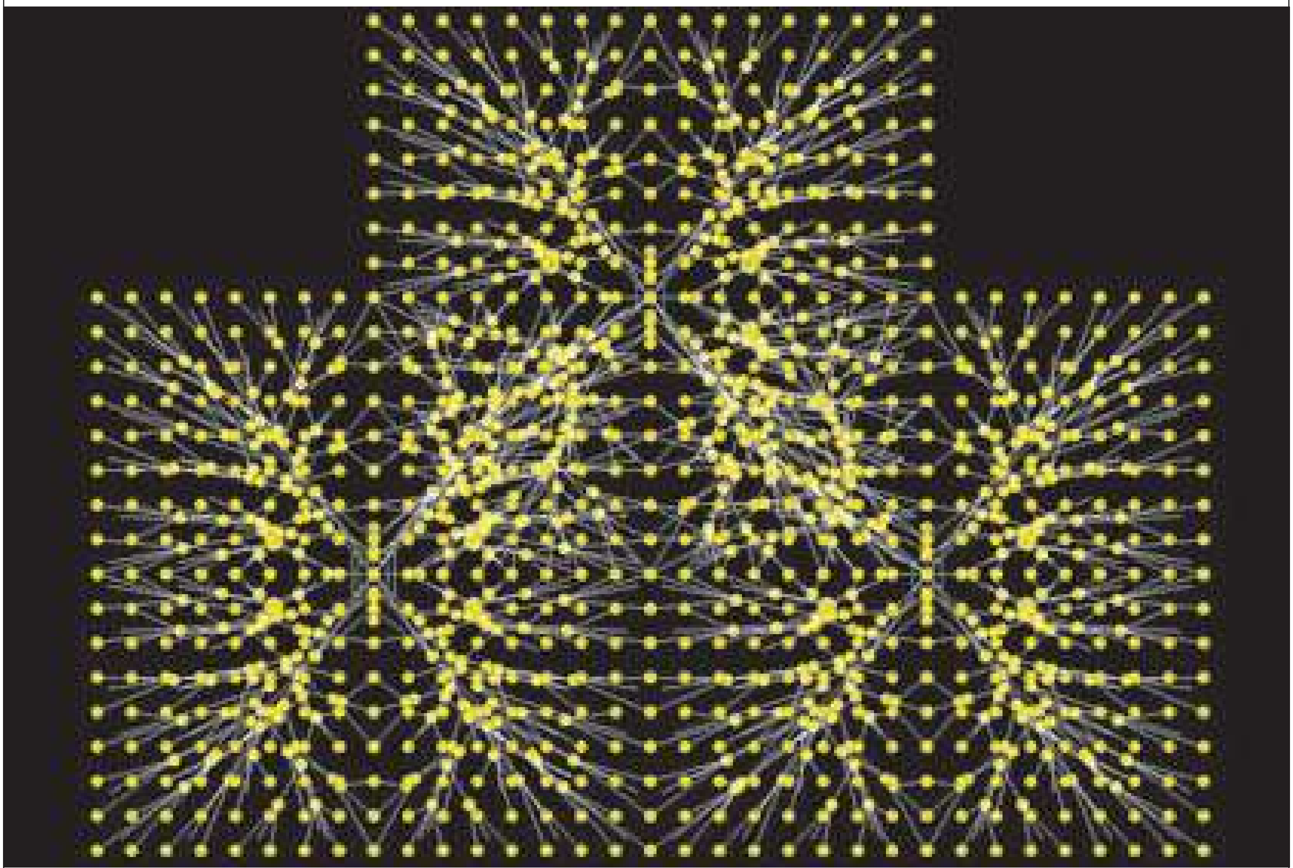
“For branching patterns in particular, attempts to provide mathematical descriptions of shape and form unfold along rather different lines than we are used to in classical geometry. Such models are in fact more properly regarded as prescriptions rather than descriptions – they do not provide geometrical labels of shape like ‘circle’ or ‘octahedron’, but instead sets of rules, called algorithms, for generating characteristic but non-unique forms.”
(Ball, 1999, cited in Hensel, Menges, Weinstock, 2010, p. 156)

Plant tropism, which is the natural force that makes organisms/parts of organisms turn or grow into a particular direction responding to external stimuli – like light (phototropism), sunlight (heliotropism) or the response to gravity (gravitropism) –, can already be mathematically described by algorithms. The picture on the left shows research in digital modelling to illustrate this growth in order to understand it better and be able to apply it to architectural solutions.
(cf. Hensel, Menges, Weinstock, 2010)

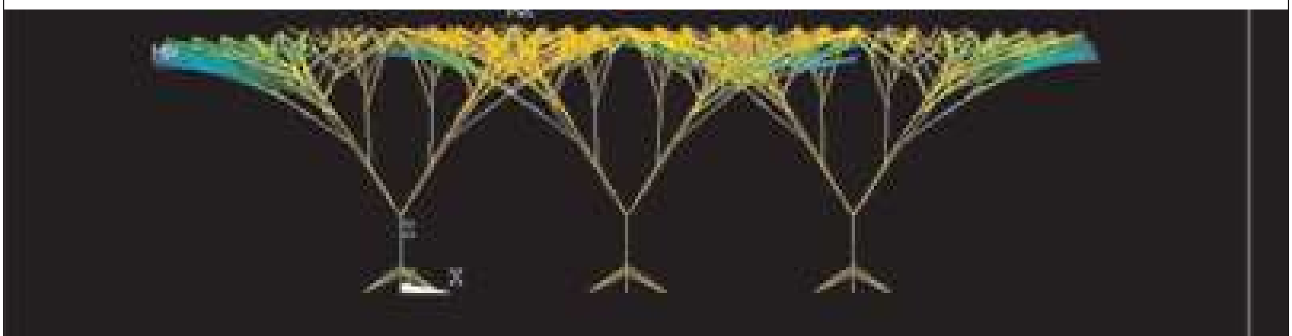
Pavel Hladik embedded geometric rules derived from Frei Otto’s form-finding method for branching systems into his digital model in order to implement this natural way of branching into an algorithm. He also verified his developed branching systems through an analysis of stress patterns associated with self-weight.
(cf. Hensel, Menges, Weinstock, 2010)



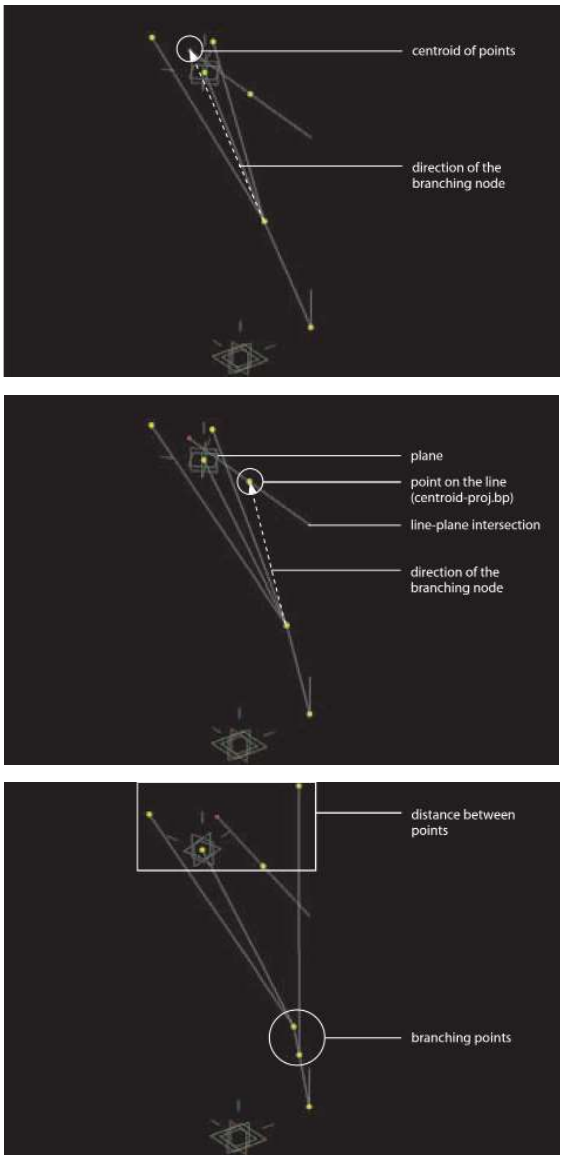

[Img. 70]



[Img. 71]



[Img. 72]


centroid of points
direction of the branching node
plane
point on the line (centroid-proj.bp)
line-plane intersection
direction of the branching node
distance between points
branching points



[Img. 73]

*[Img. 74]*

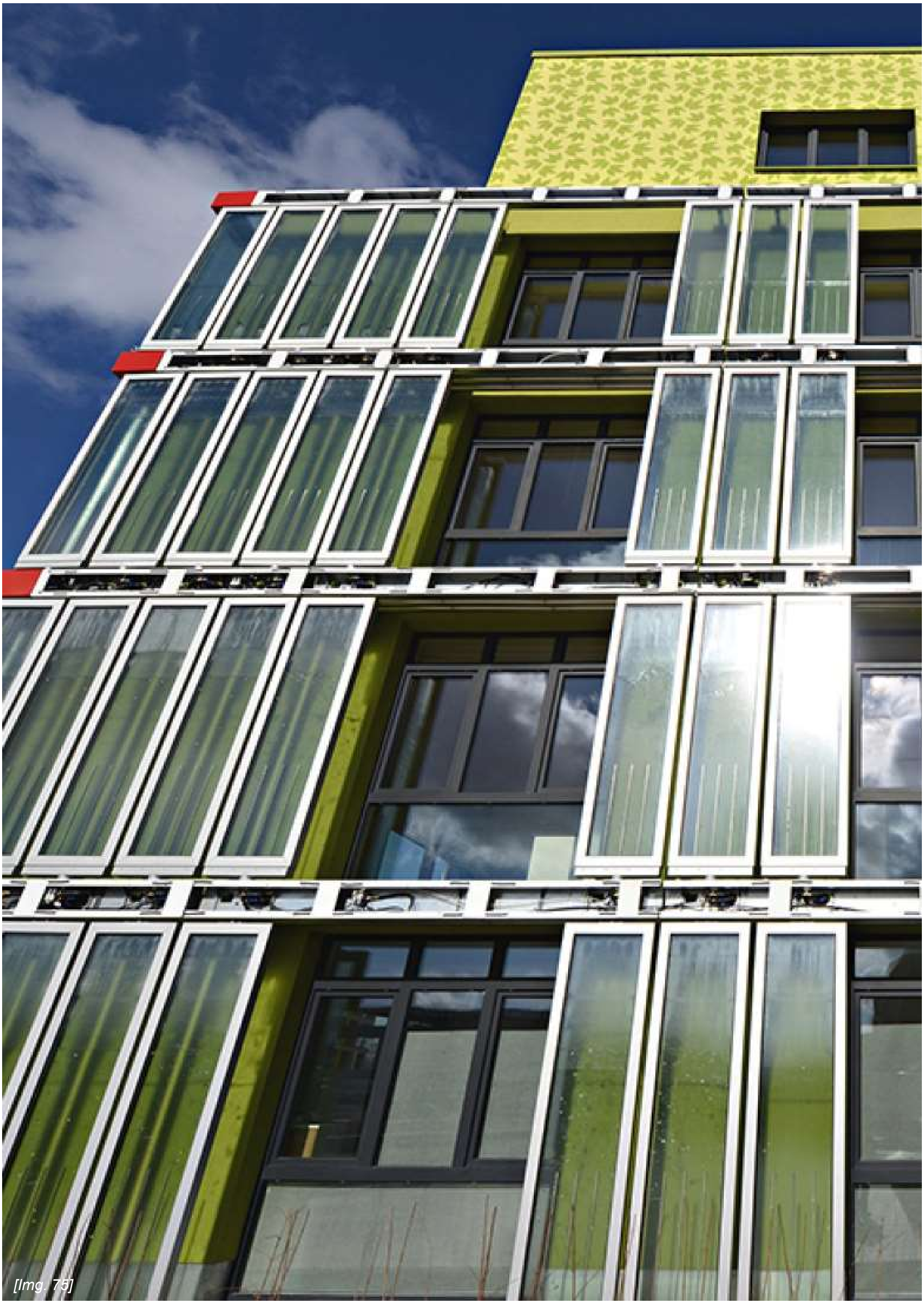
## COMPOSITE PROTOTYPE | INSTALLATION

KOKKUGIA | 2013 | BUILT PROTOTYPE

„Kokkugia is an experimental architecture research collaborative exploring generative design methodologies developed from the complex self-organizing behavior of biological, social and material systems. Kokkugia is led by Roland Snooks and Robert Stuart-Smith, with labs in Melbourne and London, operating through design experimentation, research and teaching.“ (https://www.kokkugia.com/Composite-Swarm, 24.01.2020)

Roland Snooks is the design director of this project. This prototype is about the relationship between robot manufacturing, composite material and algorithmic design. Both, form and design play a major role. The 2.5 meters high and approximately 1 millimeter thick model was inspired by nature. The social behavior of ants was observed and stored in a program, so that the robot now imitates the self-defined paths (swarm algorithms) with a black 3D print on the curved surface. The whole model aims for the cooperation of structure, surface and ornament.

