BIOMIMETIC BUILDING SKINS

30 DATASHEETS

- février 2022 -

JOURNAL PAPER

Design processes and multi-regulation of biomimetic building skins: A comparative analysis

https://www.sciencedirect.com/science/article/abs/pii/S0378778821003182#!

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ABSTRACT

Biomimetics is an opportunity for the development of energy efficient building systems. Several biomimetic building skins (Bio-BS) have been built over the past decade, however few addressed multiregulation although the biological systems they are inspired by have multi-functional properties. Recent studies have suggested that despite numerous tools and methods described in the literature for the development of biomimetic systems, their use for designing Bio-BS is scarce.
To assess the main challenges of biomimetic design processes and their influence on the final design, this paper presents a comparative analysis of several existing Bio-BS. The analyses were carried out with univariable and multivariate descriptive tools in order to highlight the main trends, similarities and differences between the projects. The authors evaluated the design process of thirty existing Bio-BS, including a focus on the steps related to the understanding of the biological models. Data was collected throughout interviews.

The univariate analysis revealed that very little Bio-BS followed a biomimetic design framework (5%). None of the Bio-BS was as multi-functional as their biological model(s) of inspiration. A further conclusion drawn that Bio-BS are mostly inspired by single biological organisms (82%), which mostly belong to the kingdom of animals (53%) and plants (37%). The multivariate analysis outlined that the Bio-BS were distributed into two main groups: (1) academic projects which present a strong correlation with the inputs in biology in their design processes and resulted in radical innovation; (2) public building projects which used conventional design and construction methods for incremental innovation by improving existing building systems. These projects did not involve biologists neither a thorough understanding of biological models during their design process.
Since some biomimetic tools are available and Bio-BS have shown limitations in terms of multifunctionality, there is a need to promote the use of multidisciplinary tools in the design process of Bio-BS, and address the needs of the designers to enhance the application of multi-regulation capabilities for improved performances.

ACKNOWLEDGMENT

FUNDERS & SPONSORS

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COLLABORATIONS & PARTNERSHIPS

This research was carried out in collaboration with the University of West England (Lidia Badarnah), the architectural school of Lyon (Omar Naim and Ginaud Chancoco), the MAP MAACC (Natasha Chayaamor-Heil), the University of Savoie Mont Blanc (Christophe Ménézo), the ISYEB (Raphaël Cornette), and the University of Stuttgart (ITKE / ICD).

ACKNOWLEDGMENT

It is acknowledged that Dr Lidia Badarnah, of the University of the West of England, Bristol is a co-author if this work.

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The authors would like to gratefully acknowledge designers who shared time and data to complete the analysis of the Bio-BS, reviewed the associated project sheets and enriched discussions. This includes Mick Pearce (Pearce Partnership), Steven Ware (Art & Build Architect), Tobias Becker (University of Stuttgart), Karl Daubmann (DAUB), Nicolas Vernoux-Thélot (In Situ Architecture) and Mathew Park (Atelier One).

LIST OF DATA SHEET

Homeostatic Façade, 2012. New York.

The Homeostatic Façade System by Martina Decker and Peter Yeadon is a self-regulating façade system that automatically adjusts to suit changing exterior environments, such as sunlight and temperature variations. The façade operates on natural principles to keep interior conditions in check.

The system comprises an engineered ribbon, inside the cavity of a double-skin glass façade. The ribbon is made of dielectric elastomers: polymeric materials that can be polarized by applying an electrical current, causing them to elongate. These materials are flexible and consume very little power. The silver layers/electrodes distribute an electrical charge across the material and can reflect light. As environmental conditions change, the charge in the silver layer causes motion using a sensitive actuator.

An artificial muscle is created by wrapping the dielectric electro-active polymer over a flexible polymer core. Increased charges causes the elastomer to expand, making the core bend and pulling the elastomer yo one side. The effect is that the facade closes up. This helps the façade to regulate temperature inside the building.

Name:
Year of construction: 2012
Climate: Temperate (Cfb)
City: New York
Country: USA, NYC

Surface: na
Cost (€/m²): na
Project use: office
Renovation: No

Data sheet completed by Estelle Cruz & Tessa Hubert (literature)

Data sheet reviewed by **Martina Decker**
decker@njit.edu

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Biomimetic

Definition
- ● Biomimetics
- ○ Bioinspiration
- ○ Biomimicry

Approach
- ○ Biology-push
- ○ Technology-pull

Origins of bioinspiration
- ● Random opportunities
- ○ Interdisciplinary collaborations
- ○ Call for projects
- ○ Other

Targeted performance
- ● Thermal comfort
- ● Visual comfort
- ○ Acoustic comfort
- ○ Air quality
- ○ Mechanical stress resistance
- ○ Water regulation

Integration scale of biomimetics
- ● Material (facade component)
- ● Facade system
- ○ Building

Link to biology

Model kingdom
- ● Animalia: muscle
- ○ Plantae
- ○ Fungi
- ○ Bacteria/Archaea
- ○ Protozoa
- ○ Chromista / Ecosystems

Number of models
- ● One
- ○ Two
- ○ More

Type of knowledge
- ● Existing for general public
- ○ Existing for specialist
- ○ Created during the design process

Inputs in biology
- ○ Background of the designer
- ● Acquisition during the design
- ○ Biologists integrated in the process

Design process

Use of design framework
- ○ Yes
- ○ No

Eco-design approach
- ○ Yes
- ○ No

Major constraints
- ○ Lack of funds
- ○ Use of biomimetic tools
- ○ Law regulations
- ● Technical problems
- ○ Other

Design complexity
- ● High (software, design process)
- ○ Low (well-known design)

Outcome

Technology readiness level
- ● TRL6 - demonstrated in relevant environment
- ○ TRL7 - system prototype demonstration in operational environment
- ○ TRL8 - system complete and qualified
- ○ TRL9 - actual system proven in operational environment

Overtime performance
- ○ Still operating
- ○ Not operating yet
- ○ Destroyed

Construction complexity
- ● High (new technology)
- ○ Low (existing technology)

Main component of the building envelope
- ● Polymers
- ○ Alloys
- ○ Textiles
- ○ Wood
- ○ Concrete
- ○ Carbon-glass fiber

Level of innovation
- ● Breakthrough innovation
- ○ Improvement of existing systems

Adaptable to renovation
- ● Yes
- ○ No

Adaptability

Adaptation to stimuli
- ● Yes
- ○ No

Type of trigger (input)
- ○ Mechanical (e.g. wind load)
- ○ Thermal (e.g. air temperature)
- ○ Electromagnetic
- ○ Optical (e.g. daylight level)
- ○ Air quality (e.g. humidity)
- ○ Occupancy
- ● Other (internet data, BMS, etc.)

Type of actuator (output)
- ● Mechanical
- ○ Pneumatical
- ○ Electromagnetic
- ○ Thermal
- ○ Chemical
- ○ Other

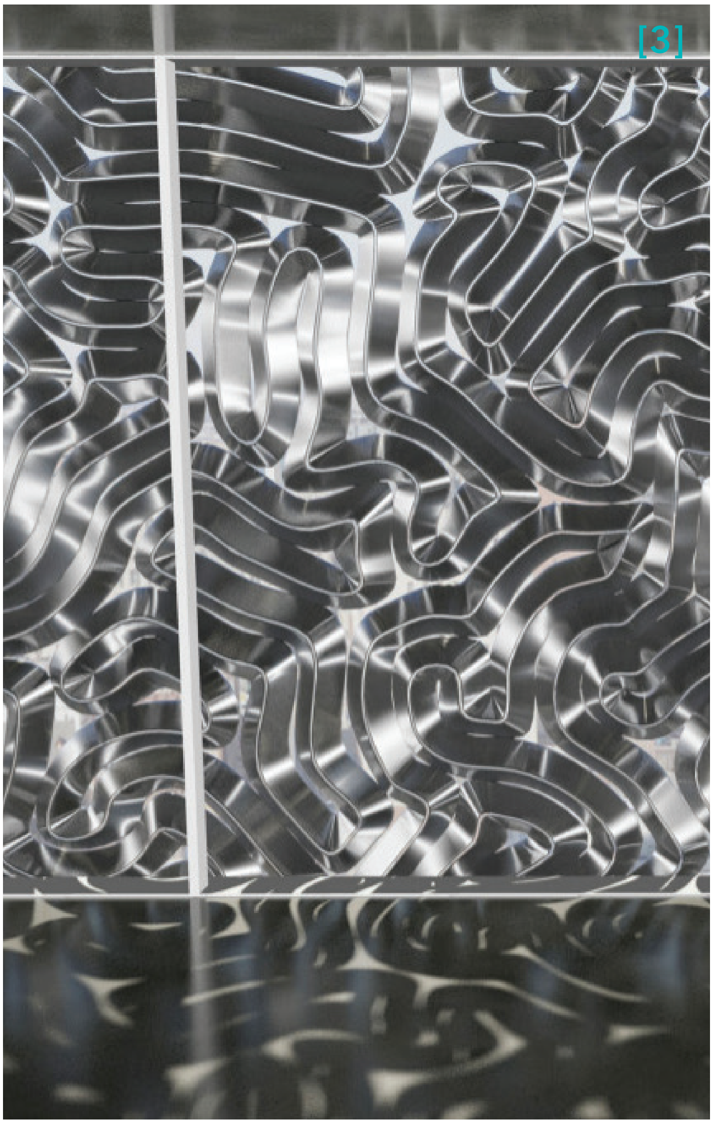
Control
- ○ Intrinsic (auto-reactive)
- ● Extrinsic (external control)

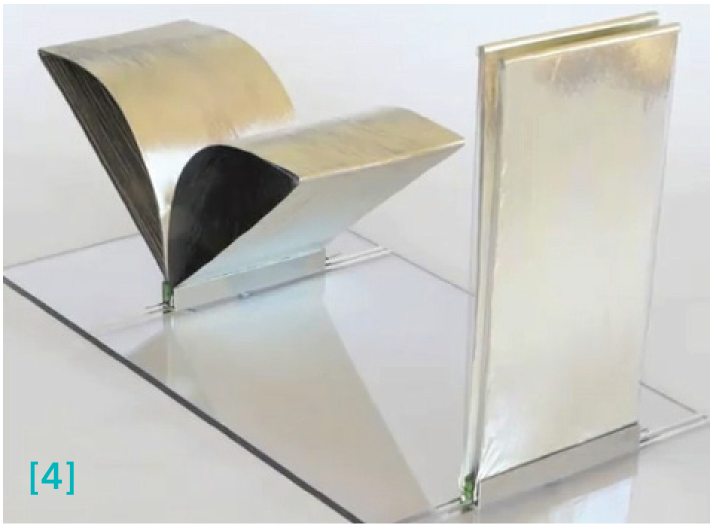
Response time
- ● Seconds
- ○ Minutes
- ○ Hours
- ○ Days
- ○ Weeks
- ○ Months