Each material on its own would not be stable enough to support such a large model. The combination of the two elements, the overlapping wave pattern of the ants and the double curved surface, stiffens the material to such an extent that it even seems possible to use it on a large scale in architecture. The project works with swarm intelligence and multi-agent algorithms. These calculate the intersecting ant paths and merge them into a grid. These are then fused into a smooth surface by the fiber composite and an additional layer of epoxy resin to ensure strength.
(cf. https://www.kokkugia.com/Composite-Swarm, 24.01.2020)


[Img. 75]

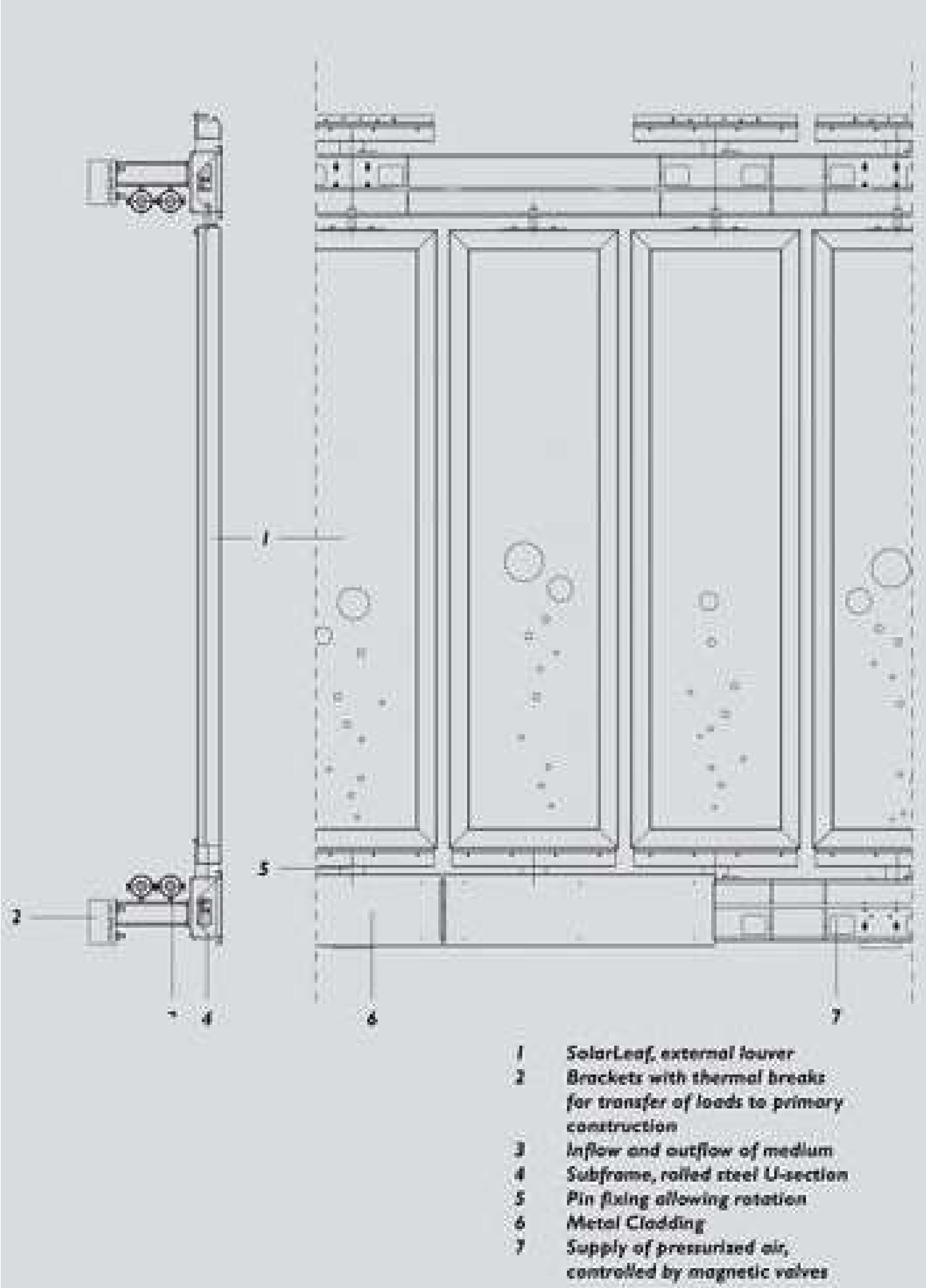
# SOLARLEAF FACADE ON BIQ HOUSE

SPLITTERWERK ARCHITECTS & ARUP | 2013 | BUILT

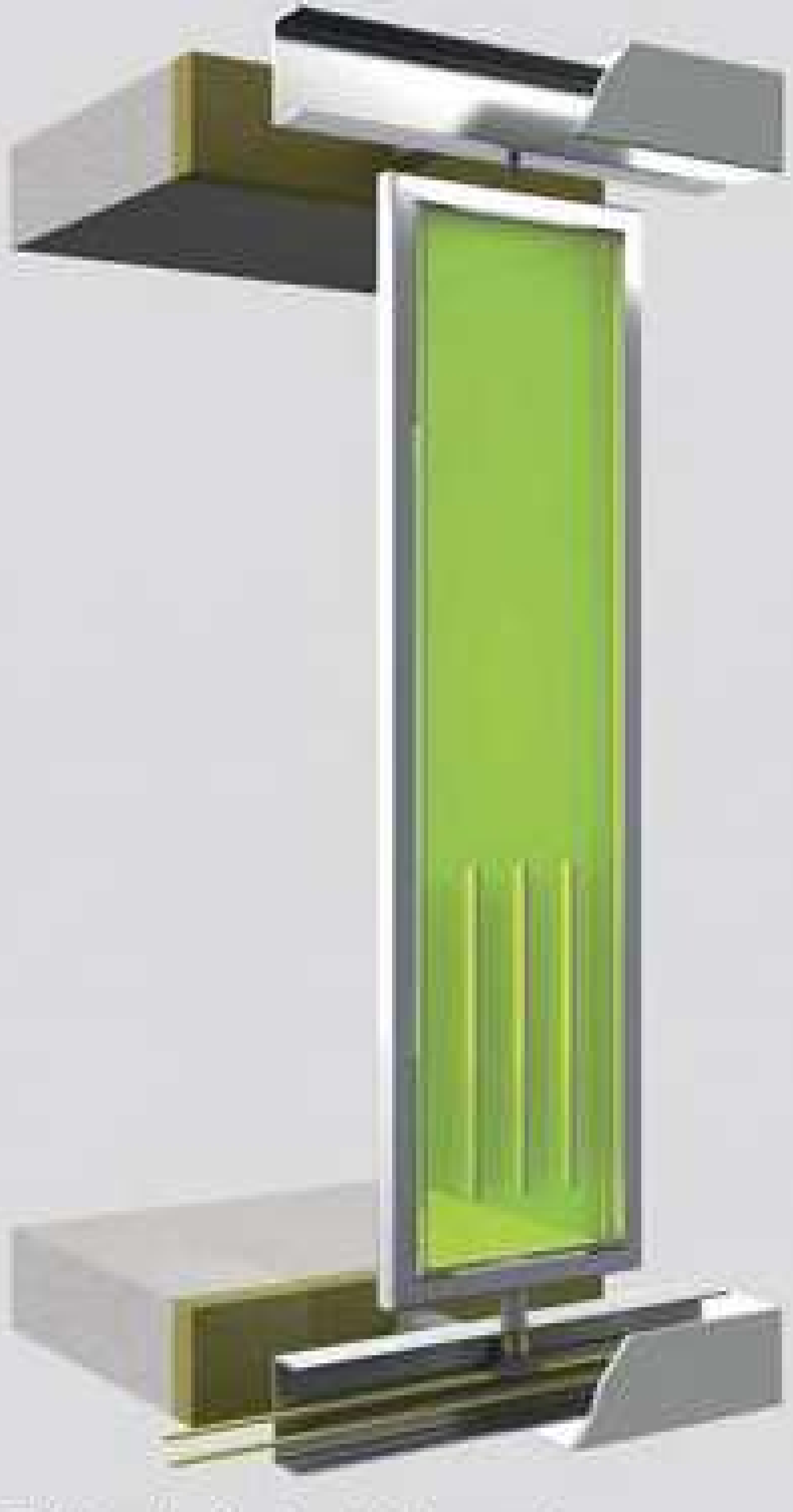
“Composed of microbe-infused glazing panels, the system utilizes living microalgae to harvest solar power while providing shade.”
(Brwonell, Swackhamer, 2015, p. 96)

This facade, which is called SolarLeaf, is a bio-adaptive facade, which captures solar thermal heat and generates biomass for harvest. Additionally, the more light a window would get, the more biomass grows and works as shading.

This example is fascinating in the way that it includes an element that on the one hand is used for the sole satisfaction of human needs (shading), but on the other hand it also produces something passively, that can lessen the environmental impact of the building (biofuel).


1
2
4
5
6
7
1 SolarLeaf, external louver
2 Brackets with thermal breaks for transfer of loads to primary construction
3 Inflow and outflow of medium
4 Subframe, rolled steel U-section
5 Pin fixing allowing rotation
6 Metal Cladding
7 Supply of pressurized air, controlled by magnetic valves

[Img. 76]



*The bioreactive facade – principle construction methodology of the SolarLeaf*

[Img. 77]


[Img. 78]

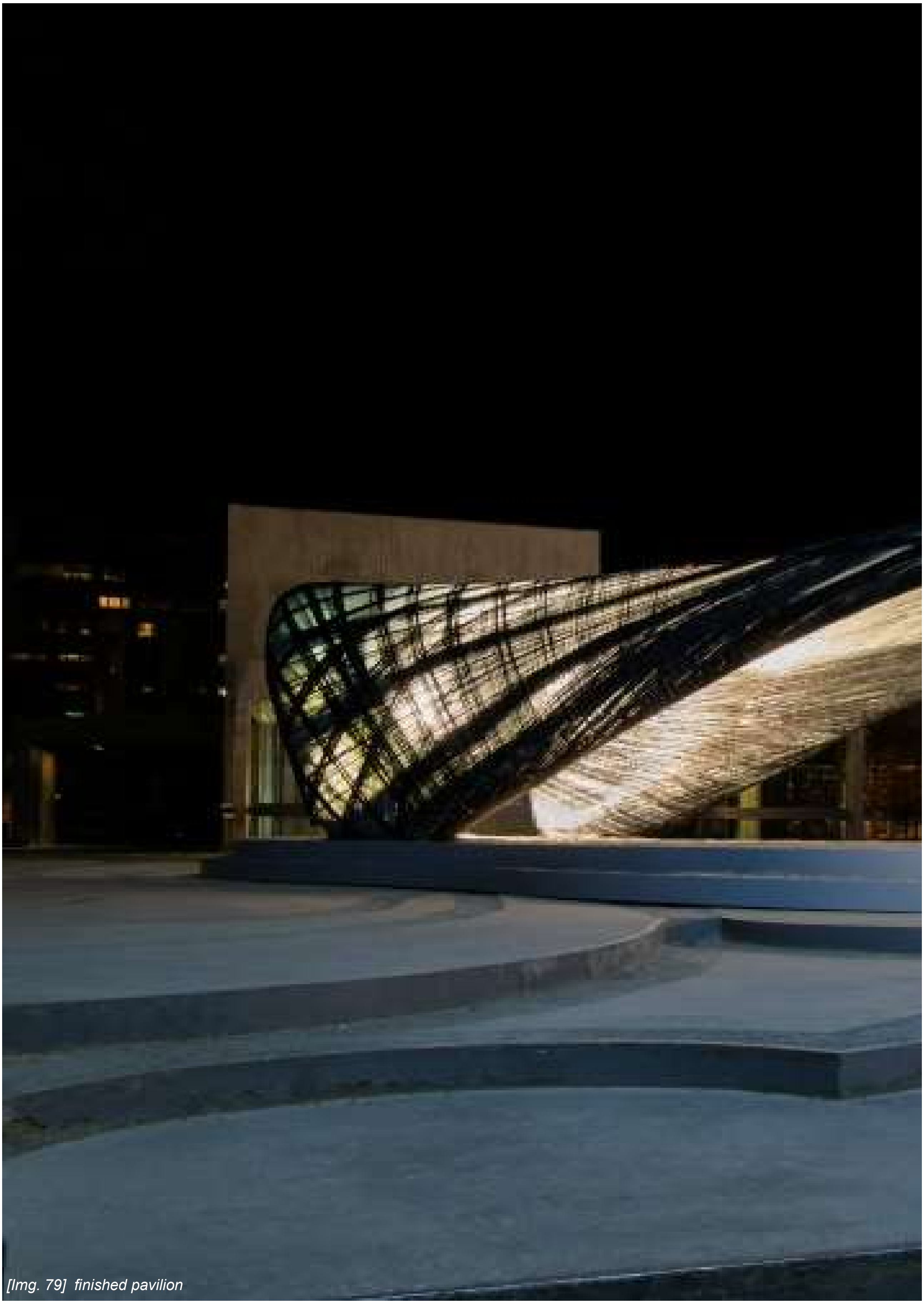
# RESEARCH PAVILLON

ICD & ITKE | 2016/2017 | BUILT

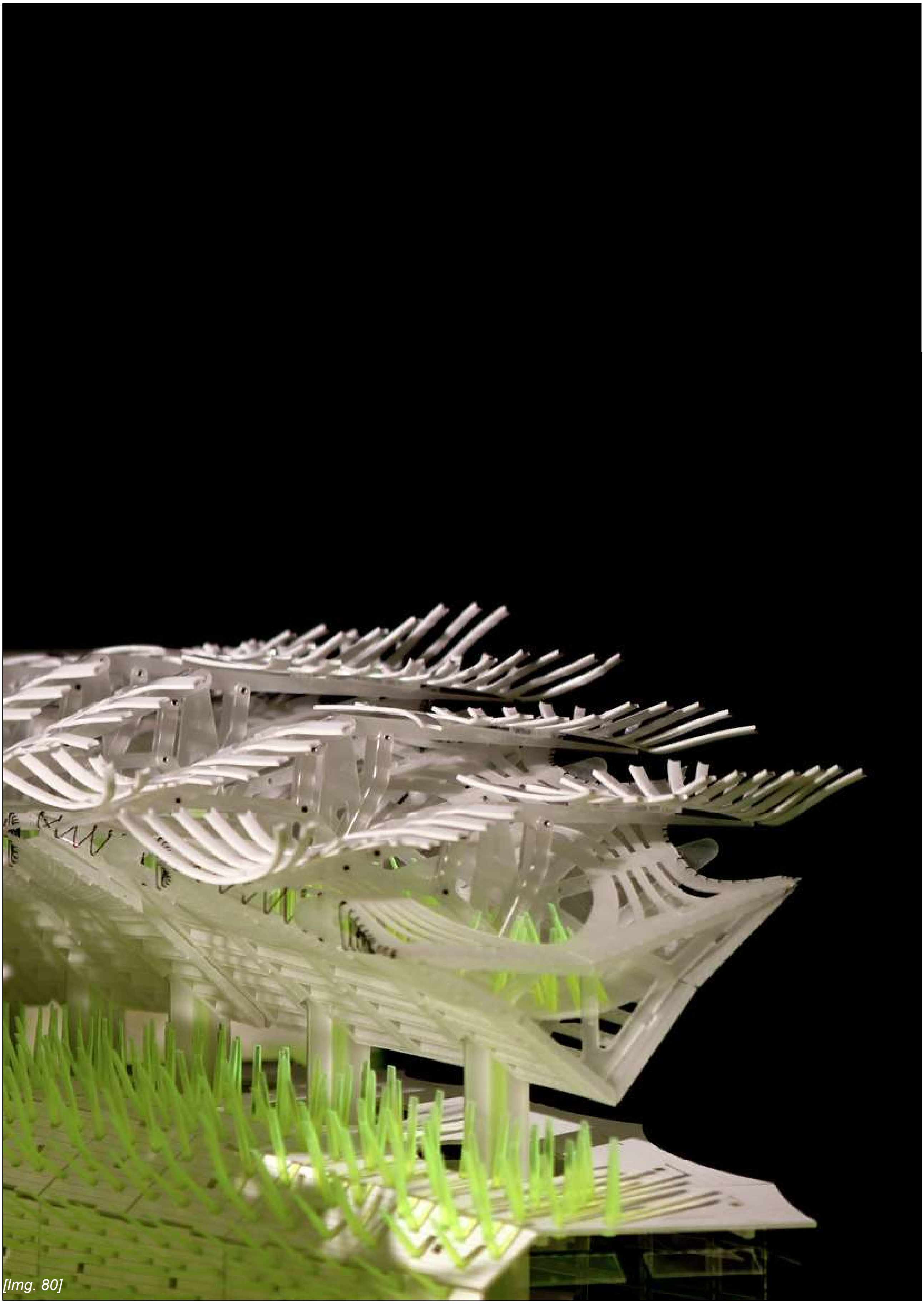
This research pavilion, which was conceived by an interdisciplinary team of students and researchers from the fields of biology, architecture and engineering.