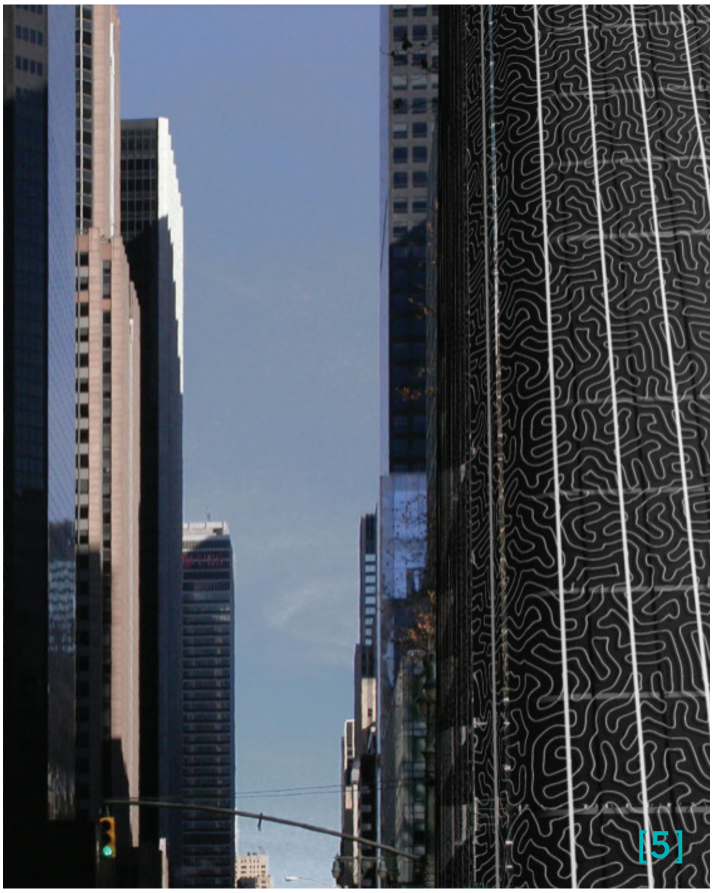
Spatial adaptation
- ○ Nanometers
- ○ Micrometers
- ○ Millimeters
- ● Centimeters
- ○ Meters

Material adaptation
- ● Elasticity
- ○ Inflatable
- ○ Bi-material
- ○ Other

Degree of adaptability
- ○ On-Off
- ● Gradual







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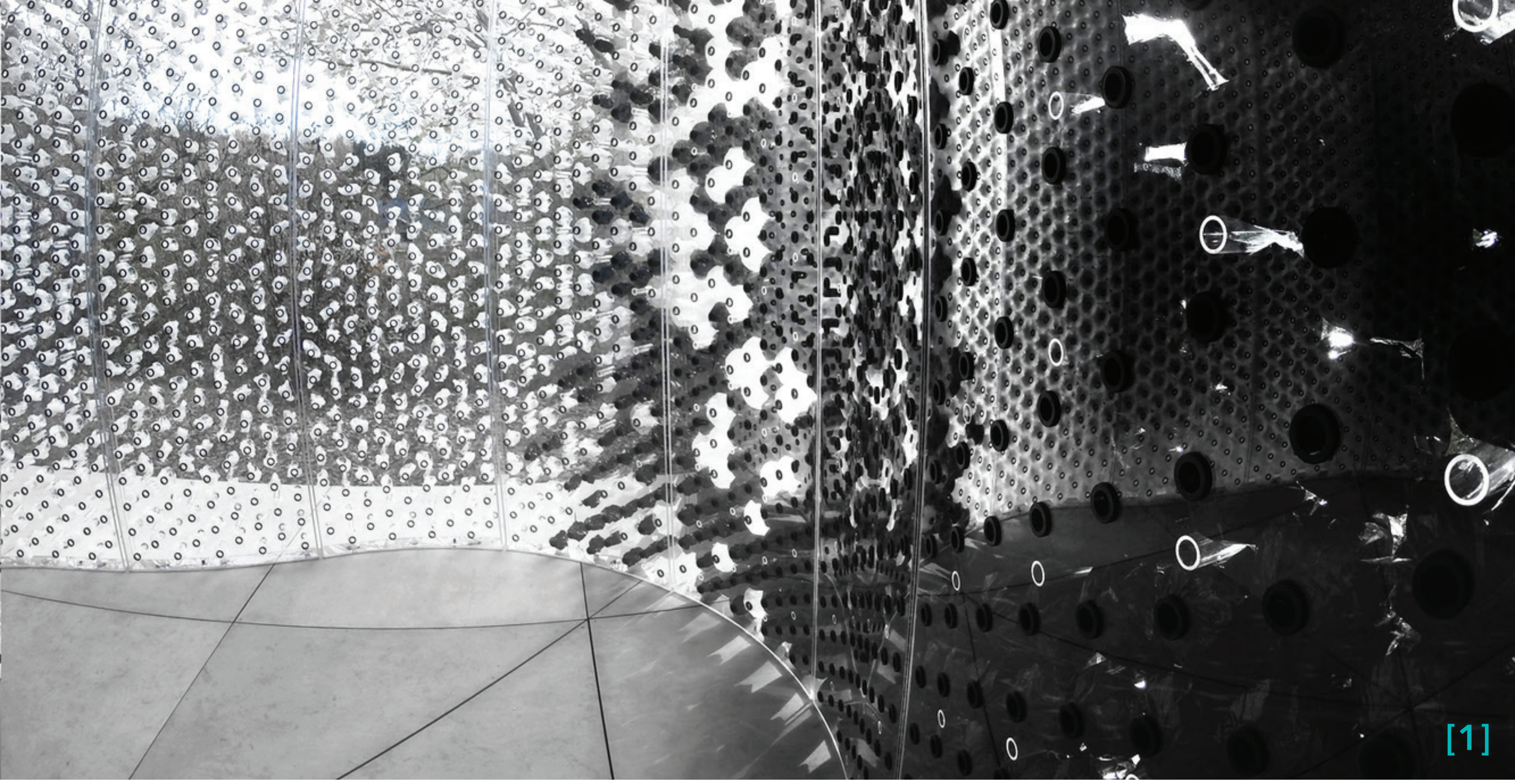
[1] [2] [3] Facade, interior view

[4] Facade component inspired by muscles

[5] Facade, exterior view



[1]

Breathing Skin showroom, 2015. Germany

The Breathing Skin showroom is an award winning project that presents a new technology of a responsive architecture that adapts to internal and external influences and requirements : Breathing Skins. The technology is inspired by organic skins that adjust their permeability to control the flow of substances between inside and outside. Pneumatic muscles regulate the amount of incident light, views, and air passing the Breathing Skin.

The technology is based on the idea of a skin that ´breathes´ through adjustable air channels. These channels can be closed pneumatically through the application of air pressure within the facade. On every square meter, 140 air channels are controlled without any visible technical installations. The deformation processes, operated by a pneumatic actuator, require minimal energetic input. Slight under pressure opens the pneumatic muscles, that are joined reversibly between two glass plates and can be separately dismantled and recycled. The more they widen, the more the appearance of the facade changes. This routine adapts locally the permeability for air, light and views.

Around 2800 air channels are integrated into the facade, that amounts a length of over ten meter, and an area of 25sqm. To achieve the appearance of a continuous skin, all constructive parts are assembled by extruded glass (Polycarbonat).

Name: Breathing Skin showroom
Year of construction: 2015
Climate: Temperate (Cfb)
City: Mandelbachtal
Country: Germany

Surface: 8 m²
Cost (€/m²): na
Project use: pavilion
Renovation: No

Data sheet completed by Estelle Cruz & Tessa Hubert (literature)

Data sheet reviewed by **Tobias Becker**
tb@breathingskins.com

References

- https://www.breathingskins.com/
- https://vimeo.com/195996560
- https://vimeo.com/158980746

Biomimetic

Definition
○ Biomimetics
● Bioinspiration
○ Biomimicry

Approach
● Biology-push
○ Technology-pull

Origins of bioinspiration
○ Random opportunities
● Interdisciplinary collaborations
○ Call for projects
○ Other

Targeted performance
● Thermal comfort
● Visual comfort
○ Acoustic comfort
● Air quality
○ Mechanical stress resistance
○ Water regulation

Integration scale of biomimetics
● Material (facade component)
○ Facade system
○ Building

Link to biology

Model kingdom
● Animalia: human skin
○ Plantae
○ Fungi
○ Bacteria/Archaea
○ Protozoa
○ Chromista / Ecosystems

Number of models
● One
○ Two
○ More

Type of knowledge
● Existing for general public
● Existing for specialist
○ Created during the design process

Inputs in biology
● Background of the designer
○ Acquisition during the design
○ Biologists integrated in the process

Design process

Use of design framework
○ Yes
● No

Eco-design approach
○ Yes
○ No

Major constraints
○ Lack of funds
○ Use of biomimetic tools
○ Law regulations
○ Technical problems
○ Other

Design complexity
● High (software, design process)
○ Low (well-known design)

Outcome

Technology readiness level
● TRL6 - demonstrated in relevant environment
○ TRL7 - system prototype demonstration in operational environment
○ TRL8 - system complete and qualified
○ TRL9 - actual system proven in operational environment

Overtime performance
● Still operating
○ Not operating yet
○ Destroyed

Construction complexity
● High (new technology)
○ Low (existing technology)

Main component of the building envelope
● Polymers
○ Alloys
○ Textiles
○ Wood
○ Concrete
○ Carbon-glass fiber

Level of innovation
● Breakthrough innovation
○ Improvement of existing systems

Adaptable to renovation
● Yes
○ No

Adaptability

Adaptation to stimuli
● Yes
○ No

Type of trigger (input)
○ Mechanical (e.g. wind load)
○ Thermal (e.g. air temperature)
○ Electromagnetic
○ Optical (e.g. daylight level)
○ Air quality (e.g. humidity)
○ Occupancy
● Other (internet data, BMS, etc.)

Type of actuator (output)
○ Mechanical
● Pneumatical
○ Electromagnetic
○ Thermal
○ Chemical
○ Other

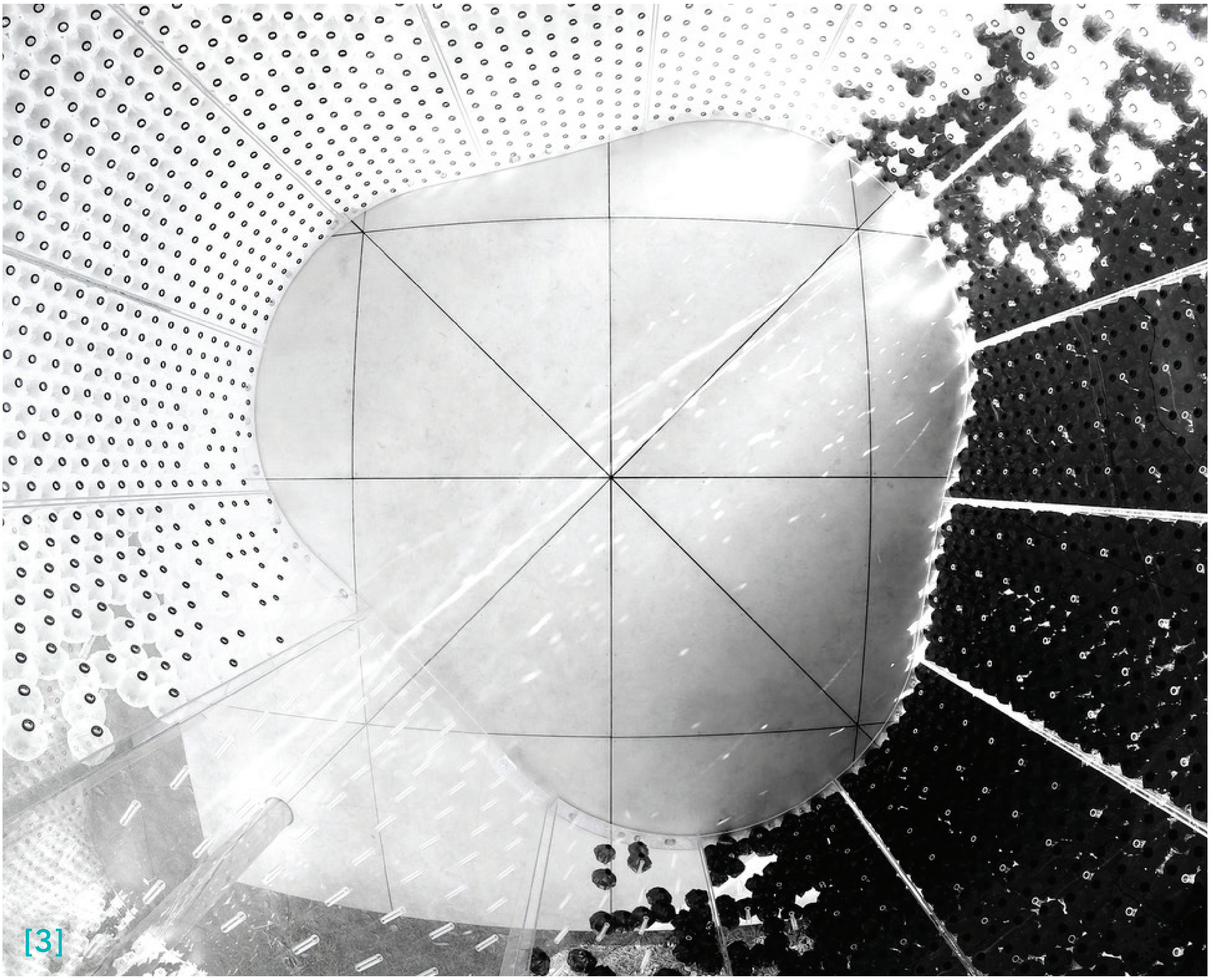
Control
○ Intrinsic (auto-reactive)
● Extrinsic (external control)