They followed a bottom-up biomimetic design strategy by investigating natural construction processes of long span fiber composite structures while simultaneously investigating the development of novel robotic fabrication methods for fiber reinforced polymer structures.

Although it incorporates the biomimetic approach in a way that an organism is taken as the base for architectural innovation, it fails to consider a lot of important aspects in the context of being part of an ecosystem, such as materiality and ecological footprint.
(cf. https://www.icd.uni-stuttgart.de/projects/icditke-research-pavilion-2016-17/, 27.12.2019)



[Img. 79]  finished pavilion


[Img. 80]

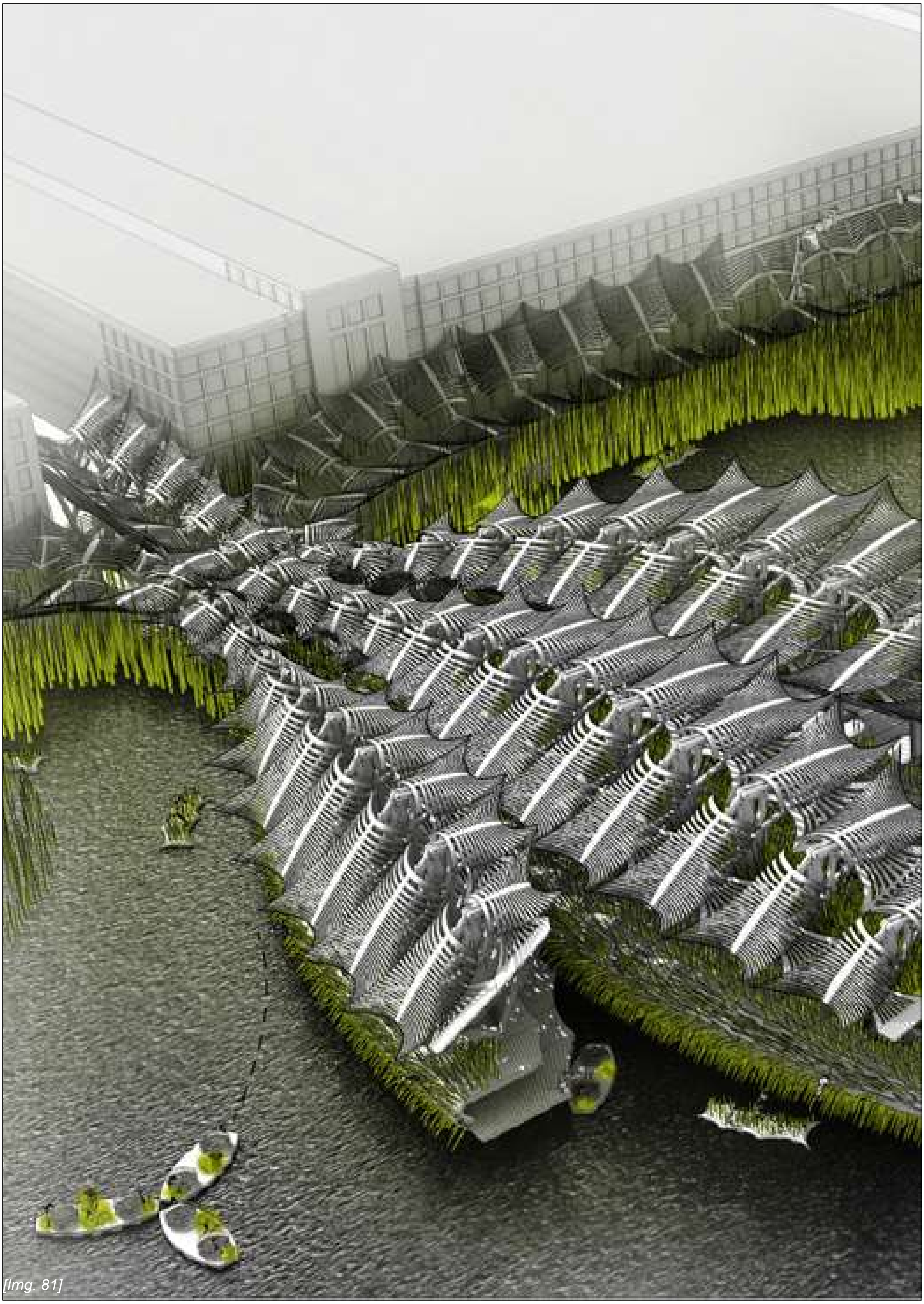
# HYDRAMAX
FUTURE CITIES LAB | 2012 | BUILT IN MODEL

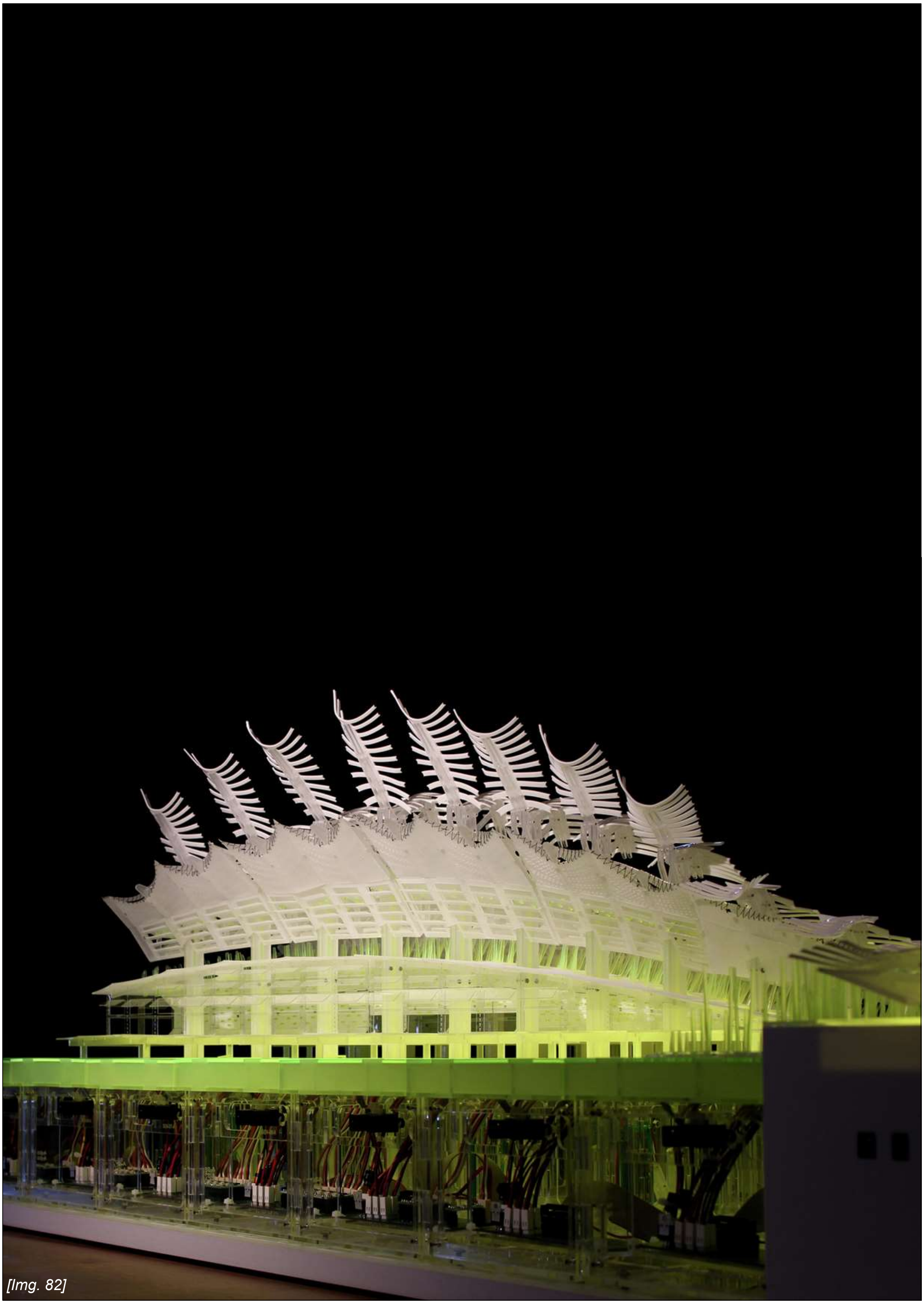
“Plants and animals persistently monitor their environments and adapt automatically to change. Buildings, on the other hand, traditionally remain unvarying from day to day or season to season.”
(Brwonell, Swackhamer, 2015, p. 81)

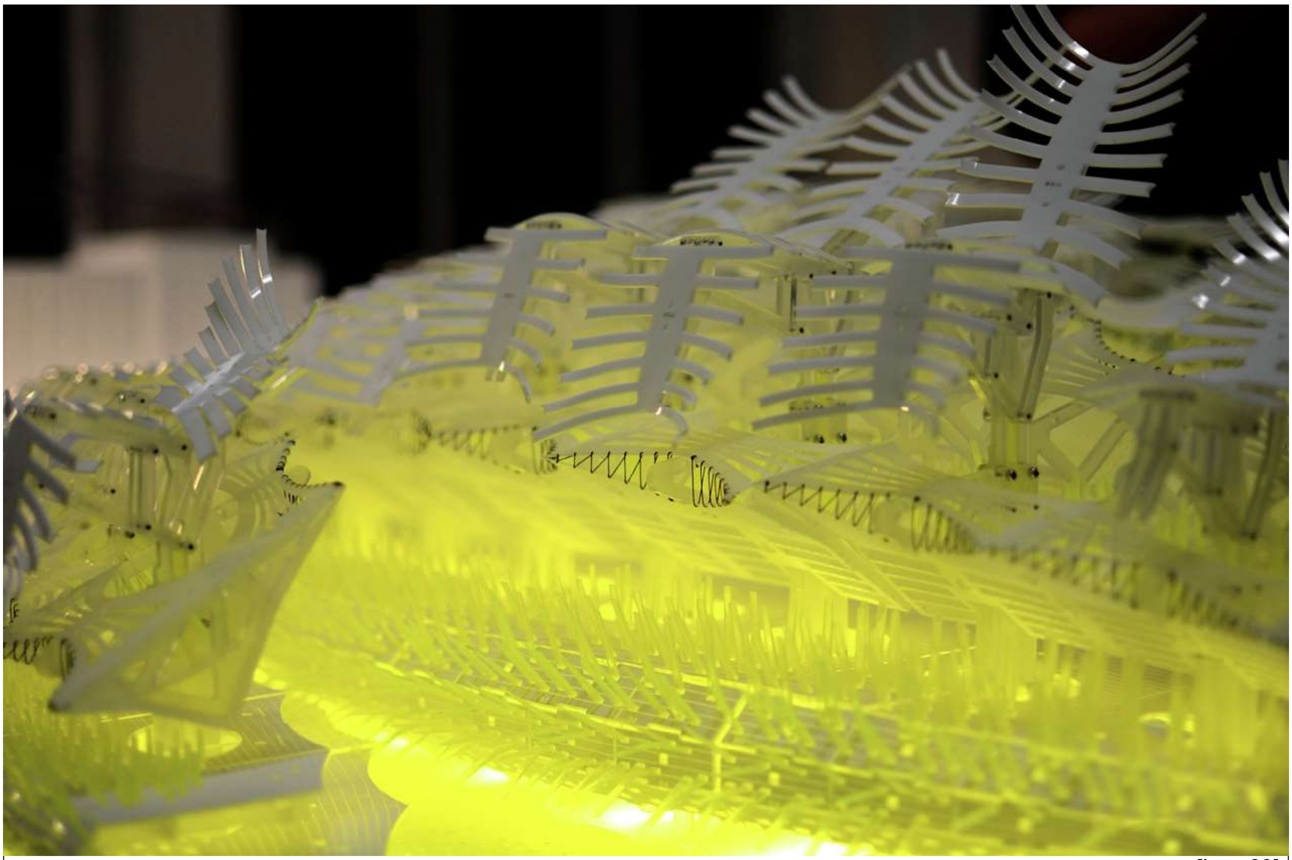
The main features of Hydramax, the fog feathers, work with dynamic building movement and automated responses to collect and harvest bay fog and convert it to water stored in the building’s trusses which in turn can be used for the various operations in this building.

In this case the proposal is articulated in a model, which uses infrared proximity sensors to record the distance of gallery visitors to its edges, simulating the appearance of fog. This information is forwarded to the feather-like fog harvesting robots which control the brightness of the embedded LEDs. Future cities lab calls this model a ‘live mode‘ because it uses the interaction of people with the model to simulate the effects of the planned structure in connection with environmental forces such as fog, wind and sunlight. (cf. http://www.future-cities-lab.net/hydramax, 15.01.2020)

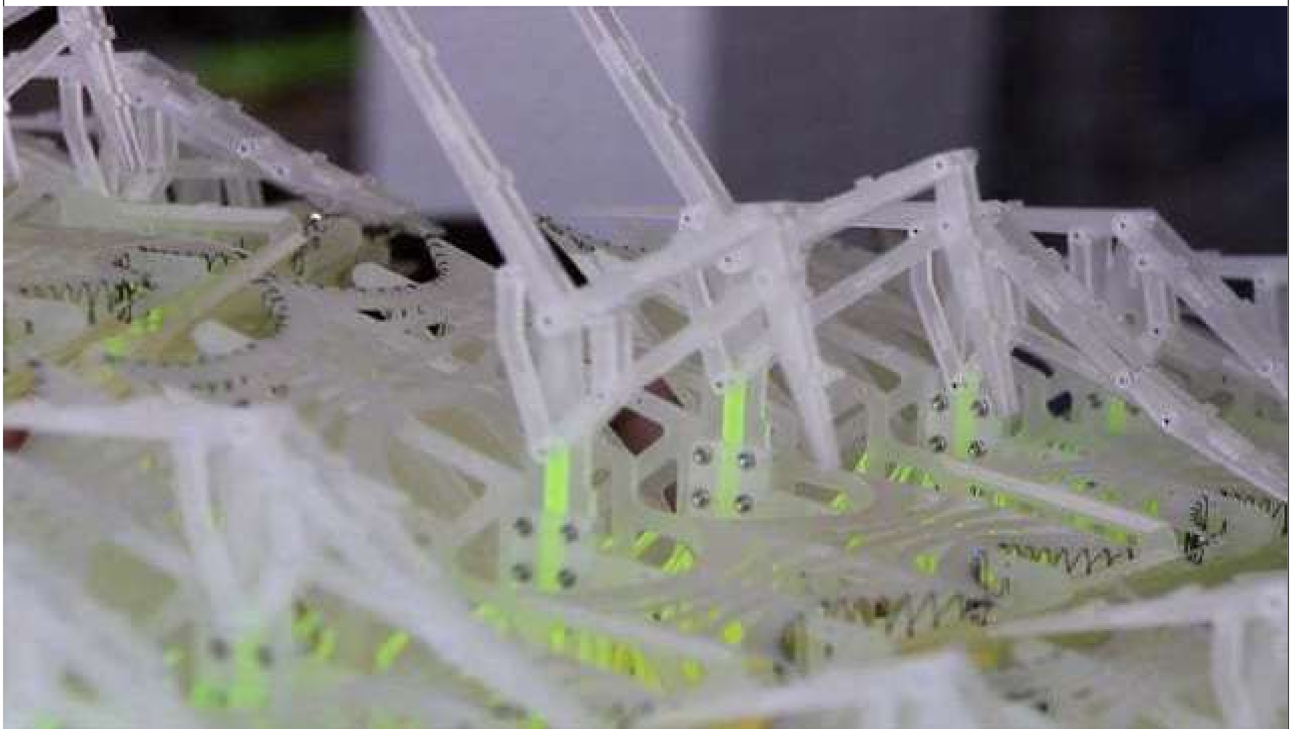
Although in this project the true efficiency and ecological footprint are very hard to imagine, the true value lies in the physical model. Through the model, intricate and very complex processes become very understandable, even for people who have never heard of converting fog into water for usage in the building.


[Img. 81]


[Img. 82]



[Img. 83]





[Img. 84]

*[Img. 85]*

# AN EXPERIMENTAL APPROACH

Ultimately not only new technologies inspire innovation and give input for thinking about future solutions in architecture creatively.

When it comes to imagining the unimaginable, experimental practices are at the forefront. Because with those experimental appraoches, projects can be structured in a far more open way, leaving a lot of different outcomes and outputs a chance to see the light of day, especially when compared to projects that are conceived to be built for a specific purpose. In this experimental fields, Alisa Andrasek and Claudia Pasquero (in conncection with her work with EcoLogic Studio) are very familiar names, because both of them inquire into a very abstract form of architecture, that although being in an experimental stage, yields many very innovative outputs as well as processes in the field of architecture, which could be very significant assets in the question of how architecture will evolve in this time of crisis.

[Img. 86]

# ENDEMIC INTERSTICES

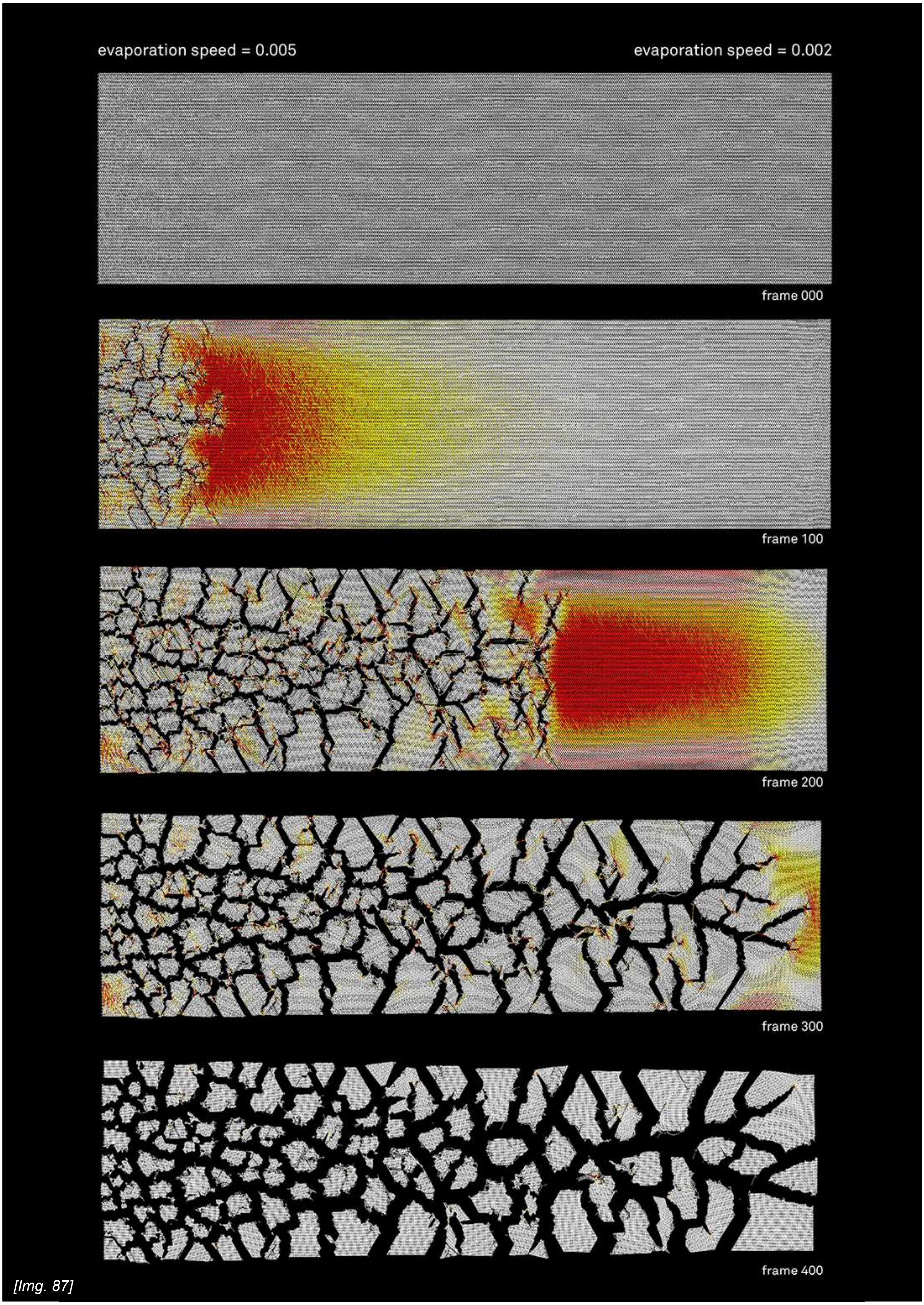
ALISA ANDRASEK & JOSE SANCHEZ | 2012 | NOT BUILT

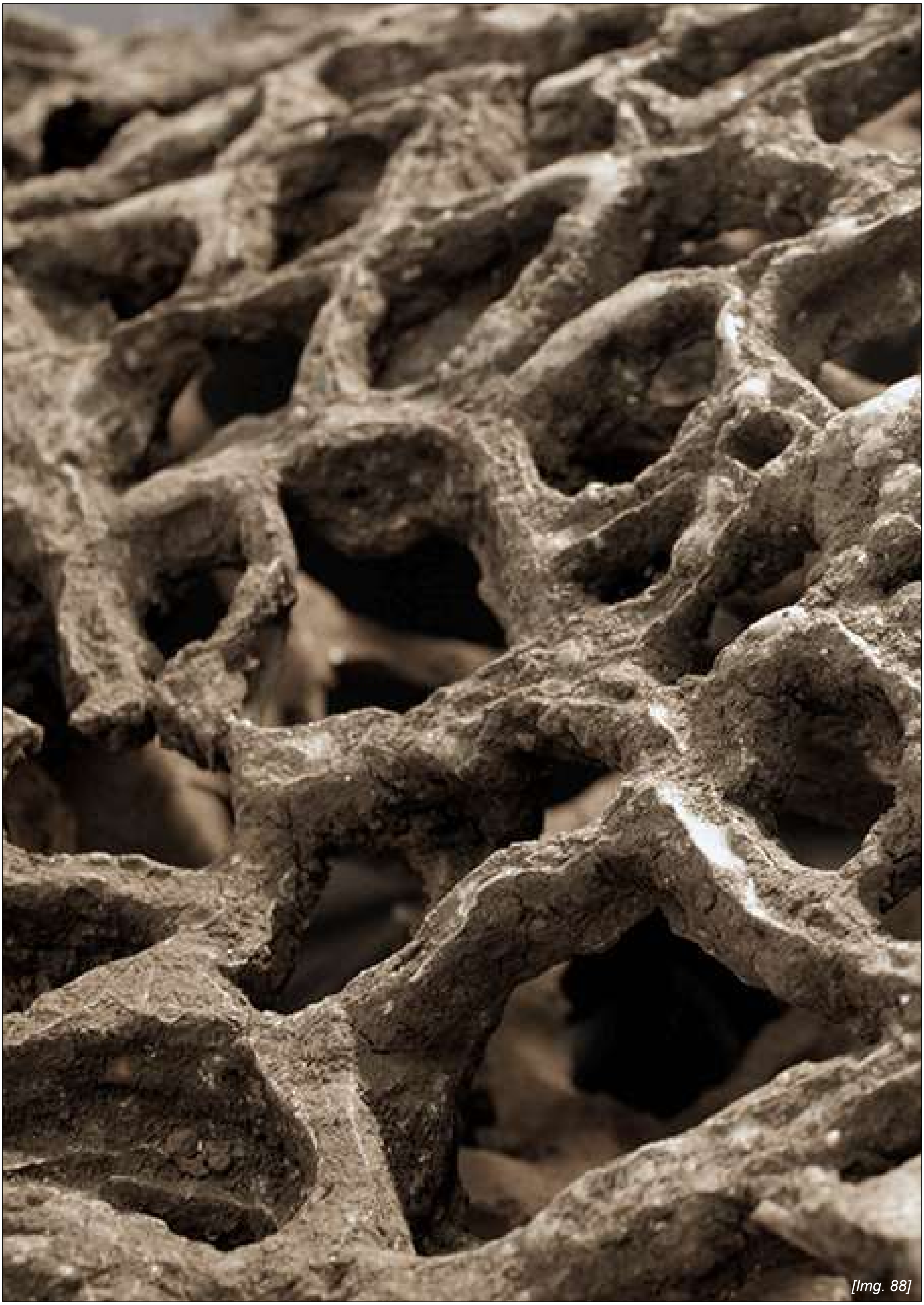
“Endemic Interstices targets the production of proto-architectural entities as a bottom up system with the capacity to self structure, adapt and co-evolve within the environment considering natural resources as part of a tectonic system. The project aims to create synthetic ecologies by harvesting the physics of natural processes not only as a design generator but also as a tool for fabricating complex formations by computation of matter. More specifically the main driver of our thesis is a nonlinear fabrication technique that utilizes cracks in clay soil as a formwork for casting intricate structures. By programming the material behavior and exposing it to certain environmental condition we are able to control the emergence of  a wide range of crack patterns which are responsible for different performative qualities such as structural stability, solar shading and airflow modulation consequent to their morphological features of different size, density and porosity. The deployment of the system on site employs earth works protocols and Top Down construction techniques in order to achieve a temporary scaffold. These features and qualities are  explored through physical experiments and digital simulations at various scales. As a result, different crack morphologies are articulated together into a new tectonic language. “ (endemicinterstices.wordpress.com, 15.01.2020)

In this project, the fabrication process can only be initiated when some conditions are met: As long as the environmental and geological preconditions allow it, the soil needs to be able to crack to a desired morphology, where the in-between cracks can be injected with a material suitable for the statics of the construction (e. g. bio-plastic). Subsequently a second layer of clay can be added for better structural integrity. In the end, the form work will be removed through a natural decay (weathering, erosion, rain…).  (cf. Andrasek, 2018)

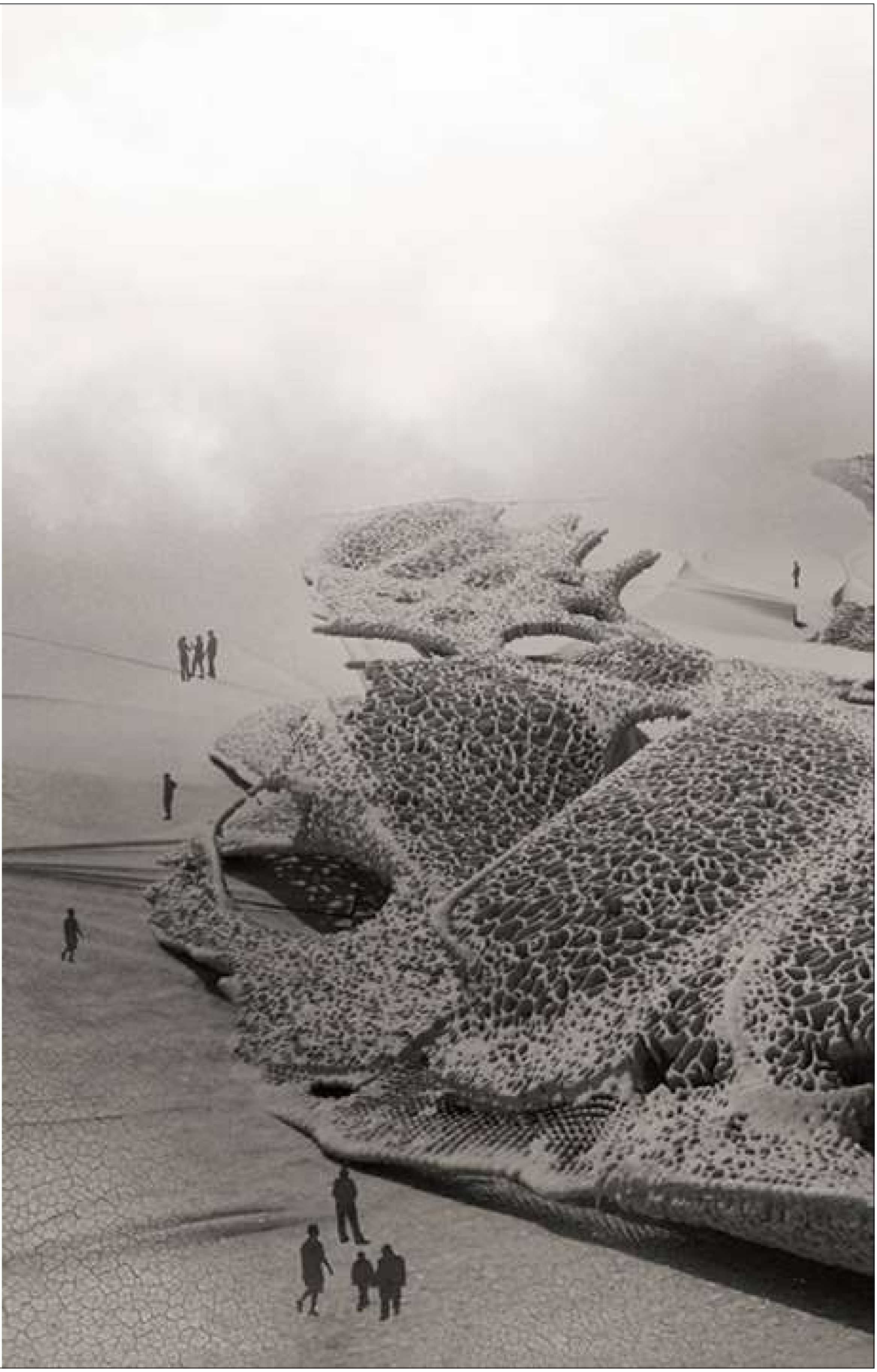
The project is related to and dependent on non-linear dynamics of local conditions and climate, as well as other location-based physics, such as air humidity collection through the pores of the structure – which was learned from the vernacular architecture in the desert -, local winds and similar. Furthermore, local culture and practices of collective construction with mud also had it’s influence on this project. The behavior and agency of the material is related to computational simulation, as well as information on the host environment in order to create somewhat of a synthetic ecology – synthesizing nature and artifice. (cf. Andrasek, 2018)