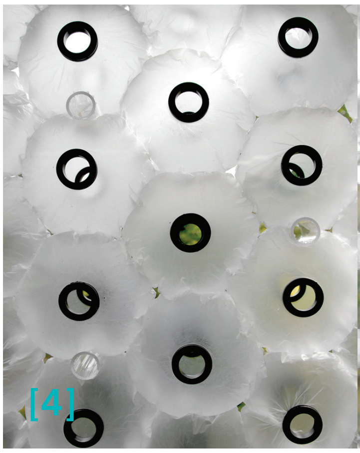
Response time
● Seconds
○ Minutes
○ Hours
○ Days
○ Weeks
○ Months

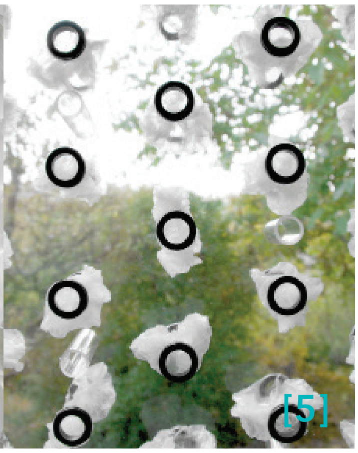
Spatial adaptation
○ Nanometers
○ Micrometers
○ Millimeters
● Centimeters
○ Meters

Material adaptation
○ Elasticity
● Inflatable
○ Bi-material
○ Other

Degree of adaptability
● On-Off
○ Gradual







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[1] Interior view

[2] Exterior view

[3] Top view

[4] [5] Pneumatic muscles regulate the amount of incident light, views, and air passing the Breathing Skin

[1]

Pho’liage, 2020. France

Like leaves or petals which open and close as a response to environmental conditions, a façade’s sunshade system can be designed to protect a building from overheating through overexposure to sunlight. The response is passive, requiring no energy or motorisation as the physical properties inherent in the material dictate its change in form.

The concept for the project initially arose from the observation of mechanisms that operate in the stomata, specialised orifice cells in the epidermis of plants. Each stoma opens when required to allow gaseous exchange between the plant and the surrounding air, and closes when the required equilibrium is achieved.

The design team aims to reproduce this automatic phenomenon on an architectural scale, not to achieve gaseous exchange but rather to control levels of solar gain. Material science is needed. Using existing knowledge of thermo-bimetals, two flexible alloys with varying thermal responses are identified according to the temperature range expected for a façade heated by the sun. The two alloys are bonded together using a cold lamination process. When subjected to temperature changes the bonded alloys bend together in a predictable fashion thanks to their respective expansion coefficients, always returning to their original form as the temperature returns to normal. This mechanical property can be repeated indefinitely.

Name: Pho’liage
Year of construction: 2020
Climate: Temperate (Cfb)
City: Lyon
Country: France

Dimension: 444 cm² area each trilobial petal-like components
Cost (€/m²): €300/m² for 8 trilobial (€ 30/pc)

Project use: Tertiary public
Renovation: Yes

Data sheet completed by Estelle Cruz & Tessa Hubert (literature & interview)

Data sheet reviewed by **Steven Ware**
swa@artbuild.com

References

• EMMANUELLE N’HAUX. (2018, March). A Lyon, le biomimétisme inspire le futur bâtiment du Circ. Retrieved from https://www.lemoniteur.fr/article/a-lyon-le-biomimetisme-inspire-le-futur-batiment-du-circ.1953634

• https://www.artbuild.eu/projects/laboratories/circ-iarc-lyon-international-agency-research-cancer

• https://www.artbuild.eu/sites/default/files/press/hs_29_art_build_hd-compressed.pdf

Biomimetic

Definition
- ● Biomimetics
- ○ Bioinspiration
- ○ Biomimicry

Approach
- ○ Biology-push
- ● Technology-pull

Origins of bioinspiration
- ○ Random opportunities
- ● Interdisciplinary collaborations
- ○ Call for projects
- ○ Other

Targeted performance
- ● Thermal comfort
- ● Visual comfort
- ○ Acoustic comfort
- ○ Air quality
- ○ Mechanical stress resistance
- ○ Water regulation

Integration scale of biomimetics
- ● Material (facade component)
- ○ Facade system
- ○ Building

Link to biology

Model kingdom
- ○ Animalia
- ● Plantae: angiosperms
- ○ Fungi
- ○ Bacteria/Archaea
- ○ Protozoa
- ○ Chromista / Ecosystems

Number of models
- ● One
- ○ Two
- ○ More

Type of knowledge
- ● Existing for general public
- ● Existing for specialist
- ○ Created during the design process

Inputs in biology
- ○ Background of the designer
- ○ Acquisition during the design
- ● Biologists integrated in the process

Design process

Use of design framework
- ○ Yes
- ● No

Eco-design approach
- ● Yes
- ○ No

Major constraints
- ○ Lack of funds
- ○ Use of biomimetic tools
- ● Law regulations
- ● Technical problems
- ○ Other

Design complexity
- ● High (software, design process)
- ○ Low (well-known design)

Outcome

Technology readiness level
- ○ TRL6 - demonstrated in relevant environment
- ○ TRL7 - system prototype demonstration in operational environment
- ● TRL8 - system complete and qualified
- ○ TRL9 - actual system proven in operational environment

Overtime performance
- ● Still operating
- ○ Not operating yet
- ○ Destroyed

Construction complexity
- ● High (new technology)
- ○ Low (existing technology)

Main component of the building envelope
- ○ Polymers
- ● Alloys
- ○ Textiles
- ○ Wood
- ○ Concrete
- ○ Carbon-glass fiber

Level of innovation
- ● Breakthrough innovation
- ○ Improvement of existing systems

Adaptable to renovation
- ● Yes
- ○ No

Adaptability

Adaptation to stimuli
- ● Yes
- ○ No

Type of trigger (input)
- ○ Mechanical (e.g. wind load)
- ● Thermal (e.g. air temperature)
- ○ Electromagnetic
- ○ Optical (e.g. daylight level)
- ○ Air quality (e.g. humidity)
- ○ Occupancy
- ○ Other (internet data, BMS, etc.)

Type of actuator (output)
- ○ Mechanical
- ○ Pneumatical
- ○ Electromagnetic
- ● Thermal
- ○ Chemical
- ○ Other

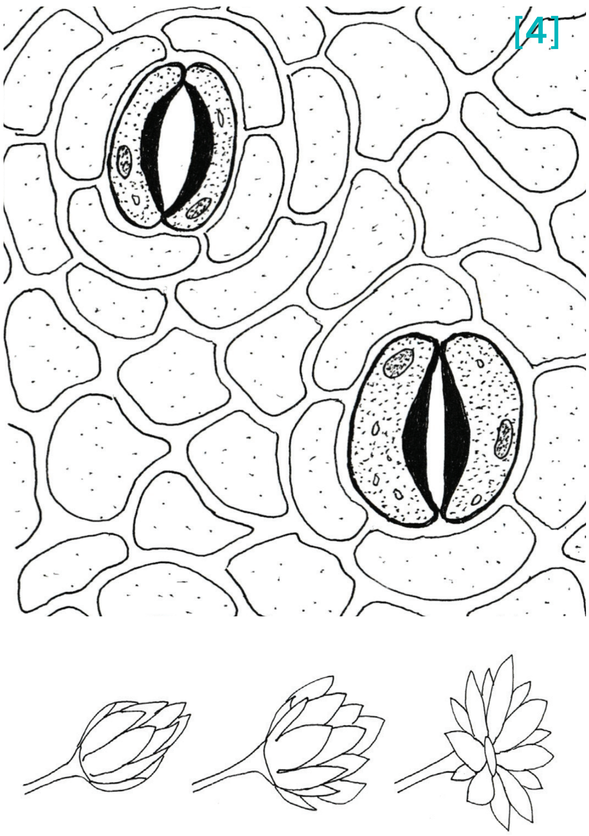
Control
- ● Intrinsic (auto-reactive)
- ○ Extrinsic (external control)

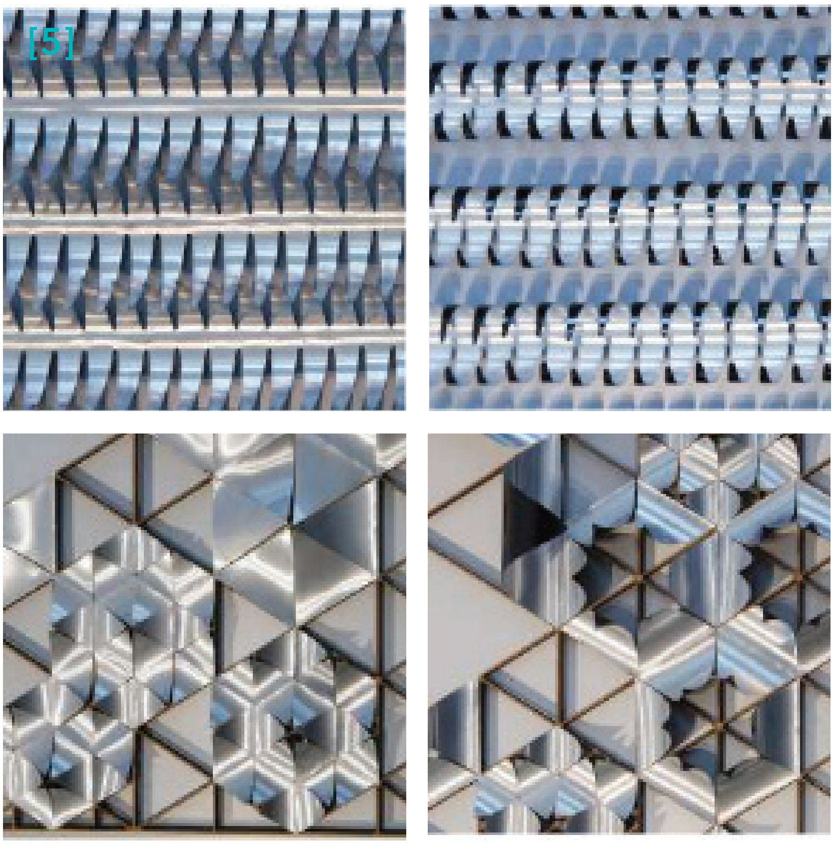
Response time
- ○ Seconds
- ● Minutes
- ○ Hours
- ○ Days
- ○ Weeks
- ○ Months

Spatial adaptation
- ○ Nanometers
- ○ Micrometers
- ○ Millimeters
- ● Centimeters
- ○ Meters

Material adaptation
- ○ Elasticity
- ○ Inflatable
- ● Bi-material
- ○ Other

Degree of adaptability
- ○ On-Off
- ● Gradual





Pictures and credits
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[1] Pho'liage picture
[2] Exterior rendering and areal view of the the CIRC
[3] Pho'liage picture
[4] Biomimetic inspiration (stomata and flower opeining)
[5] Old prototypes of Pho'liage


[1]

Sierpinski Forest prototypes, 2019. Japan

The Sierpinski Forest system is a roof of assembled modules that reduces the heating of large areas including urban heat islands. These modules are inspired by the fractal geometry of trees and Sierpinski's tetrahedron, a mathematical object with the same fractal dimensions. The fractal shape of the tetrahedron allows heat dissipation while ensuring a shaded area.

The roof, consisting of several units, blocks 100% of the light rays, coming from a specific direction, or from all directions at the hottest hours of the day in summer. Rays from other directions penetrate the roof partially and create a shaded area under the roof.

This prototype has been tested at the Taiwan Museum of Fine Arts designed by architect Shigeru Ban. Since Tainan has strong solar radiation all throughout the year, in order to create shading for the entire building, the architecture studio Shigeru Ban Architect developed "Fractal Shading", with Professor Satoshi Sakai of Kyoto University. He originally developed a plastic pergola type of fractal shading, and they adapt its prototype to a large scale metal version to shade the whole building.

Name: Fine Art Museum
Year of construction: 2019
Climate: Temperate (Cfb)
City: Tainan
Country: Taiwan

Surface: 19 071 m²
Cost (£/m²): na
Project use: tertiary public building
Renovation: No

京都大学
KYOTO UNIVERSITY

Data sheet completed by Tessa Hubert (literature) & Estelle Cruz (research exchange of three months at Kyoto University in 2015).

Contact: **Pr. Satoshi Sakai**, University of Kyoto - sakai@gaia.h.kyoto-u.ac.jp

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- ● Random opportunities
- ○ Interdisciplinary collaborations
- ○ Call for projects
- ○ Other

Targeted performance
- ● Thermal comfort
- ● Visual comfort
- ○ Acoustic comfort
- ○ Air quality
- ○ Mechanical stress resistance
- ○ Water regulation

Integration scale of biomimetics
- ○ Material (facade component)
- ● Facade system
- ○ Building

Link to biology

Model kingdom
- ○ Animalia
- ● Plantae: trees
- ○ Fungi
- ○ Bacteria/Archaea
- ○ Protozoa
- ○ Chromista / Ecosystems

Number of models
- ● One
- ○ Two
- ○ More

Type of knowledge
- ○ Existing for general public
- ● Existing for specialist
- ● Created during the design process

Inputs in biology
- ● Background of the designer
- ● Acquisition during the design
- ○ Biologists integrated in the process

Design process

Use of design framework
- ○ Yes
- ● No

Eco-design approach
- ● Yes
- ○ No

Major constraints
- ○ Lack of funds
- ○ Use of biomimetic tools
- ○ Law regulations
- ○ Technical problems
- ● Other

Design complexity
- ○ High (software, design process)
- ● Low (well-known design)

Outcome

Technology readiness level
- ○ TRL6 - demonstrated in relevant environment
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Overtime performance
- ● Still operating
- ○ Not operating yet
- ○ Destroyed

Construction complexity
- ○ High (new technology)
- ● Low (existing technology)

Main component of the building envelope
- ● Polymers
- ● Alloys
- ○ Textiles
- ○ Wood
- ○ Concrete
- ○ Carbon-glass fiber

Level of innovation
- ● Breakthrough innovation
- ○ Improvement of existing systems

Adaptable to renovation
- ● Yes
- ○ No

Adaptability

Adaptation to stimuli
- ○ Yes
- ● No

Type of trigger (input)
- ○ Mechanical (e.g. wind load)
- ○ Thermal (e.g. air temperature)
- ○ Electromagnetic
- ○ Optical (e.g. daylight level)
- ○ Air quality (e.g. humidity)
- ○ Occupancy
- ○ Other (internet data, BMS, etc.)

Type of actuator (output)
- ○ Mechanical
- ○ Pneumatical
- ○ Electromagnetic
- ○ Thermal
- ○ Chemical
- ○ Other

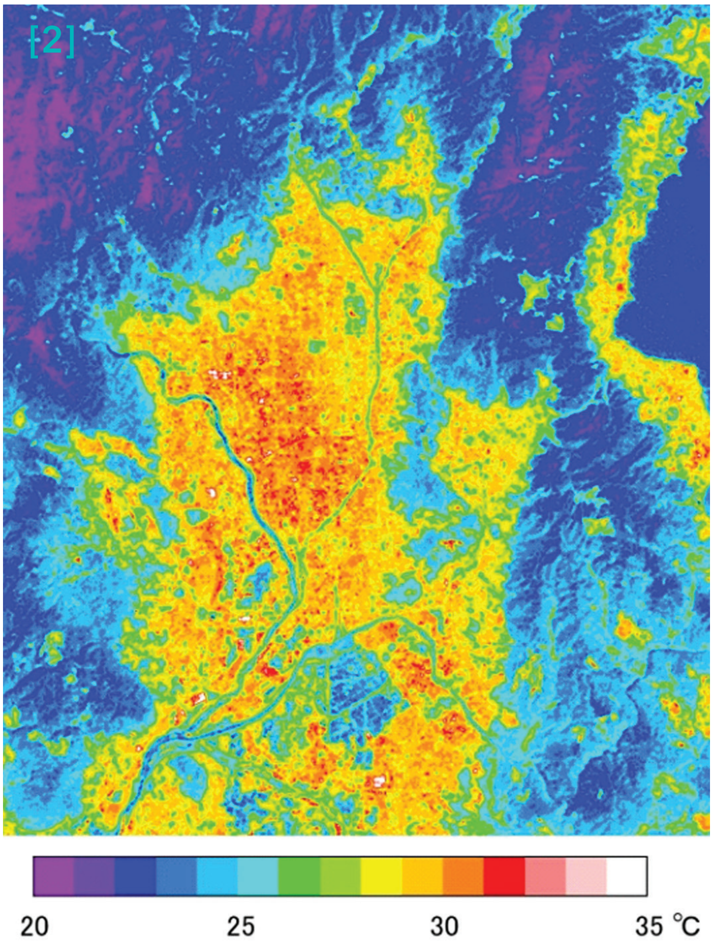
Control
- ○ Intrinsic (auto-reactive)
- ○ Extrinsic (external control)

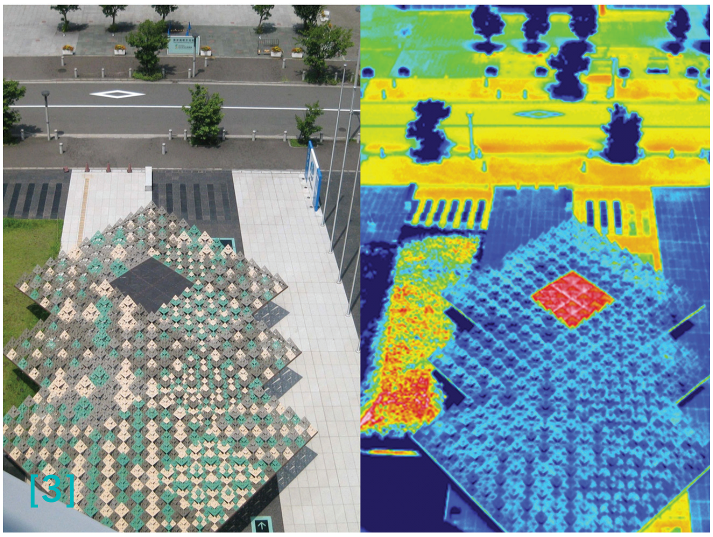
Response time
- ○ Seconds
- ○ Minutes
- ○ Hours
- ○ Days
- ○ Weeks
- ○ Months

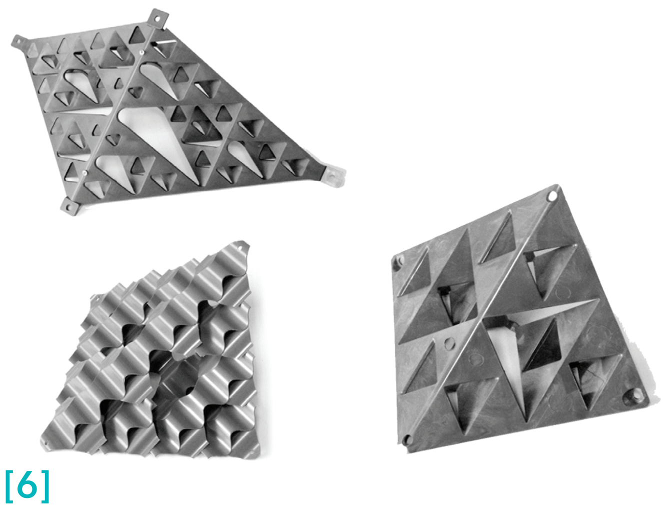
Spatial adaptation
- ○ Nanometers
- ○ Micrometers
- ○ Millimeters
- ○ Centimeters
- ○ Meters

Material adaptation
- ○ Elasticity
- ○ Inflatable
- ○ Bi-material
- ○ Other

Degree of adaptability
- ○ On-Off
- ○ Gradual







Pictures and credits

[1] Sierpinski Forest prototype CC0 Estelle Cruz

[2] Earth's surface temperature of around Kyoto, August 25, 2000 © LANDSAT

[3] Sierpinski Forest simulation at the scale of Kyoto with Pr. Satoshi Sakai. CC0 Estelle Cruz

[4] Sierpinski Forest simulations © Prof. Satoshi Sakai

[5] Sierpinski plastic tetrahedron. CC0 Estelle Cruz

[6] Sierpinski models © Prof. Satoshi Sakai

Esplanade – Theatres on the Bay. Singapore

The initial design idea called for a fully glazed design because the views from the building are beautiful in all directions. But Singapore is so close to the equator, in the hot climate of Singapore, a fully glazed building would have let overheat and /or very high-energy consumption for cooling. A new design concept is the intent of generating an alternative skin strategy that would help to mediate excessive solar heat gain while still preserving the desired architectural expression and views.

The durian fruit (Durio zibethinus), the fruit wall, the 'pericarp', is composed of three layers, the outer most layer 'exocarp', the middle layer 'mesocarp' and the inner most layer 'endocarp. The sponge like material of the middle layer has a thermal property to help keeping the durian fruit always fresh and secure inside the cocoon, while the outer layer has the spikes-like characteristic that helps to protect the fruit from overheat from the sun radiation.

The external fins vary in geometry around the building to allow views outside while still providing the maximum amount of shading. The fin-shading devices allow the building to have a transparent façade to give unobstructed views of the outside from the performing centre, while blocking out the glare of sunlight.

Name: Esplanade theater Singapore
Year of construction: 1996 - 2002
Climate: Tropical rainforest (Af)
City: Singapore
Country: Singapore

Surface: 80 500 m²
Cost (€/m²): 350 millions € total cost, (4 655 € / m²)
Project use: museum
Renovation: no

MICHAEL WILFORD

atelier one STRUCTURAL ENGINEERS

DPA DP ARCHITECTS

Data sheet completed by Estelle Cruz, Tessa Hubert (literature) and Natasha Chayaamor-Heil (interview and visit of the building in 2012).