Besides the obvious advancements in technology, like very advanced microscopes and tools for geological analysis, what factors into the relevance of this project is the fact that it doesn’t take an approach to this topic with looking for the great examples of nature on how to do something, but it rather proposes a very different strategy: To look at something that happens in nature, that in our eyes possibly is some kind of a fault, but rather than trying to fix it, this project aims to make use of this porosity that occurs in mud. Here we can see a very delicate approach, which even factors in for nature’s forces to help the whole process of creating the structure and doesn’t try to control or overpower the natural site it’s built on.


evaporation speed = 0.005
evaporation speed = 0.002
frame 000
frame 100
frame 200
frame 300
frame 400
[Img. 87]



[Img. 88]



[Img. 90]


[Img. 91]

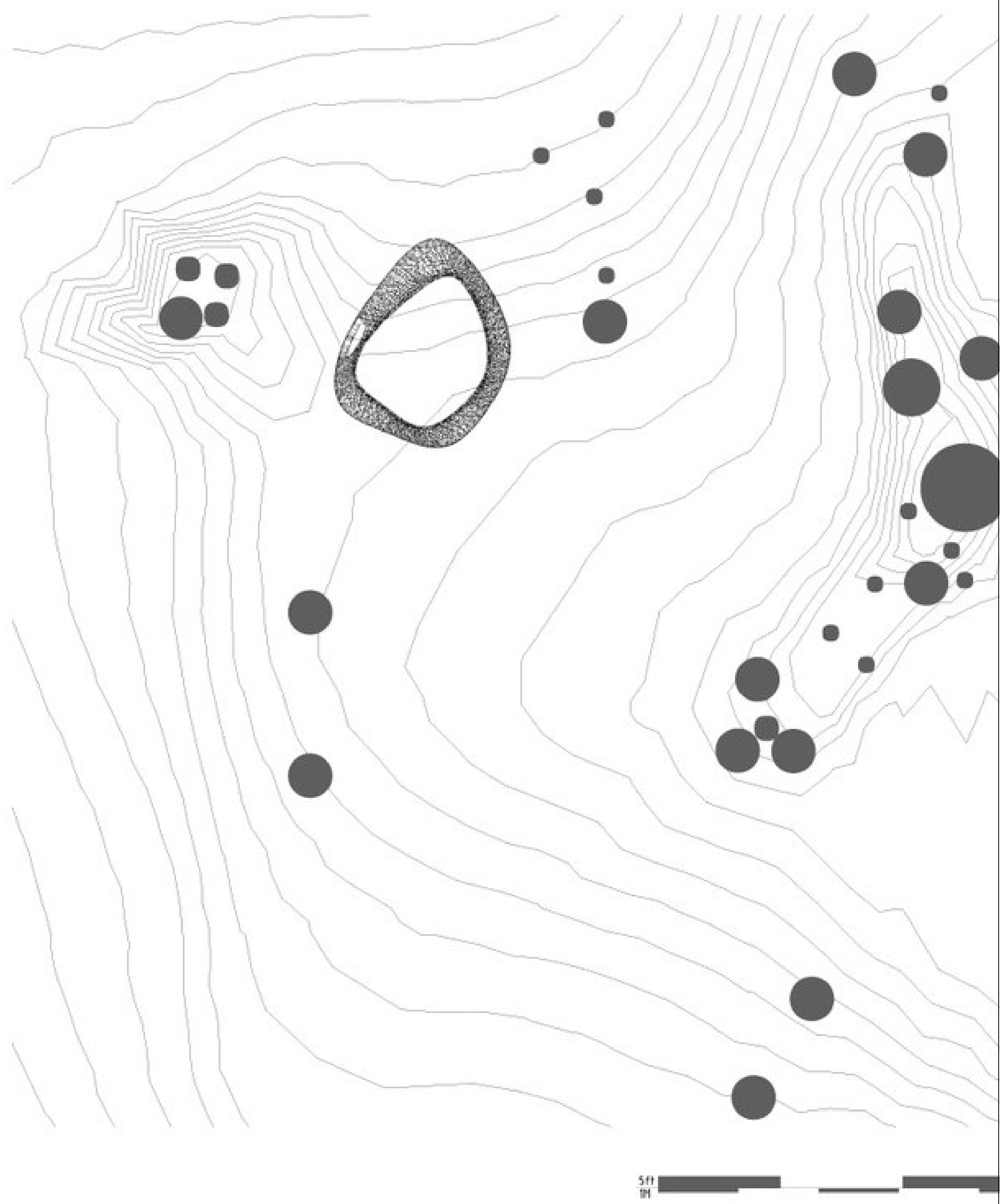
# ECHOVIREN

SMITH|ALLEN | 2013 | BUILT

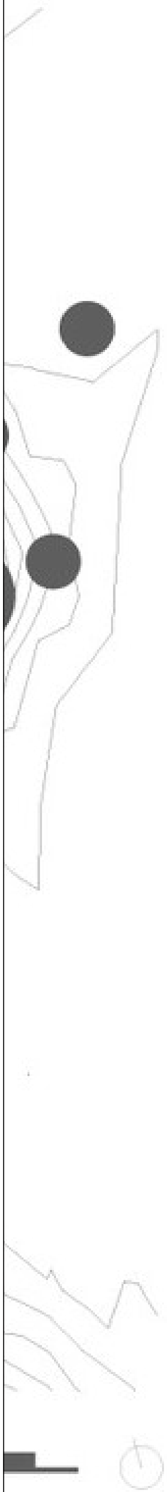
This installation is made of plant-based PLA bioplastic, so it will decay in thirty to fifty years. After that, it will become food for the growth of new organisms. Also, the design was consciously made as a base, meant for change through the natural surroundings.

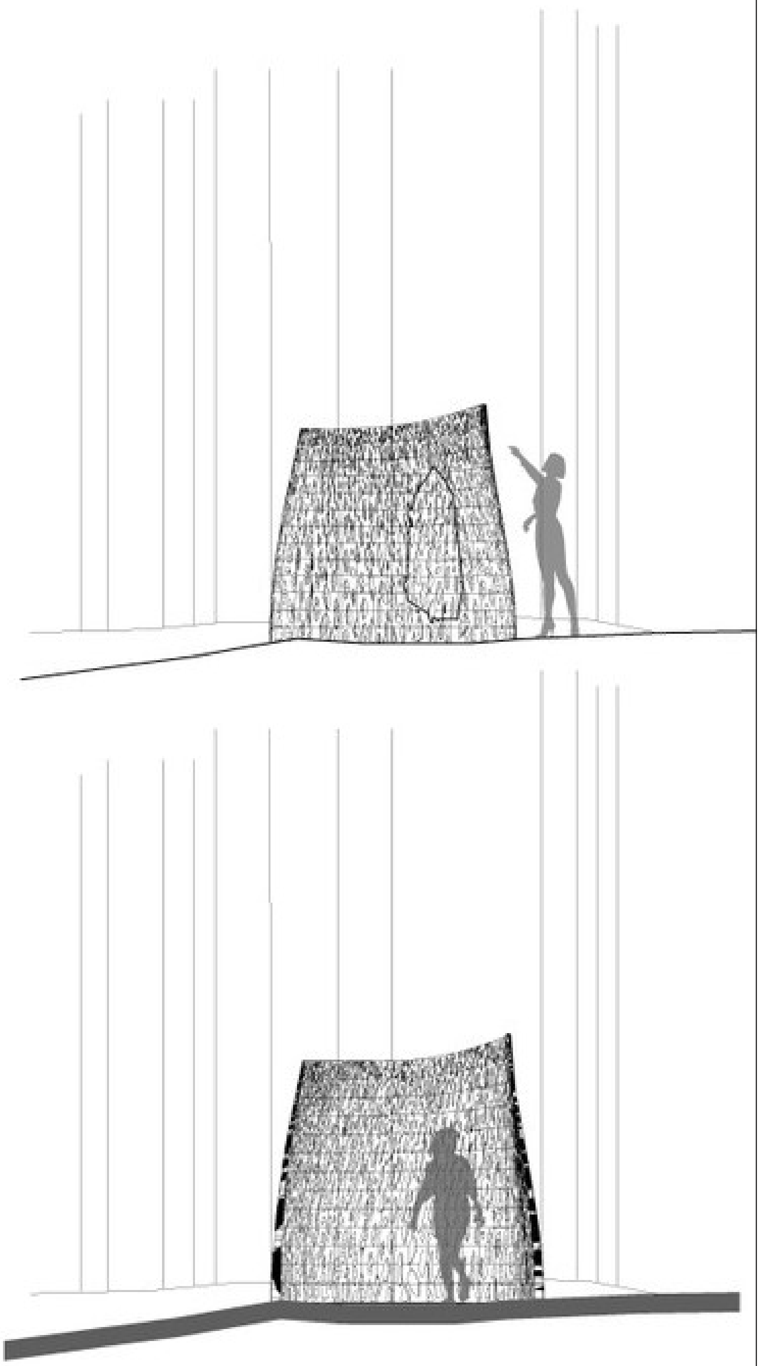
“Spanning 10 x 10 x 8 feet, Echoviren is a translucent white enclosure, stark and artificial against the natural palette of reds and greens of the forest. Walking around and within the structure, the viewer is immediately consumed by the juxtaposition, as well as uncanny similarity, of natural and unnatural: the large oculus, open floor, and porous surface framing the surrounding coastal landscape. This artifical frame draws the viewer up from the plane of the forest, through a forced perspective into the canopy. A graft within the space of the forest, Echoviren is a space for contemplation of the landscape, of the natural, and our relationship with these constructs. It focuses on the essence of the forest not as a natural system, but as a palimpsest. The hybridized experience within the piece highlights the accumulated iterations of a site, hidden within contemporary landscapes. Echoviren exposes an ecosystem of dynamic natural and unnatural interventions: the interplay of man and nature moderated by technology.“
(https://www.archdaily.com/419306/echoviren-smith-allen, 14.01.2020)

Through juxtaposing the natural and the built while still keeping in mind the ecosystem into which this installation was built by using self-decomposing fabrics, this intallation rather than proposing a specific architectural approach for the future, forces the viewer to contemplate on its relationship with nature as well as the relationship of the built environment to its natural environment.




*[Img. 92]*





[Img. 93]


[Img. 94]


[Img. 95]


[Img. 96]

# ALIEN WITHIN FAMILIAR

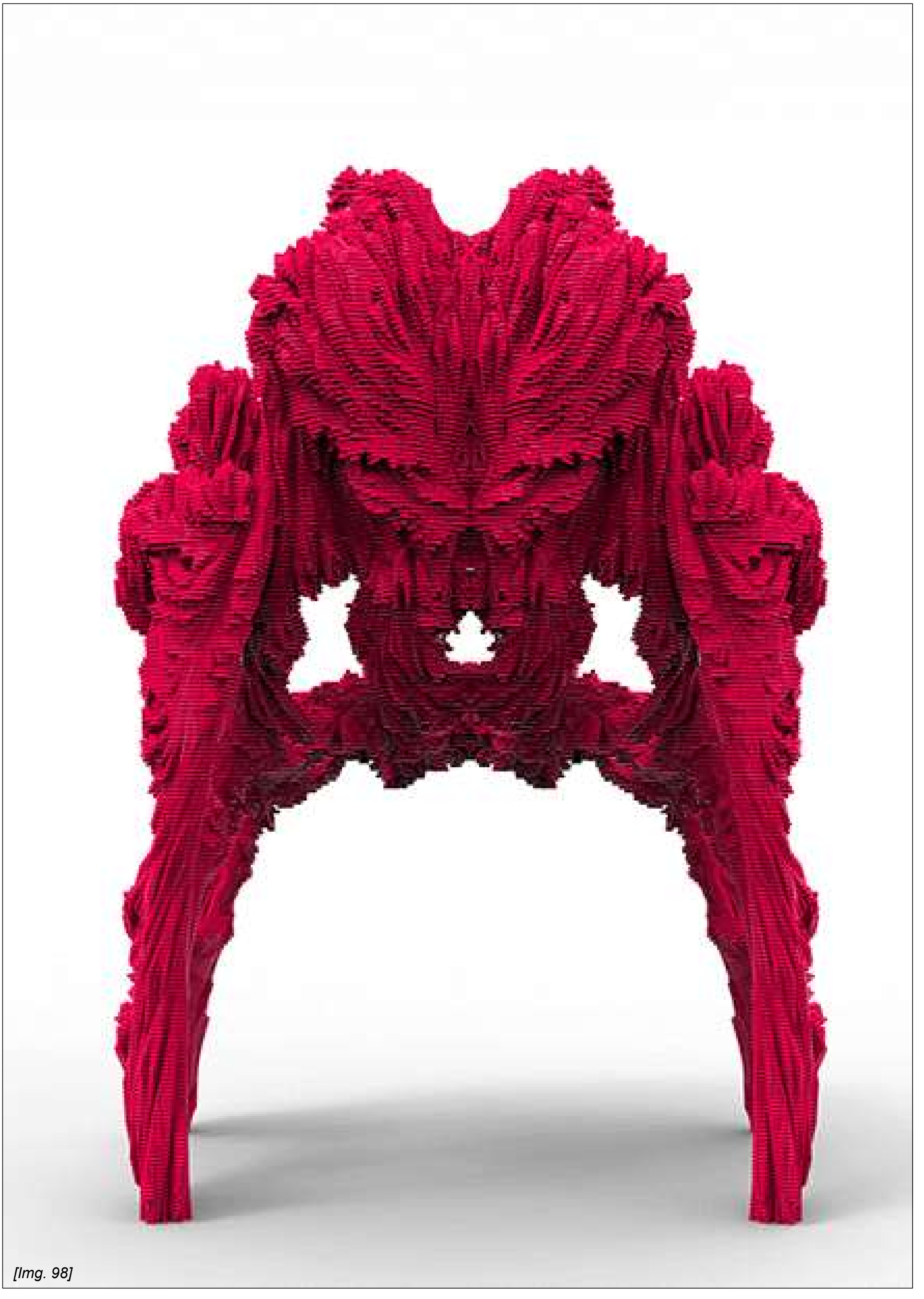
ALISA ANDRASEK | 2015 | BUILT PROTOTYPES

“For the first time in history, design and architecture can start to approach extreme resolutions found in material systems in nature. Recognizing that architecture is as fundamentally informational as it is material, with an intrinsic structure of information and concepts on which to operate, architecture’s logical core can be rewritten, by using accelerating capacities used to process information. Architecture is opening to concepts and techniques utilized in broader extra-disciplinary informational ecologies. It relates to the logics of formation of the contemporary world at large. Through large data, computer and material science, as well as new methods of building, matter can be accessed in its native resolution, both in vitro through simulation, and in vivo through robotic fabrication. We can now design and construct across many orders of scale, from material science to large scale design ecologies, from micro to macro. What could be called “data materialization” is opening up the potential for architecture to finally resonate with the complexity of ecology. Finer scale building blocks of matter and energy are now becoming available for increased resolution in manufacturing, construction and design. We can imagine a new scale of structures—microstructures capable of finer blending of material states, micro-precision design engineered for massive scale applications—increasingly malleable, plastic and intricate, primed for super-performance and unseen aesthetics.” (https://www.alisaandrasek.com/projects/alien-within-familiar, 18.01.2020)