Data sheet reviewed by **Michael Wilford**
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References

• https://www.michaelwilford.com/
• http://www.atelierone.com/singapore-arts-centre

Biomimetic

Definition
- ● Biomimetics
- ○ Bioinspiration
- ○ Biomimicry

Approach
- ○ Biology-push
- ● Technology-pull

Origins of bioinspiration
- ○ Random opportunities
- ○ Interdisciplinary collaborations
- ○ Call for projects
- ● Other

Targeted performance
- ● Thermal comfort
- ● Visual comfort
- ○ Acoustic comfort
- ○ Air quality
- ○ Mechanical stress resistance
- ○ Water regulation

Integration scale of biomimetics
- ○ Material (facade component)
- ● Facade system
- ○ Building

Link to biology

Model kingdom
- ○ Animalia: Coleoptera coccinellidae
- ● Plantae
- ○ Fungi
- ○ Bacteria/Archaea
- ○ Protozoa
- ○ Chromista / Ecosystems

Number of models
- ● One
- ○ Two
- ○ More

Type of knowledge
- ● Existing for general public
- ○ Existing for specialist
- ○ Created during the design process

Inputs in biology
- ● Background of the designer
- ○ Acquisition during the design
- ○ Biologists integrated in the process

Design process

Use of design framework
- ○ Yes
- ○ No

Eco-design approach
- ● Yes
- ○ No

Major constraints
- ○ Lack of funds
- ○ Use of biomimetic tools
- ○ Law regulations
- ○ Technical problems
- ○ Other

Design complexity
- ● High (software, design process)
- ○ Low (well-known design)

Outcome

Technology readiness level
- ○ TRL6 - demonstrated in relevant environment
- ○ TRL7 - system prototype demonstration in operational environment
- ○ TRL8 - system complete and qualified
- ● TRL9 - actual system proven in operational environment

Overtime performance
- ● Still operating
- ○ Not operating yet
- ○ Destroyed

Construction complexity
- ● High (new technology)
- ○ Low (existing technology)

Main component of the building envelope
- ○ Polymers
- ● Alloys (Aluminium for fins and metal for nodes)
- ○ Textiles
- ○ Wood
- ○ Concrete

Level of innovation
- ● Breakthrough innovation
- ○ Improvement of existing systems

Adaptable to renovation
- ● Yes
- ○ No

Adaptability

Adaptation to stimuli
- ○ Yes
- ● No

Type of trigger (input)
- ○ Mechanical (e.g. wind load)
- ○ Thermal (e.g. air temperature)
- ○ Electromagnetic
- ○ Optical (e.g. daylight level)
- ○ Air quality (e.g. humidity)
- ○ Occupancy
- ○ Other (internet data, BMS, etc.)

Type of actuator (output)
- ○ Mechanical
- ○ Pneumatical
- ○ Electromagnetic
- ○ Thermal
- ○ Chemical
- ○ Other

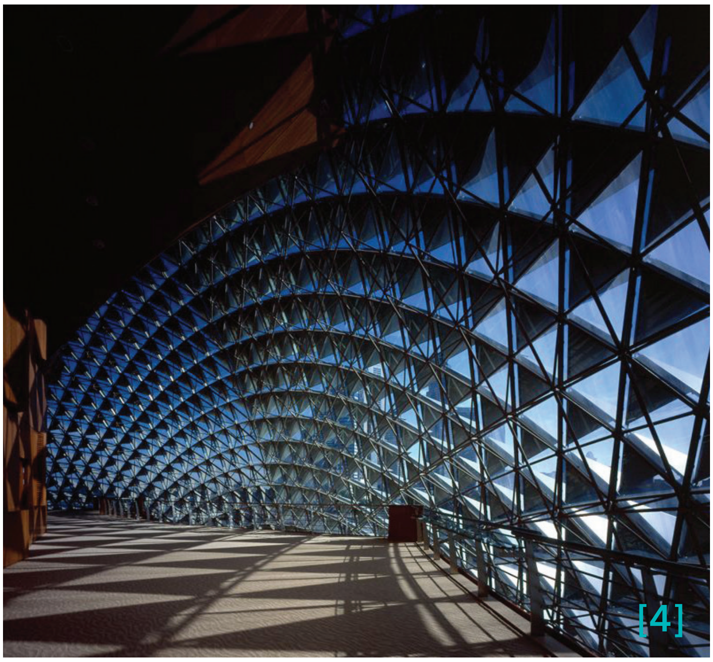
Control
- ○ Intrinsic (auto-reactive)
- ○ Extrinsic (external control)

Response time
- ○ Seconds
- ○ Minutes
- ○ Hours
- ○ Days
- ○ Weeks
- ○ Months

Spatial adaptation
- ○ Nanometers
- ○ Micrometers
- ○ Millimeters
- ○ Centimeters
- ○ Meters

Material adaptation
- ○ Elasticity
- ○ Inflatable
- ○ Bi-material
- ○ Other

Degree of adaptability
- ○ On-Off
- ○ Gradual



Pictures and credits

[1] Riverside view, Use by permission from © Tom Ravenscroft

[2] Building façade detail, CC0 Creative Commons

[4] Areal view, use by permission from © DP Architects

[3] Inside view, use by permission from © DP Architects


[1]

Eden Project 2001, Cornwall

Designed by Grimshaw Architects, the two Biome buildings each consist of several domes joined together, and are joined in the middle by the Link building. Grimshaw's starting point was the geodesic system made famous by the American architect Buckminster Fuller, who designed the Montreal Biosphere in Canada. Before Eden, Grimshaw had designed a similar structure for Waterloo International Station in London. The geodesic concept provided for least weight and maximum surface area on the curve – with strength.

Each dome has what's known as a hex-tri-hex space frame with two layers. The outer layer is made of hexagons (the largest is 11 metres across), plus the odd pentagon. The inner layer comprises hexagons and triangles bolted together. The steelwork weighs only slightly more than the air contained by the Biomes.

The transparent 'windows' in each hexagon and pentagon are made of ethylene tetrafluoroethylene copolymer (ETFE), or 'cling film with attitude', as we like to call it. Each window has three layers of this incredible stuff, inflated to create a two-metre-deep pillow. Although our ETFE windows are very light (less than 1% of the equivalent area of glass) they are strong enough to take the weight of a car. What's more, ETFE can transmit UV light, and is non-stick, self-cleaning and lasts for over 25 years.

Name: The Eden Project
Year of construction: 2001
Climate: Temperate (Cfb)
City: Cornwall
Country: England

Surface: 23 000 m²
Cost (£/m²): £ 160 millions / $ 239 millions = 10 000 $ / m²
Project use: green house (tertiary private)
Renovation: No

GRIMSHAW

Data sheet completed by Estelle Cruz & Tessa Hubert (literature), Natasha Chayaamor-Heil (interview)

Data sheet reviewed by **Andy Watts** - andy.watts@grimshaw-architects.com

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Biomimetic

Definition
- ● Biomimetics
- ● Bioinspiration
- ○ Biomimicry

Approach
- ○ Biology-push
- ● Technology-pull

Origins of bioinspiration
- ○ Random opportunities
- ○ Interdisciplinary collaborations
- ○ Call for projects
- ● Other

Targeted performance
- ○ Thermal comfort
- ○ Visual comfort
- ○ Acoustic comfort
- ○ Air quality
- ● Mechanical stress resistance
- ○ Water regulation

Integration scale of biomimetics
- ○ Material (facade component)
- ○ Facade system
- ● Building

Link to biology

Model kingdom
- ○ Animalia: Coleoptera coccinellidae
- ○ Plantae
- ○ Fungi
- ○ Bacteria/Archaea
- ○ Protozoa
- ● Other: soap formation

Number of models
- ● One
- ○ Two
- ○ More

Type of knowledge
- ● Existing for general public
- ○ Existing for specialist
- ○ Created during the design process

Inputs in biology
- ● Background of the designer
- ● Acquisition during the design
- ○ Biologists integrated in the process

Design process

Use of design framework
- ○ Yes
- ● No

Eco-design approach
- ● Yes
- ○ No

Major constraints
- ○ Lack of funds
- ○ Use of biomimetic tools
- ○ Law regulations
- ○ Technical problems
- ○ Other

Design complexity
- ● High (software, design process)
- ○ Low (well-known design)

Outcome

Technology readiness level
- ○ TRL6 - demonstrated in relevant environment
- ○ TRL7 - system prototype demonstration in operational environment
- ○ TRL8 - system complete and qualified
- ● TRL9 - actual system proven in operational environment

Overtime performance
- ● Still operating
- ○ Not operating yet
- ○ Destroyed

Construction complexity
- ● High (new technology)
- ○ Low (existing technology)

Main component of the building envelope
- ● Polymers: ETFE
- ● Alloys: lightweigh steel
- ○ Textiles
- ○ Wood
- ○ Concrete
- ○ Carbon-glass fiber

Level of innovation
- ○ Breakthrough innovation
- ● Improvement of existing systems

Adaptable to renovation
- ○ Yes
- ● No

Adaptability

Adaptation to stimuli
- ○ Yes
- ● No

Type of trigger (input)
- ○ Mechanical (e.g. wind load)
- ○ Thermal (e.g. air temperature)
- ○ Electromagnetic
- ○ Optical (e.g. daylight level)
- ○ Air quality (e.g. humidity)
- ○ Occupancy
- ○ Other (internet data, BMS, etc.)

Type of actuator (output)
- ○ Mechanical
- ○ Pneumatical
- ○ Electromagnetic
- ○ Thermal
- ○ Chemical
- ○ Other

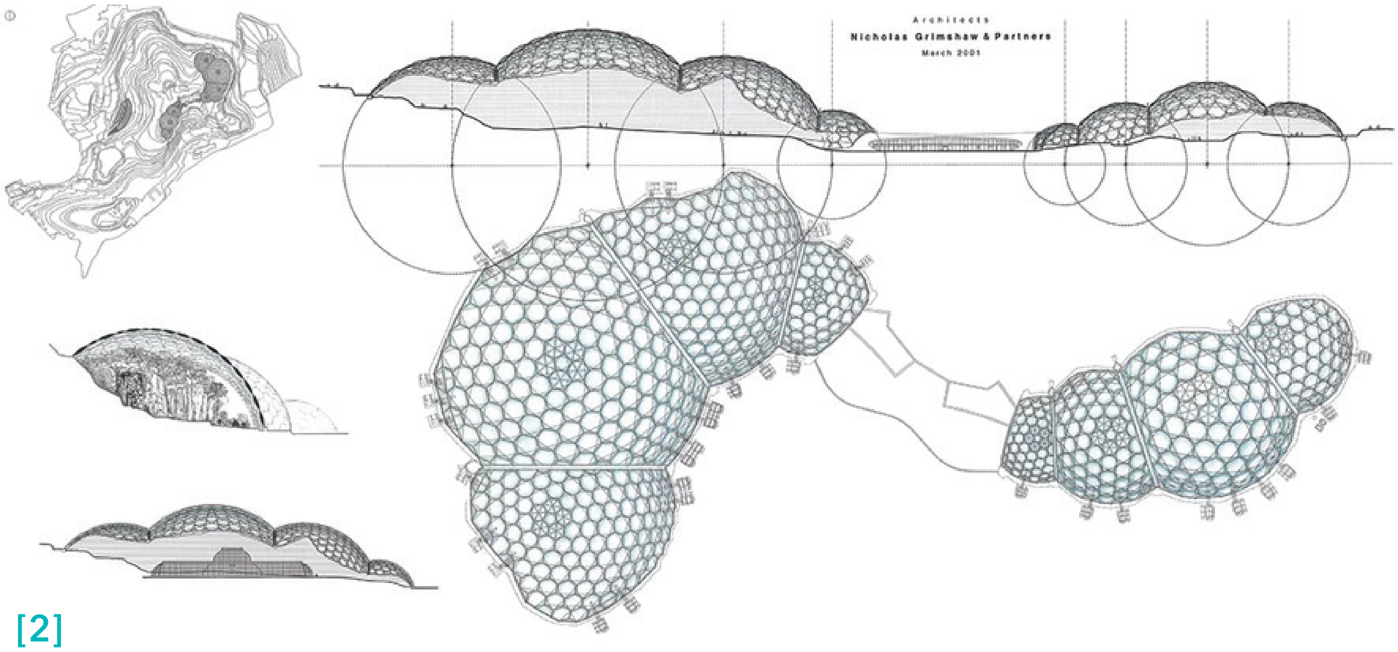
Control
- ○ Intrinsic (auto-reactive)
- ○ Extrinsic (external control)

Response time
- ○ Seconds
- ○ Minutes
- ○ Hours
- ○ Days
- ○ Weeks
- ○ Months

Spatial adaptation
- ○ Nanometers
- ○ Micrometers
- ○ Millimeters
- ○ Centimeters
- ○ Meters

Material adaptation
- ○ Elasticity
- ○ Inflatable
- ○ Bi-material
- ○ Other

Degree of adaptability
- ○ On-Off
- ○ Gradual



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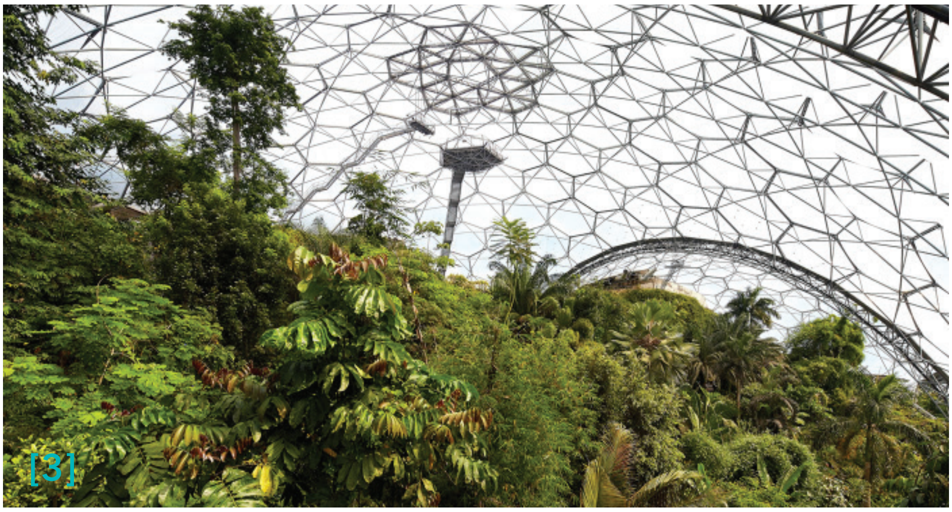


[3]

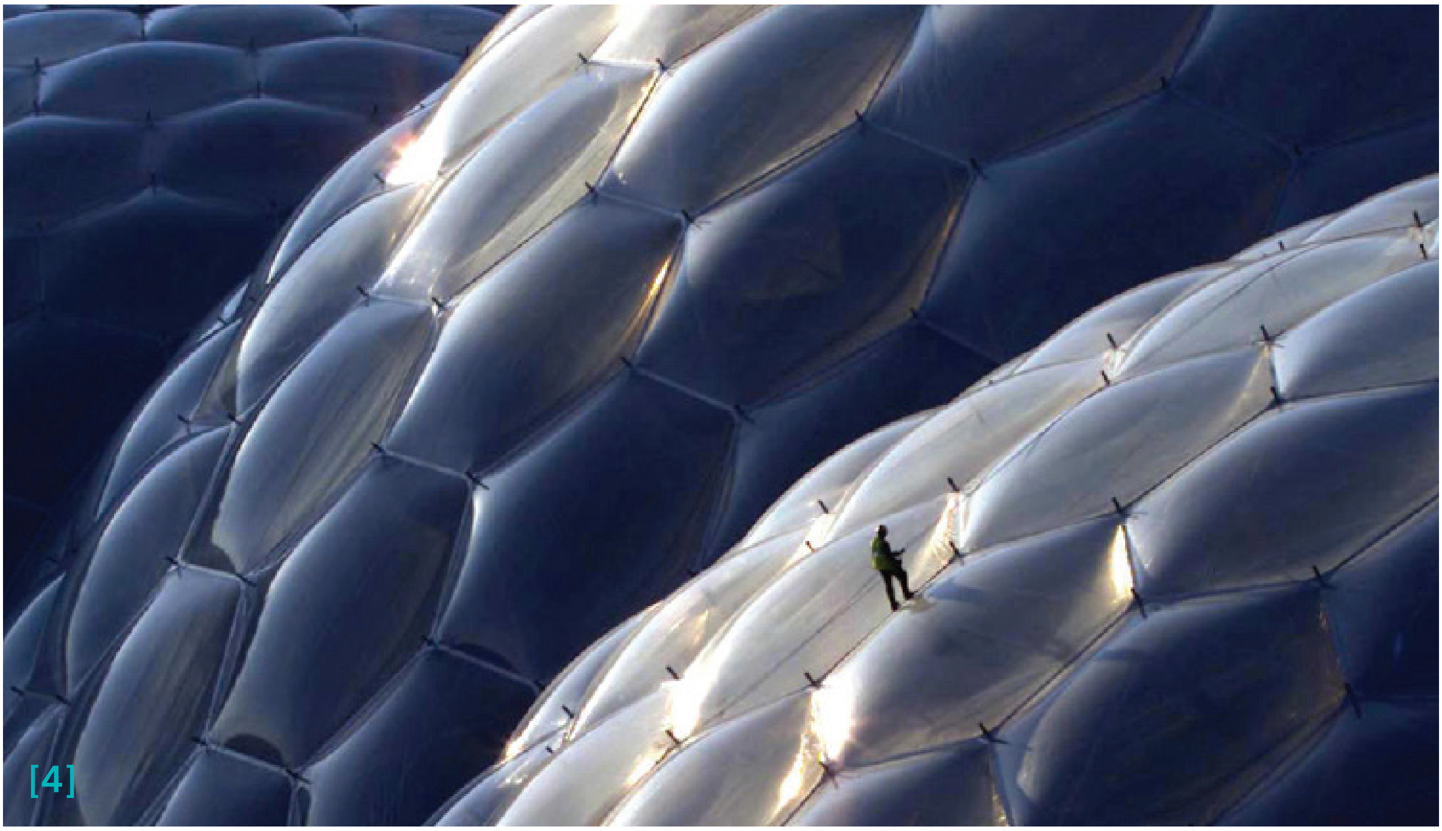
Pictures and credits

[1] Aerial view use by permission from © Tamsyn Williams

[2] Plan and section use by permission from © Grimshaw Architects

[3] Inside view use by permission from © Hufton + Crow

[4] Top view use by permission from © Hufton + Crow



[4]


[1]

West German Pavilion 1967, Montreal

"In collaboration with architect Rolf Gutbrod, Frei Otto was responsible for the exhibition pavilion of the Federal Republic of Germany, a tensile canopy structure that brought his experiments in lightweight architecture to the international stage for the first time.

The origin of Otto's fascination with tensile structures and minimally resource-intensive design dates to his experiences during the Second World War. After the war ended, he translated these efforts into a full-time architectural pursuit, investigating their potential application on an industrial scale. His radically simple design premise—creating an architecture guided by resource conservation, structural intelligence, and construction efficiency—found warm reception in the optimistic intellectual culture of the 1950s and 60s. Otto believed that his tensile canopies promised an architectural solution that was cheap, durable, and highly versatile."

Extracted from *https://www.archdaily.com/623689/ad-classics-german-pavilion-expo-67-frei-otto-and-rolf-gutbrod*

Name: West German Pavilion
Year of construction: 1967
Climate: 1967
City: Montreal
Country: Canada

Surface: 8 000 m^2
Cost (€/m²): na
Project use: exhibition
Renovation: no

Data sheet completed by Estelle Cruz & Tessa Hubert (literature)

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Biomimetic

Definition
● Biomimetics
○ Bioinspiration
○ Biomimicry

Approach
● Biology-push
○ Technology-pull

Origins of bioinspiration
○ Random opportunities
○ Interdisciplinary collaborations
○ Call for projects
● Other

Targeted performance
○ Thermal comfort
○ Visual comfort
○ Acoustic comfort
○ Air quality
● Mechanical stress resistance
○ Water regulation

Integration scale of biomimetics
○ Material (facade component)
● Facade system
○ Building

Link to biology

Model kingdom
○ Animalia: Coleoptera coccinellidae
○ Plantae
○ Fungi
○ Bacteria/Archaea
● Protozoa
○ Chromista / Ecosystems

Number of models
○ One
○ Two
● More

Type of knowledge
● Existing for general public
● Existing for specialist
● Created during the design process

Inputs in biology
● Background of the designer
● Acquisition during the design
● Biologists integrated in the process

Design process

Use of design framework
● Yes
○ No

Eco-design approach
● Yes
○ No

Major constraints
○ Lack of funds
○ Use of biomimetic tools
○ Law regulations
○ Technical problems
○ Other

Design complexity
● High (software, design process)
○ Low (well-known design)

Outcome

Technology readiness level
○ TRL6 - demonstrated in relevant environment
○ TRL7 - system prototype demonstration in operational environment
○ TRL8 - system complete and qualified
● TRL9 - actual system proven in operational environment

Overtime performance
● Still operating
○ Not operating yet
○ Destroyed

Construction complexity
● High (new technology)
○ Low (existing technology)

Main component of the building envelope
○ Polymers
○ Alloys
● Textiles
○ Wood
○ Concrete
○ Carbon-glass fiber

Level of innovation
● Breakthrough innovation
○ Improvement of existing systems

Adaptable to renovation
● Yes
○ No

Adaptability

Adaptation to stimuli
○ Yes
● No

Type of trigger (input)
○ Mechanical (e.g. wind load)
○ Thermal (e.g. air temperature)
○ Electromagnetic
○ Optical (e.g. daylight level)
○ Air quality (e.g. humidity)
○ Occupancy
○ Other (internet data, BMS, etc.)