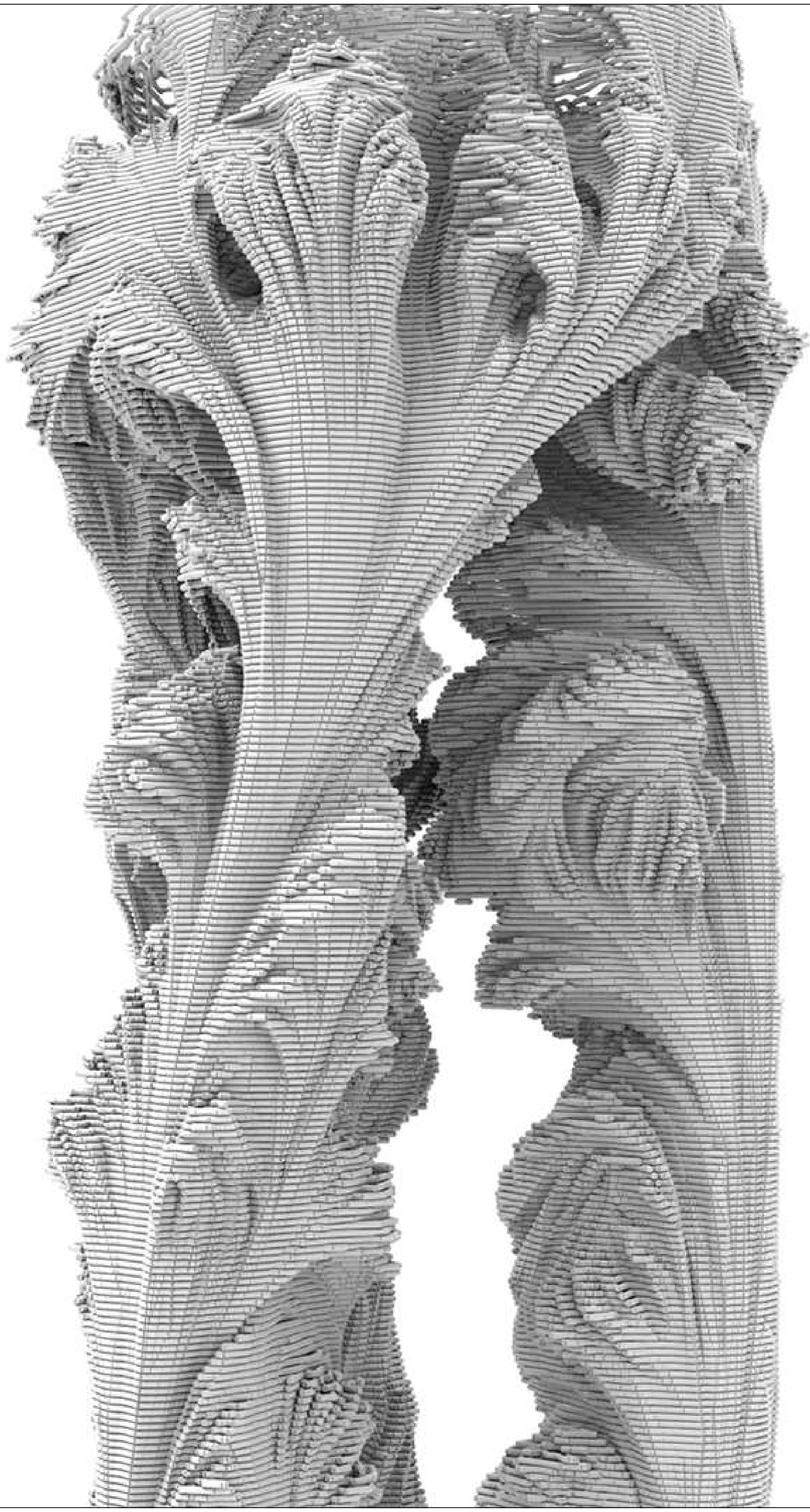
This project uses simulation, AI, supercomputing and multi-material 3D printing in order to build heterogeneous structures at a very high resolution within a speculative forecasting of architectural possibilities, which means high performances of the structures, how they transmit light, heat, sound and similar. Cellular division, with strongly weighted directional vectors mimicking very strong gravity forces, was used as an inspiration to grow initial generic fields into the shape of familiar elements, such as chairs or aisles.
(cf. Andrasek, 2018)

Although this project seems to aim for optimizing a design from a static and structural viewpoint, it also seems to touch a very important topic in the context of this book, which is what we expect architecture to look like. With the title of this project being ‘Alien within familiar’ it also suggests, that through generating unseen forms of something we already know with methods that we are just experimenting with as of now, we can create objects that, although we are somehow familiar with as to how to use them and what they are in an architectural context, we could have never created without this experimental process and therefore they might contain ideas far above our capacity for innovation.

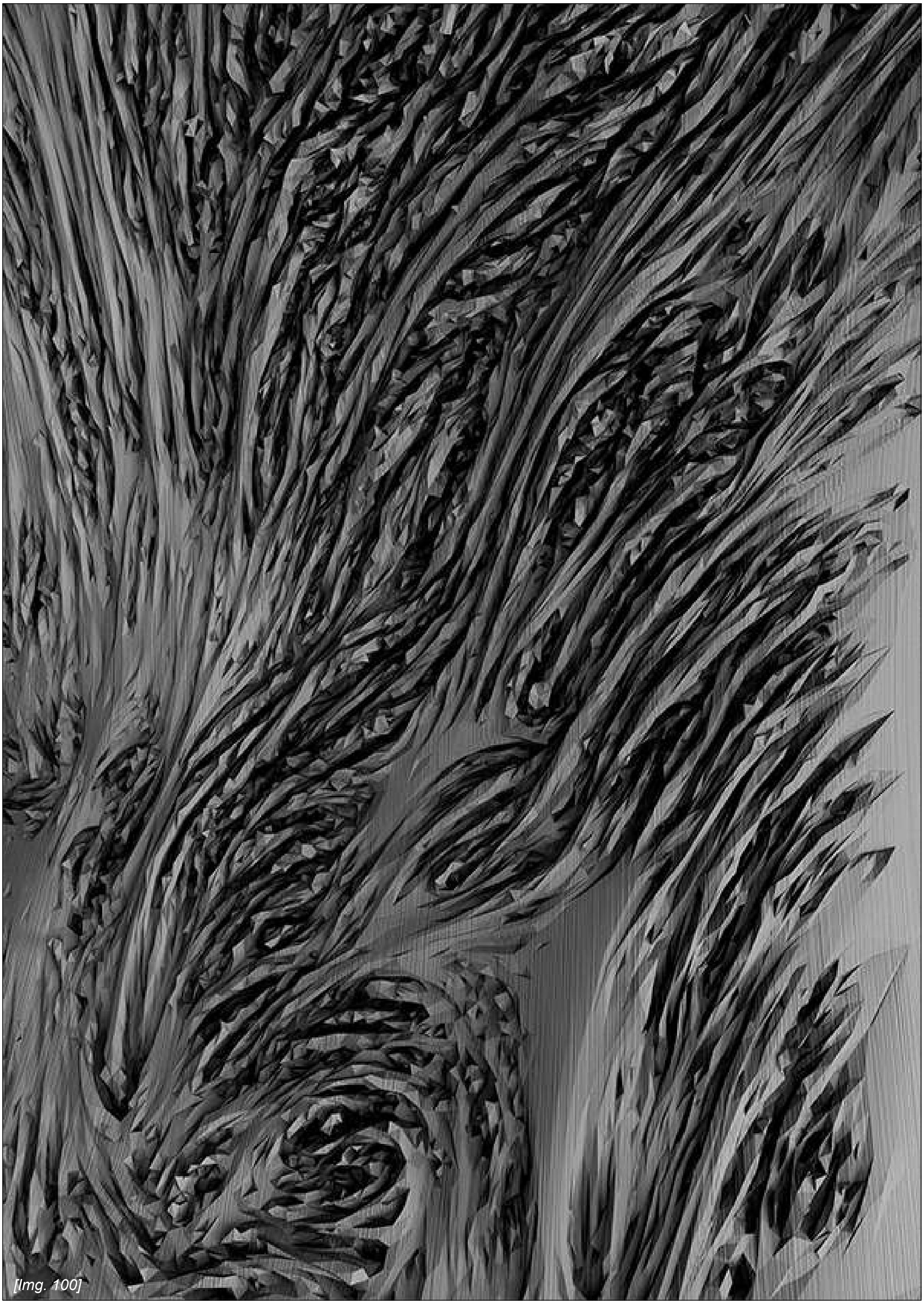
[Img. 97]



[Img. 98]



[Img. 99]



[Img. 100]

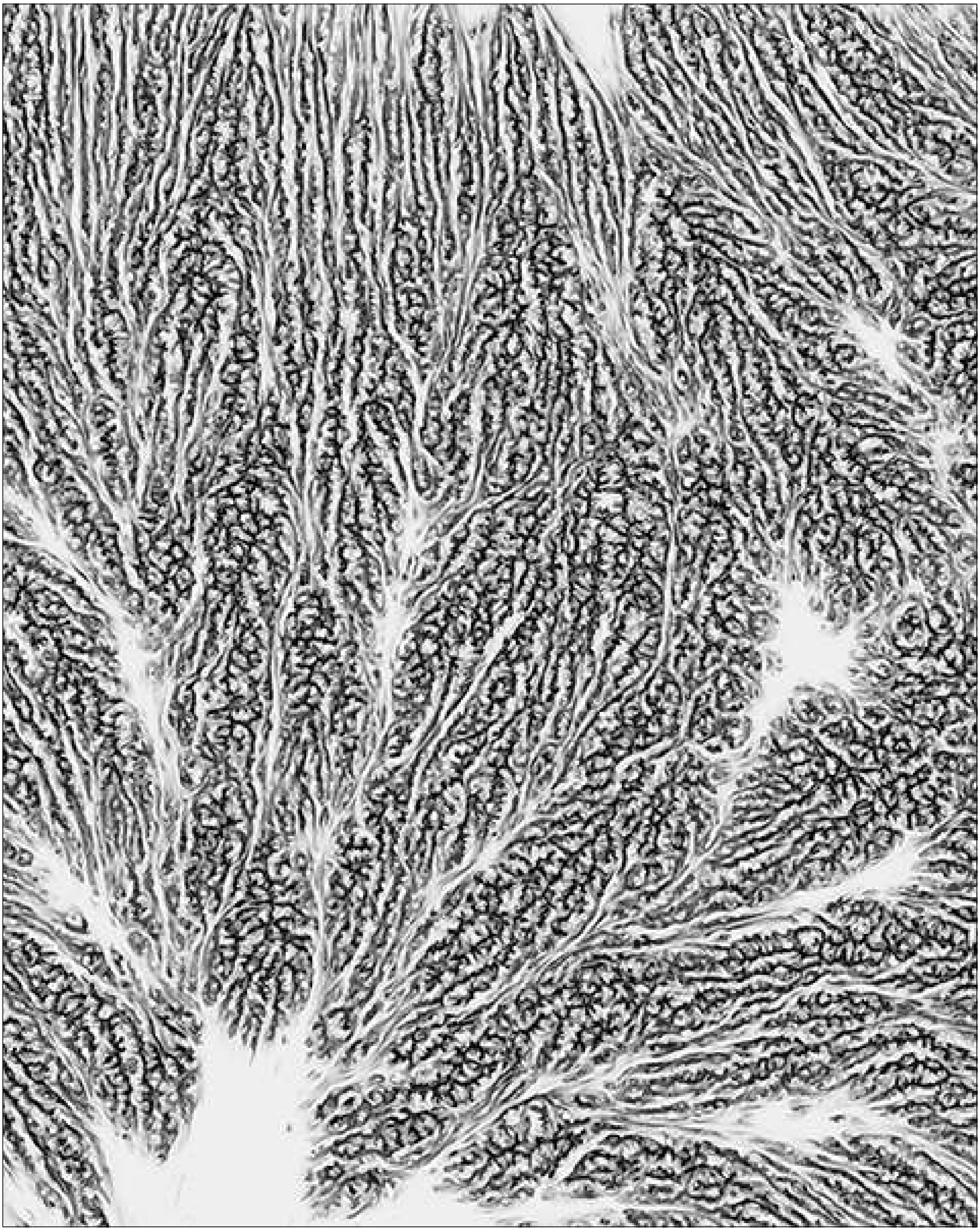
# MORPHOCYTE

ANDRASEK & CAM & LOMAS & ZHOU | 2016 | NOT BUILT

“Morphocyte generates fresh phenomena, through the relationship of physics, aesthetics and perception. Under the umbrella of awe and wonder, we looked at how physics affect perception. Our initial reference was Richard Serra’s work Torqued Ellipses (Govan et al. 1997). Like much of his work this piece emphasises the fabrication process and nature of materials, as well as the counter-intuitive effects the work has on the viewer; seemingly defying gravity and logic, it creates surprising experiences that are out of balance and affect the viewer’s behaviour, generating physical and phenomenological sensations where the body is accelerating and decelerating as it explores Serra’s labyrinths of torqued metal. In addition to changes in resolution, additional inflections were designed into the code, to produce local directional biases, amplifying “pull” in one direction versus the other.

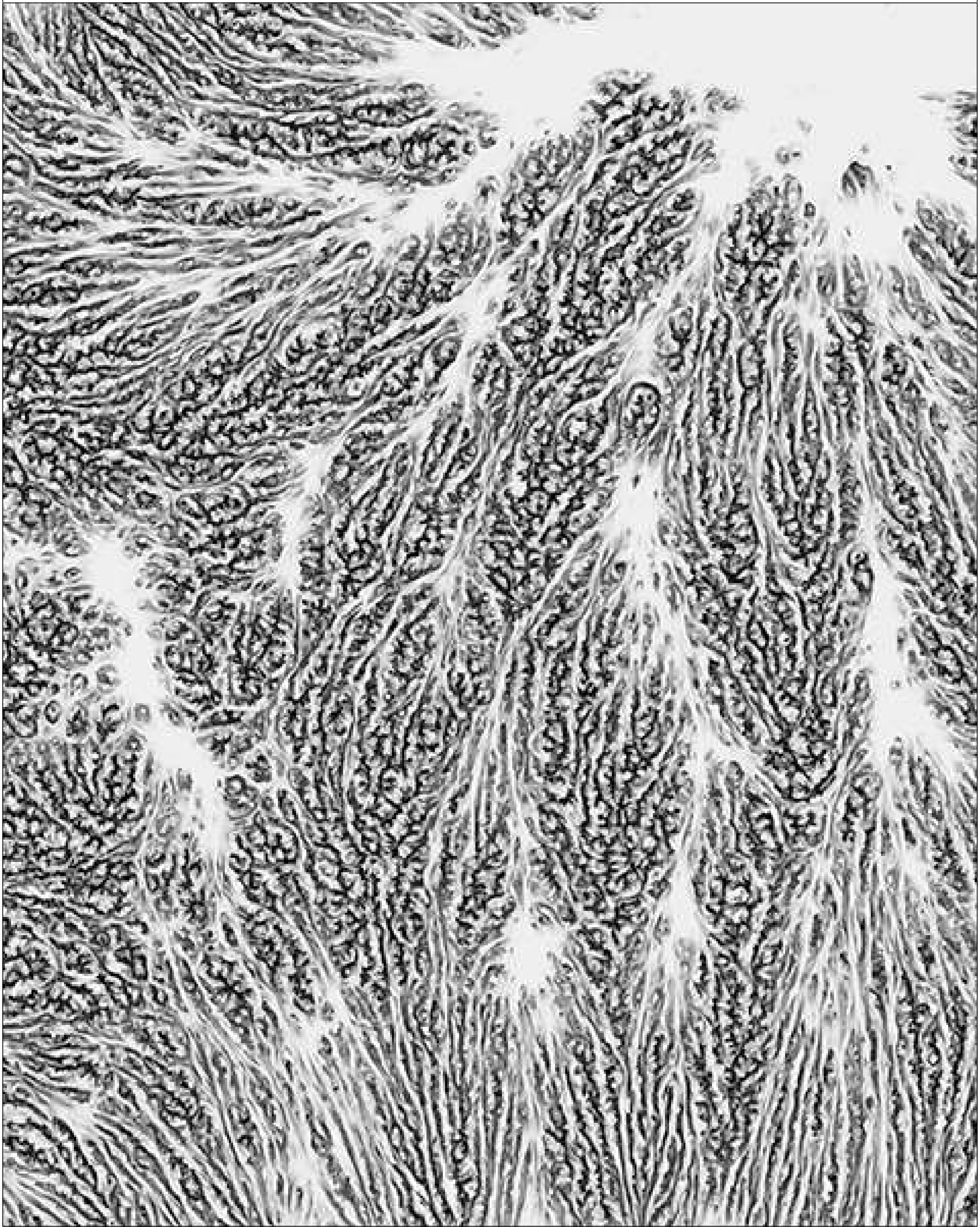
Morphocyte used this work as its starting point of inspiration, and tried to accelerate such spatial effect by working with extreme resolution—designing highly articulated deep surface textures that amplify a sense of gravitational pull through the space. Specifically, this project was targeted towards 3D printing of fibre-reinforced concrete. It used cellular division to introduce biology’s high-resolution aesthetics into the traditionally low-resolution monumentalism of concrete; and also to develop heightened performance for the 3D-printed concrete structures, by introducing a high-resolution porosity that could be achieved through 3D printing. By doing this it saves both material and printing time, while increasing the strength and decreasing the weight of such.”
(https://www.alisaandrasek.com/projects/morphocyte, 11.01.2020)

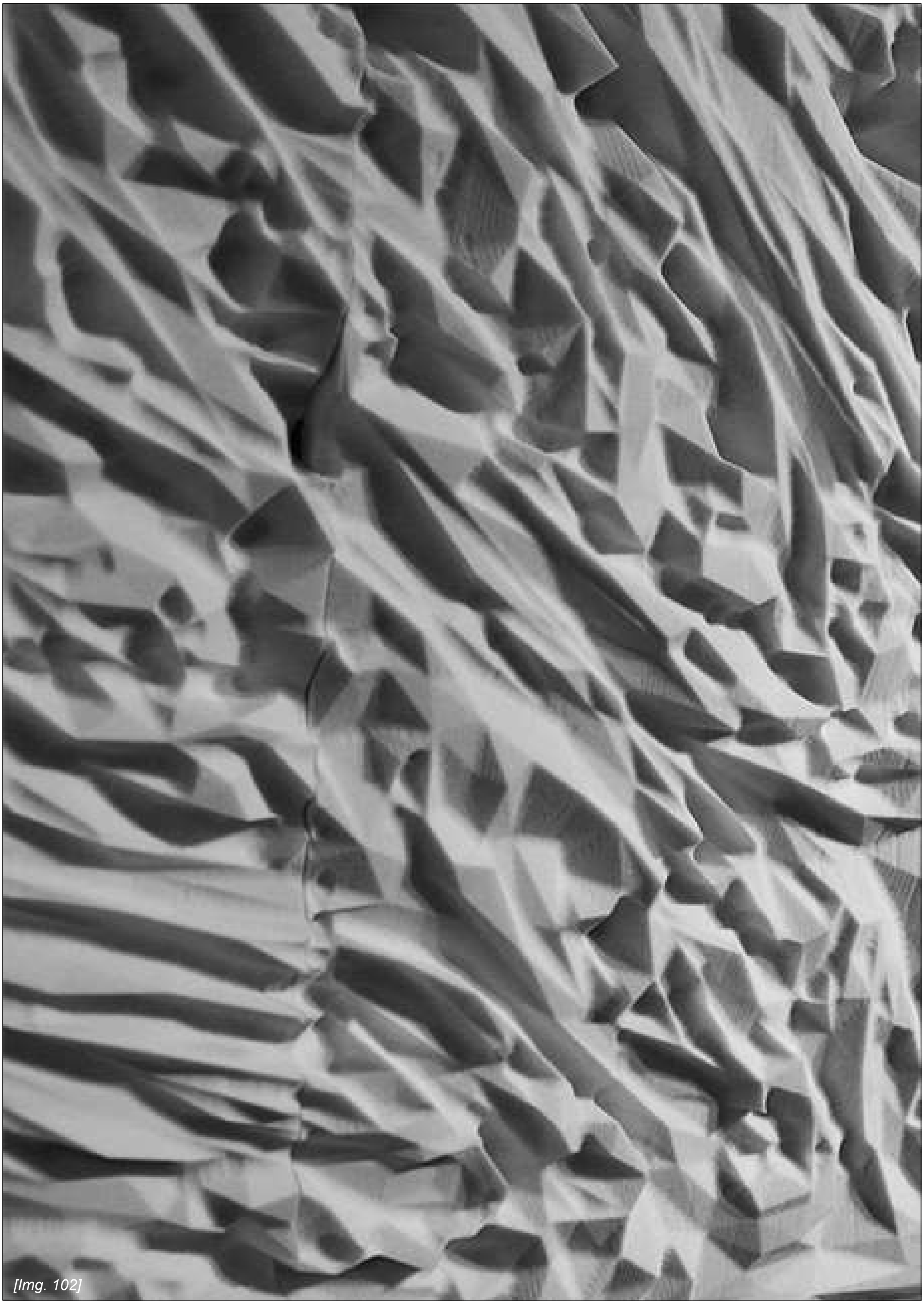
This project, just as the one before (‘Alien within familiar’), involves a very experimental process, again producing a lot of ideas and inspirations that would have not appeared with conventional methods for idea-finding.





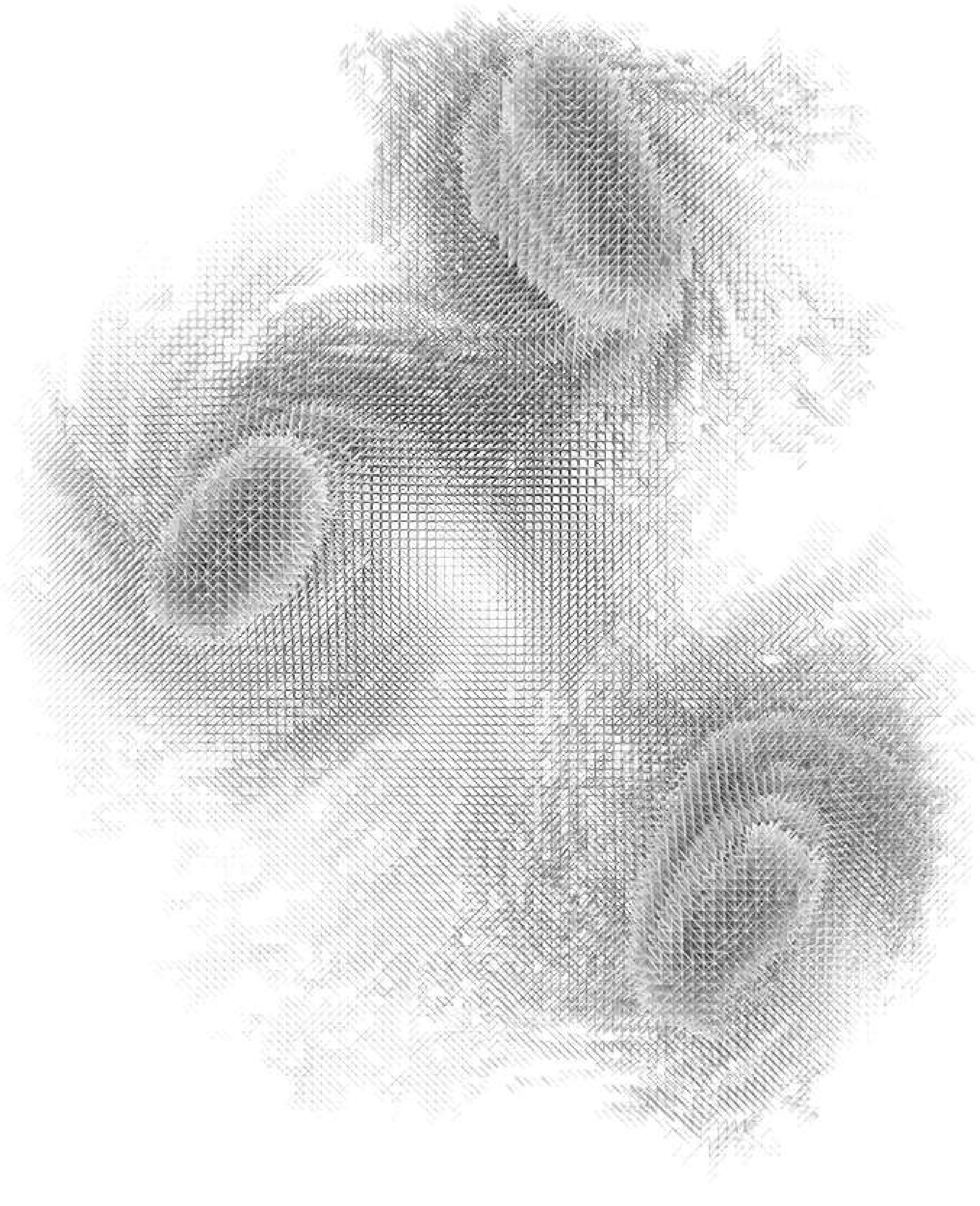
[Img. 101]





[Img. 102]

[Img. 103]





[Img. 104]

# CLOUD PERGOLA

ANDRASEK WITH ARUP ENGINEERING | 2018 | BUILT

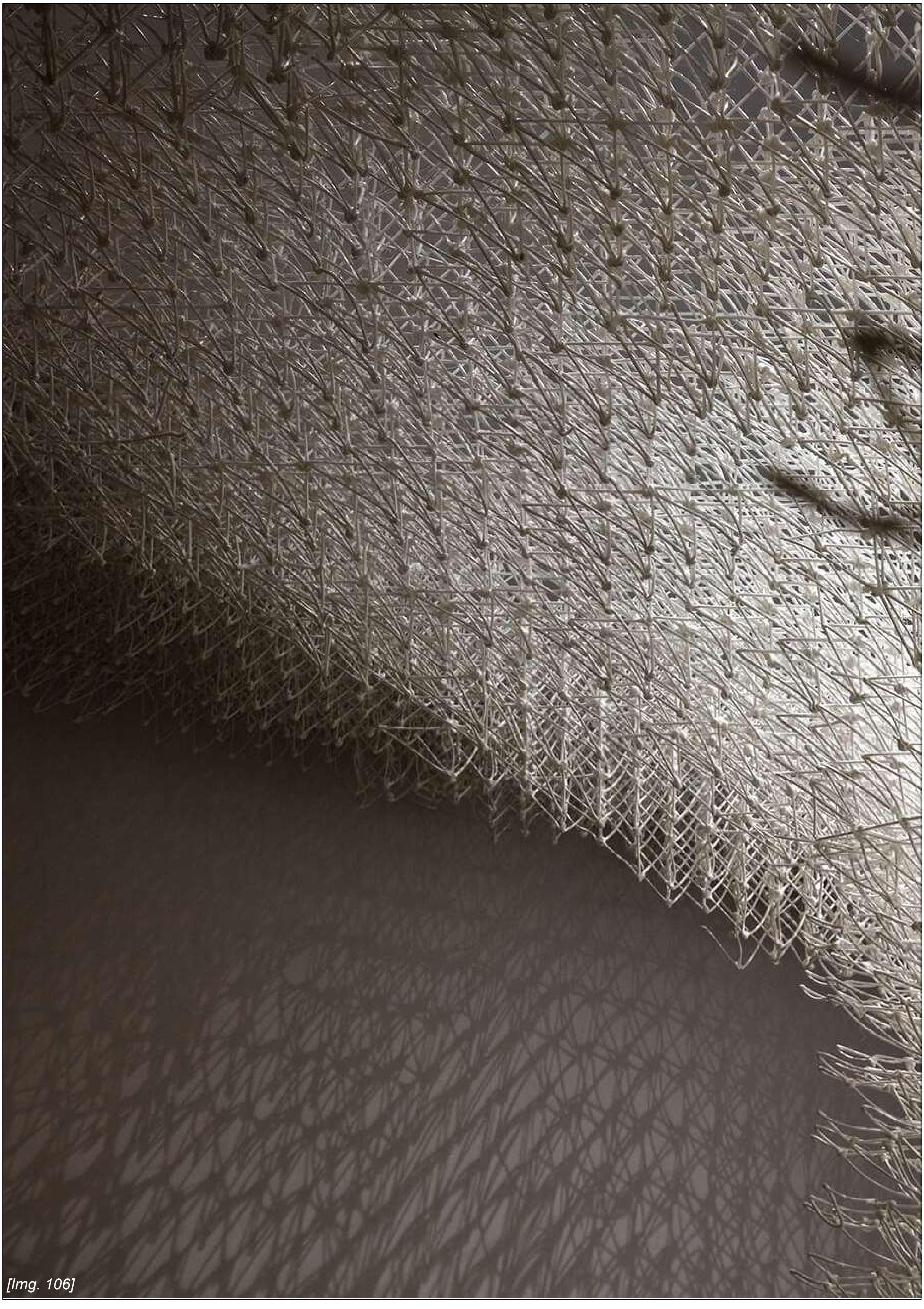
“Through Wonderlab research, numerous examples of proto-microstructures were developed using combinations of various algorithmic strategies. Its various instances are introducing applications of design and programmable multi-material printing with a high level of intricacy, resulting in super-performance (structural, thermal, acoustics and saving material) and expanded aesthetic possibilities. Robotically 3D-extruded lattice structures are one such example, designed with micro-precision for large scale applications in architecture and product design. Potential benefits of 3D printing by robots, are seen in faster construction, less material required to build in additive processes without unnecessary waste, highly specialized design fabrics, lighter structures as opposed to the current incredibly heavy buildings, and a high degree of tectonic and structural heterogeneity and local adaptation.