Type of actuator (output)
○ Mechanical
○ Pneumatical
○ Electromagnetic
○ Thermal
○ Chemical
○ Other

Control
○ Intrinsic (auto-reactive)
○ Extrinsic (external control)

Response time
○ Seconds
○ Minutes
○ Hours
○ Days
○ Weeks
○ Months

Spatial adaptation
○ Nanometers
○ Micrometers
○ Millimeters
○ Centimeters
○ Meters

Material adaptation
○ Elasticity
○ Inflatable
○ Bi-material
○ Other

Degree of adaptability
○ On-Off
○ Gradual


[2]

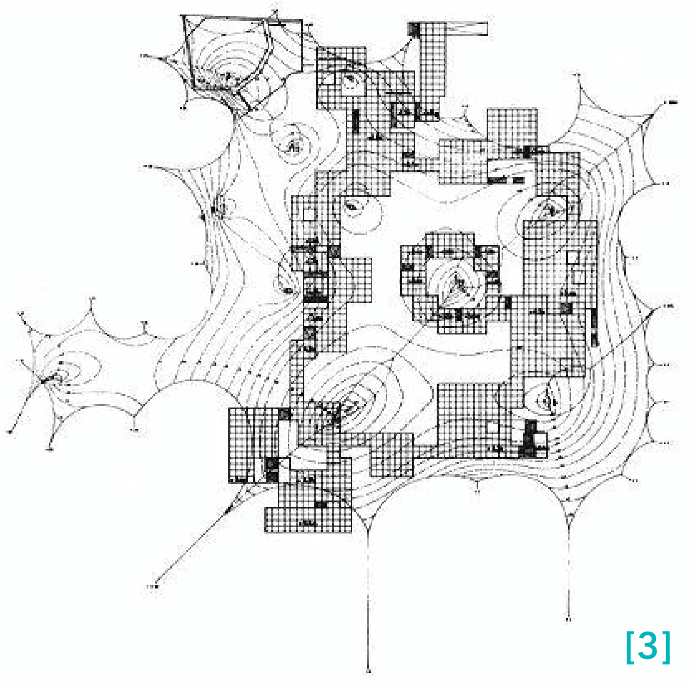
Pictures and credits © Frei Otto

[1] External view

[2] Internal view, 1967

[3] Plan (source greatbuilding.com)

[4] Form-finding study model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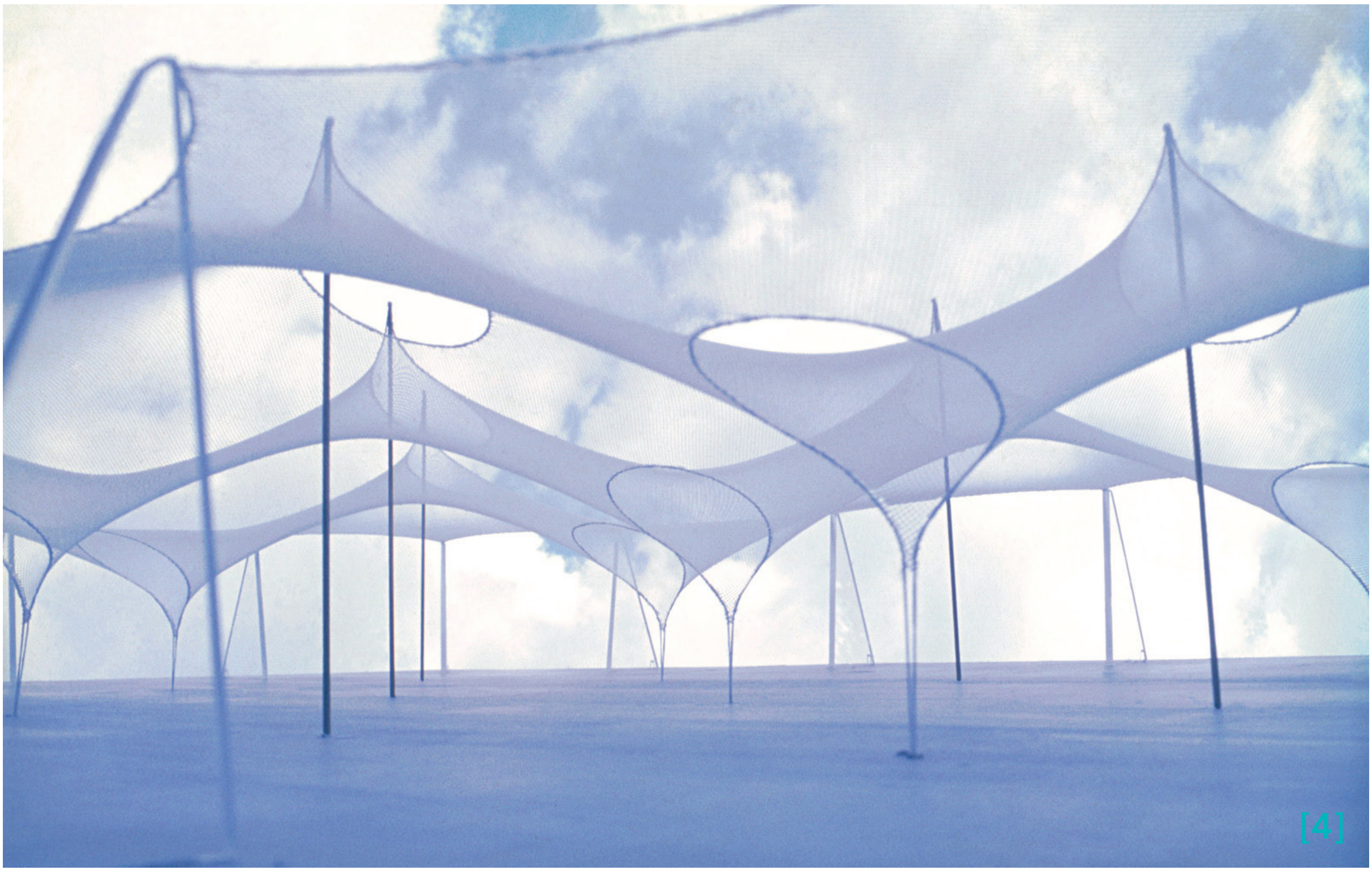
[4]


[1]

Eastgate, 1996. Zimbabwe

The Eastgate building is a commercial building and offices in Harare. Eastgate comprises two buildings side by side linked together by a glass roof.

Inspired by the ventilation system of termite mounds, the building is ventilated and thermoregulated passively. As the termite mound ventilation system, the building captures fresh air in the lower part of the building. Then the fresh air is conveyed into the collective spaces and evacuated with the chimneys on the roof. The air circulation is accentuated by building materials with high thermal inertia (bricks and granite). The structure absorbs freshness during the night and restores it during the day. Conversely, at night, the walls diffuse the heat stored during the day. The hot air being heavier than the cold, it is attracted upwards and then evacuated by 48 large chimneys. The data logger graph shows that in average conditions covering ten months of the year 3°C of cooling between outside and inside temperature is achieved. Optimum cooling is achieved when the external night temperature falls below 20°C.

Thus, the building consumes 35% less energy compared to the average consumption of six conventional buildings in Harare with full HVAC. The saving on capital cost compared with full HVAC was 10% of total building cost.

Name: Eastgate Building
Year of construction: 1993-1996
Climate: Oceanic (Cwb)
City: Harare
Country: Zimbabwe

Surface: 26 000 m²
(including 9313 m² ground floor)

Cost without land (€/m²): $30 million, $595 / m²
Project use: tertiary private building
Renovation: No

ARUP

Data sheet completed by Tessa Hubert (literature) & Estelle Cruz (during a research exchange of three months at Pearce Partnership in 2015).

Data sheet reviewed by **Mick Pearce**
anthill.mick@gmail.com

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Biomimetic

Definition
○ Biomimetics
○ Bioinspiration
● Biomimicry

Approach
● Biology-push
○ Technology-pull

Origins of bioinspiration
● Random opportunities
○ Interdisciplinary collaborations
○ Call for projects
○ Other

Targeted performance
● Thermal comfort
● Visual comfort
○ Acoustic comfort
● Air quality
○ Mechanical stress resistance
○ Water regulation

Integration scale of biomimetics
○ Material (facade component)
○ Facade system
● Building

Link to biology

Model kingdom
● Animalia: Termites Odontotermes
● Plantae: Cactaceae
○ Fungi
○ Bacteria/Archaea
○ Protozoa
○ Chromista / Ecosystems

Number of models
○ One
● Two
○ More

Type of knowledge
● Existing for general public
● Existing for specialist
● Created during the design process

Inputs in biology
● Background of the designer
○ Acquisition during the design
○ Biologists integrated in the process

Design process

Use of design framework
○ Yes
● No

Eco-design approach
● Yes
○ No

Major constraints
○ Lack of funds
○ Use of biomimetic tools
○ Law regulations
○ Technical problems
● Other

Design complexity
○ High (software, design process)
● Low (well-known design)

Outcome

Technology readiness level
○ TRL6 - demonstrated in relevant environment
○ TRL7 - system prototype demonstration in operational environment
○ TRL8 - system complete and qualified
● TRL9 - actual system proven in operational environment

Overtime performance
● Still operating
○ Not operating yet
○ Destroyed

Construction complexity
○ High (new technology)
● Low (existing technology)

Main component of the building envelope
○ Polymers
○ Alloys
○ Textiles
○ Wood
● Concrete
○ Carbon-glass fiber

Level of innovation
○ Breakthrough innovation
● Improvement of existing systems

Adaptable to renovation
○ Yes
● No

Adaptatibility

Adaptation to stimuli
○ Yes
● No

Type of trigger (input)
○ Mechanical (e.g. wind load)
○ Thermal (e.g. air temperature)
○ Electromagnetic
○ Optical (e.g. daylight level)
○ Air quality (e.g. humidity)
○ Occupancy
○ Other (internet data, BMS, etc.)

Type of actuator (output)
○ Mechanical
○ Pneumatical
○ Electromagnetic
○ Thermal
○ Chemical
○ Other

Control
○ Intrinsic (auto-reactive)
○ Extrinsic (external control)

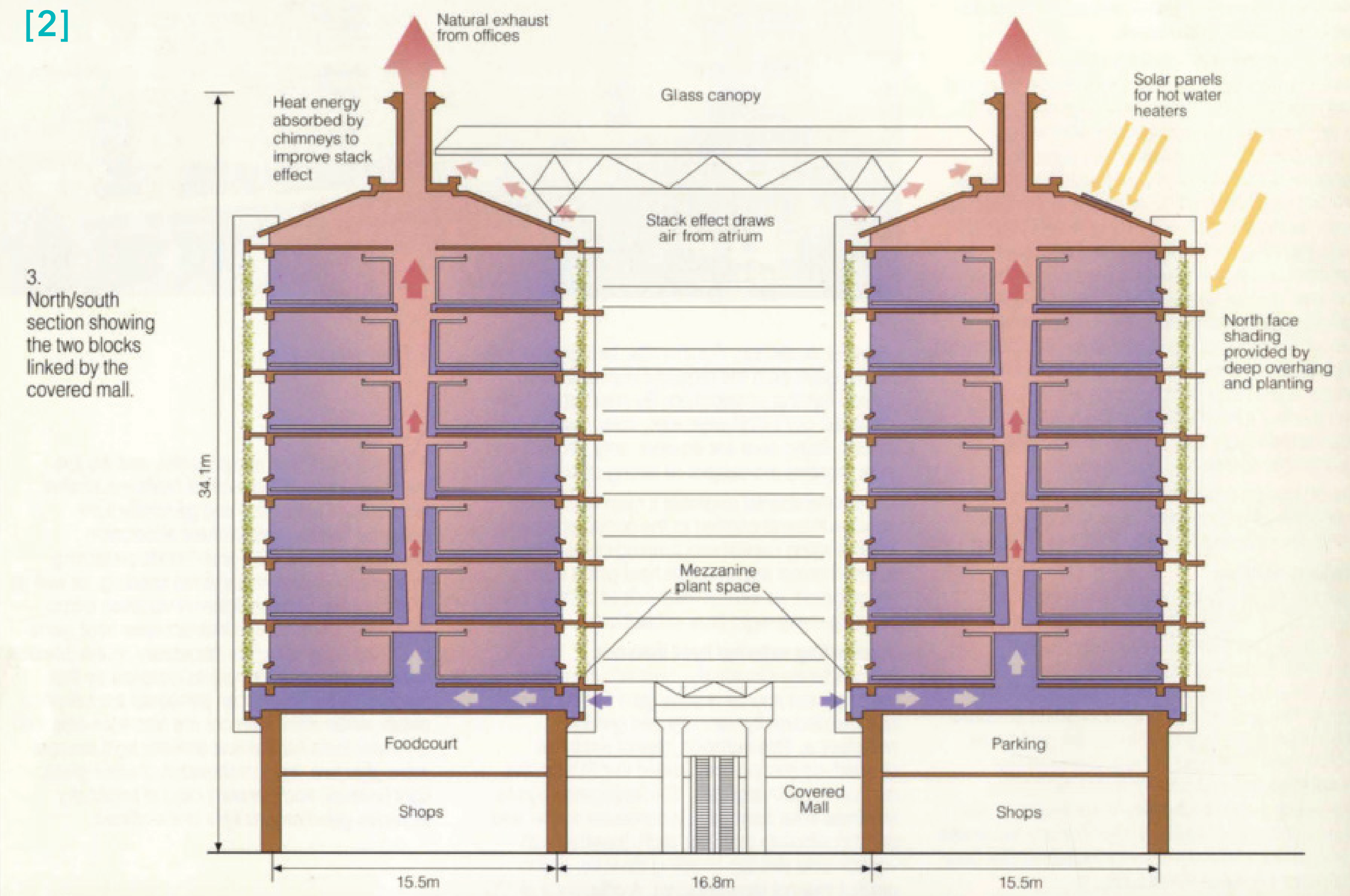
Response time
○ Seconds
○ Minutes
○ Hours
○ Days
○ Weeks
○ Months