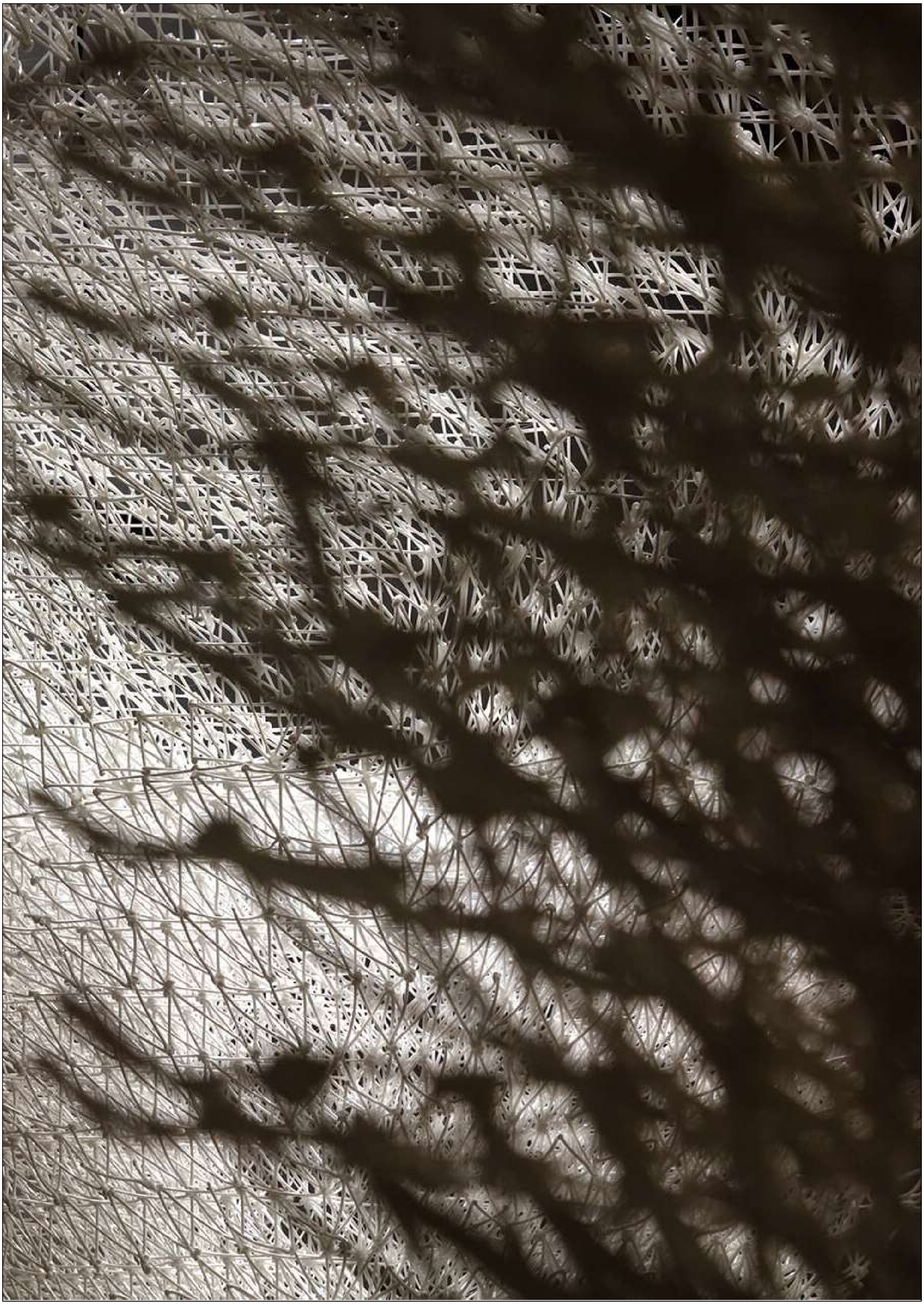
However, during the printing of thermoplastics into such complex spatial lattice, an issue arises with accumulation of tolerances and resulting imprecisions or even collapse of the structures; this is caused by the nonlinear behaviours of materials being printed, and a high number of connection points that very quickly accumulate errors—particularly in the case of extruding 3D lattices through the air where the material is only supported and connected through the nodes, while being suspended in the air the rest of the time. The problem for deep learning (AI) becomes finding the exact nodes to connect to after an accumulation of material tolerances, which inevitably mismatches the original computer simulation. To resolve this, the 3D printing path is trained to adapt real-time to the unpredictable material behaviour, by using the NVIDIA Jetson card on an industrial robotic arm. This enables path generation, real-time visual tracking of material and recomputing of robotic targets, thus increasing the speed and accuracy of such printing, and the overall stability of resulting lattice structures.

Croatian pavilion structure was designed by using the algorithm for multi-agent systems (MAS), whereby agents can be understood as active discrete elements whose behaviour is determined by a collection of rules, often based on stimulus-response logic. When agents act collectively in large populations, they are capable of producing complex behaviours and emergent effects.” (https://www.alisaandrasek.com/projects/cloud-pergola, 16.01.2020)

What is probably the most interesting aspect of this project, is the use of technology that allows adaptation throughout the construction process. Just as all organisms adapt and evolve, this technique of using technology to monitor technology and optimize the process might be something that could be translated into a bigger picture, by which we mean making it possible for the built environment to listen to it’s surrounding environment and adapt to all different kinds of changes (climate, resources, etc.), making the built environment ultimately part of the natural ecosystem instead of being in an opposition to it.


[Img. 105]


[Img. 106]



[Img. 107]

# PHOTOSYNTHETICA

## CLAUDIA PASQUERO - ECOLOGIC STUDIO | 2018 | BUILT

“PhotoSynthEtica is a bio-digital urban curtain design to fight global climate change. The project deploys a material system similar to the one of the Urban Algae Folly in order this time to cover a façade and not to generate a canopy, the material is here evolved from ETFE to bio-plastic and the algae system evolves from water and pumps to a bio-gel one.

Conceived as an “urban curtain”, PhotoSynthEtica, presented in Dublin during the week of Climate Innovation Summit 2018, captures CO2 from the atmosphere and stores it in real-time: approximately one kilo of CO2 per day, equivalent to that of 20 large trees.

Composed of 16, 2 x 7 metre modules, the unique curtain prototype envelopes the first and second floor of the main façade of the Printworks building at Dublin Castle. Each module functions as a photobioreactor, a digitally designed and custom-made bioplastic container that utilizes daylight to feed the living micro-algal cultures and releases lumines¬cent shades at night. Unfiltered urban air is introduced at the bottom of the PhotoSynthEtica façade and, while air bubbles naturally rise through the watery medium within the bioplastic photobioreac¬tors, they encounter voracious microbes. CO2 molecules and air pollutants are captured and stored by the algae and grow into biomass. This can be harvested and employed in the production of bioplastic raw material that constitutes the main building material of the photobioreactors. To culminate the process, freshly photosynthesized oxygen is released at the top of each façade unit of PhotoSynthEtica, and out into the urban microclimate.” (Pasquero, 2019, p. 274)

This is a truly interesting project in the sense that the shading system can be integrated into new buildings as well as old ones. Also, the lifecycle of this project seems very thought through.



*[Img. 108]*



[Img. 109]

[Img. 110]

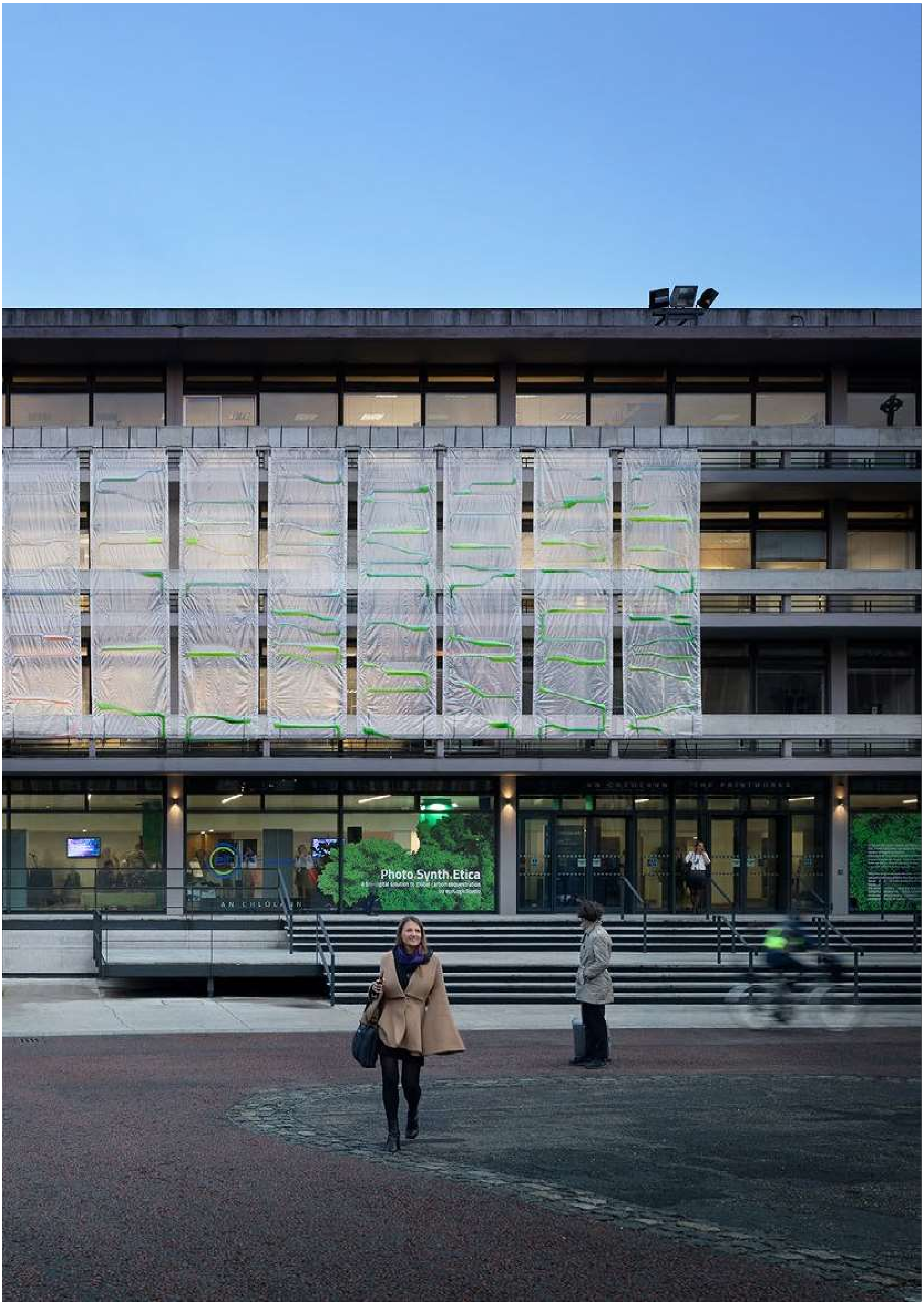


Photo.Synth.Etica

[redacted]

# OUTRO

Concluding our inquiry we looked at a lot of different projects, from different times, realized with different technologies and possibilities. What became very clear, was that thinking the relationship between the built environment and nature has a significant correlation to the time and the technological possibilities that came with it, therefore forming different solutions for this relationship and yielding various views on how that relationship can be understood and how it will develop.

Looking at organic architecture, standing for the beginning of thinking of this relationship in a modern way, was very important due to the fact that especially this architectural movement in our context shows how different a perception of the same question can be in a time where technology was not yet there or not yet used widely.

The projects of this period show, that although the techniques used seem quite primitive to our generation, the main focuses of organic architecture reappear in later works, just in a different articulation. At this time the references to architecture were understood as metaphorical references more than literal ones, also due to the fact that the technology to translate nature in a very literal way was not there yet. Still, the concept of those projects started an appreciation for nature in the architectural context that was not there before.

Building within an environment, rather than on top of it – as Frank Lloyd Wright described his aims for Falling Water – is especially visible in the most recent experimental examples, where the environment is integrated into the design process from a macro-perspective but more importantly also from a micro-perspective, which expands Wright's vision through the technology that is available nowadays.

This technological developments are also the reason why biomimicry had a chance of developing into a technique used in architecture even up until now.
The reason biomimicry is able to integrate nature at such a sophisticated level lies in the development of technology that makes it possible for us to see far more than just nature as it is visible to our naked eye, but rather enabling us to see nature from so many different perspectives and levels of depth, giving us far more information to process than Wright or Häring had available.

The foundation for those more literal translations of nature into architecture were laid with works that already looked at nature from more than just a metaphorical, conceptual level, but a structural one. Although the intention of those works was probably more to build never-before-seen structures in an efficient way, they had to happen to even start the development into biomimicry, because with the interest into structural aspects of nature, architecture became

[redacted]

more interdisciplinary, especially in connection with the field of biology. If this change wouldn't have happened, biomimicry would not have been possible, since it is a field where the need for interdisciplinarity and different points of view is crucial for any development.

But even in the field of biomimetic architecture itself, one can see how this field has developed over time with technology. From using simple information on the skin of an animal to articulate optimized thermoregulation in a building to using microscopic crack patterns to optimize a whole structure, this field has gained a lot more depth and validity in the context of architecture.

In spite of the developments architecture has made in context with its natural environment, the principle behind architecture is still the same it was at its beginning: Creating shelter and therefore creating a border between the built and natural environment, ultimately a border between the human and nature – however fluid this border might seem especially in the field of biomimicry.

Architecture is still conceived as being something that needs to fulfill our needs, allowing for a symbiotic relationship with nature only when we decide it doesn't hinder the realization of our goals. In spite of understanding the importance of fulfilling our needs, we think compromises will become more and more important if we want to continue living on this planet. Which opens up a completely different question:

Can we outsmart nature and live without it on this or any other planet or do we need this planet, and therefore nature? Our standpoint is, that even if we somehow manage to make a life without nature a possibility, it's highly controversial which the qualities of such a life would be. Furthermore, if we are able to destroy and live without this one huge entity of which we originally sprang, wouldn't it be likely that our future would then go on to be destructive to other entities, even the ones we created?

This is definitely not the future we aim for. We think the architectural concepts described in the book are a first step in the right direction, but ultimately for us it became clear that the development we desire can't spring from an architectural concept, but must include a change of paradigm. With this we come to our conclusion, which is more a call for further investigation than a definitive one:

In light of global warming and all the natural catastrophes, changes and problems that come with it, humankind is facing a pretty grim future if the way things are done will not change. But to change this, we cannot only think of new inventions, we have to alter the fundamental paradigm on which human development is based.

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