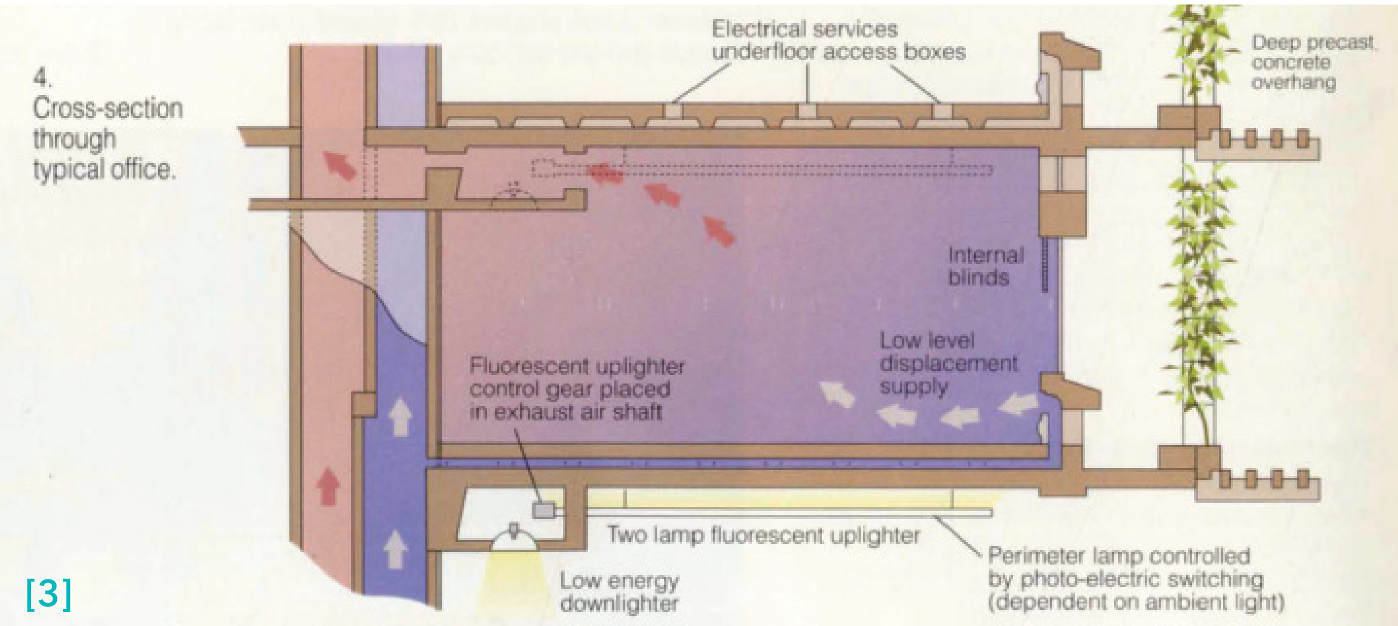
Spatial adaptation
○ Nanometers
○ Micrometers
○ Millimeters
○ Centimeters
○ Meters

Material adaptation
○ Elasticity
○ Inflatable
○ Bi-material
○ Other

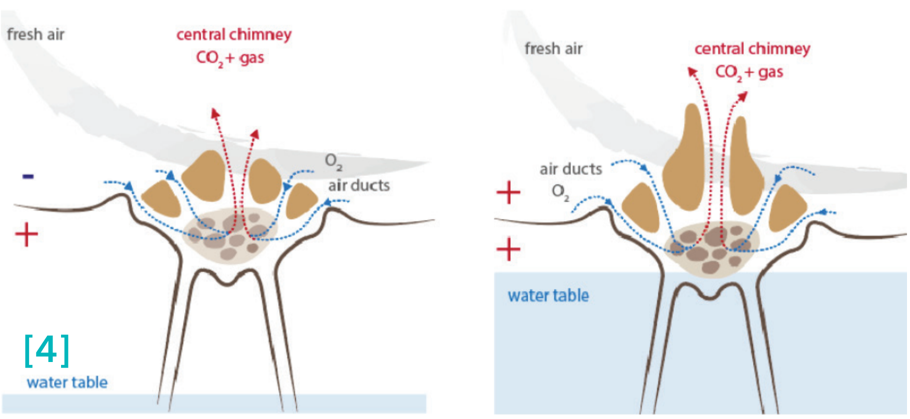
Degree of adaptability
○ On-Off
○ Gradual

[2]





[3]



[4]

Pictures and credits

[1] South Facade used by permission from © ARUP

[2] [3] Section of the ventilation system used by permission from © ARUP

[4] Mound adaptation of *Odontotermes Transvaalensis*, CC0 Estelle Cruz, World Tour of Biomimicry

[1]

Davies Alpine House, 2006. England

The Davies Alpine House, located in Kew Gardens, London, England is inspired by the ventilation system of termites mounds. The building was designed in 2006 by Wilkinson Eyre, Dewhurst MacFarlane and Atelier Ten.

The building was designed to avoid energy intensive refrigeration typically needed for the display of alpine plants. It instead uses a stack effect to cool the interior passively, while essentially remaining a glass house with high rates of air circulation. A removable shading sail is included in the design to prevent too much sunlight reaching the plants. The stack effect is enhanced through the high internal space created by the double arches, sequential apex venting as temperature increases, by vents at the bottom of the glass structure, and through a Barossa termite inspired decoupled thermal mass labyrinth below the building. The concrete block labyrinth is set between a double concrete slab that also acts to resist the forces exerted by the tension rods that support the glass ceiling. The air that is cooled within the labyrinth is recirculated so it cools the low level plants. The labyrinth is vented at night to take advantage of cooler temperatures, meaning the mass remains at a temperature usually cooler than that required for the space itself.

Name: Davies Alpine House
Year of construction: 2006
Climate: Temperate (Cfb)
City: London
Country: England

Surface: 70 m²
Cost (£/m²): £800,000 total cost, (£11 430 / m²)
Project use: green house (tertiary private)
Renovation: No

atelier ten

WilkinsonEyre

Data sheet completed by Estelle Cruz & Tessa Hubert (literature)

Data sheet reviewed by **Patrick Bellew**
patrick.bellew@atelierten.com

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- https://www.wilkinsoneyre.com/projects/royal-botanic-gardens-kew-masterplan
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Biomimetic

Definition
○ Biomimetics
○ Bioinspiration
● Biomimicry

Approach
● Biology-push
○ Technology-pull

Origins of bioinspiration
● Random opportunities
○ Interdisciplinary collaborations
○ Call for projects
○ Other

Targeted performance
● Thermal comfort
● Visual comfort
○ Acoustic comfort
● Air quality
○ Mechanical stress resistance
○ Water regulation

Integration scale of biomimetics
○ Material (facade component)
○ Facade system
● Building

Link to biology

Model kingdom
● Animalia: termites mounds
○ Plantae
○ Fungi
○ Bacteria/Archaea
○ Protozoa
○ Chromista / Ecosystems

Number of models
● One
○ Two
○ More

Type of knowledge
● Existing for general public
○ Existing for specialist
○ Created during the design process

Inputs in biology
● Background of the designer
○ Acquisition during the design
○ Biologists integrated in the process

Design process

Use of design framework
○ Yes
● No

Eco-design approach
● Yes
○ No

Major constraints
○ Lack of funds
○ Use of biomimetic tools
○ Law regulations
○ Technical problems
● Other

Design complexity
○ High (software, design process)
● Low (well-known design)

Outcome

Technology readiness level
○ TRL6 - demonstrated in relevant environment
○ TRL7 - system prototype demonstration in operational environment
○ TRL8 - system complete and qualified
● TRL9 - actual system proven in operational environment

Overtime performance
● Still operating
○ Not operating yet
○ Destroyed

Construction complexity
○ High (new technology)
● Low (existing technology)

Main component of the building envelope
○ Polymers
○ Alloys
○ Textiles
○ Wood
● Concrete
○ Carbon-glass fiber

Level of innovation
○ Breakthrough innovation
● Improvement of existing systems

Adaptable to renovation
○ Yes
● No

Adaptatibility

Adaptation to stimuli
○ Yes
● No

Type of trigger (input)
○ Mechanical (e.g. wind load)
○ Thermal (e.g. air temperature)
○ Electromagnetic
○ Optical (e.g. daylight level)
○ Air quality (e.g. humidity)
○ Occupancy
○ Other (internet data, BMS, etc.)

Type of actuator (output)
○ Mechanical
○ Pneumatical
○ Electromagnetic
○ Thermal
○ Chemical
○ Other

Control
○ Intrinsic (auto-reactive)
○ Extrinsic (external control)

Response time
○ Seconds
○ Minutes
○ Hours
○ Days
○ Weeks
○ Months

Spatial adaptation
○ Nanometers
○ Micrometers
○ Millimeters
○ Centimeters
○ Meters

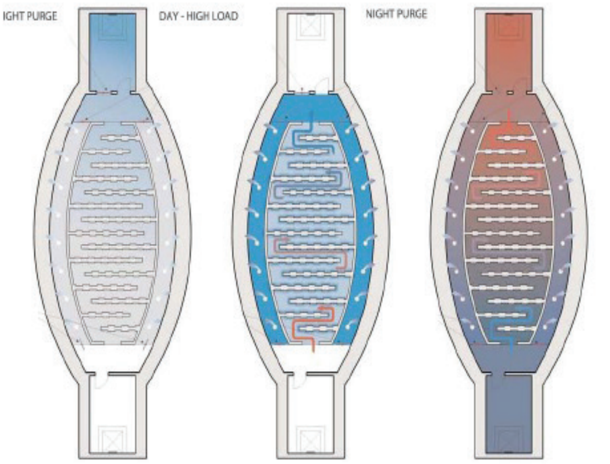
Material adaptation
○ Elasticity
○ Inflatable
○ Bi-material
○ Other

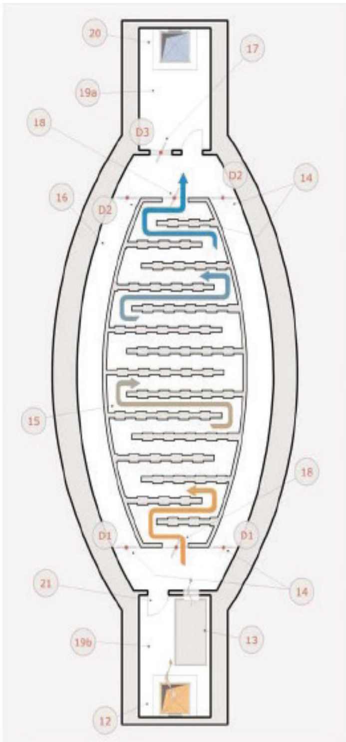
Degree of adaptability
○ On-Off
○ Gradual

[2]

[3]

[4]





[5]

Pictures and credits

[1] Exterior of the greenhouse © Oast House Archive

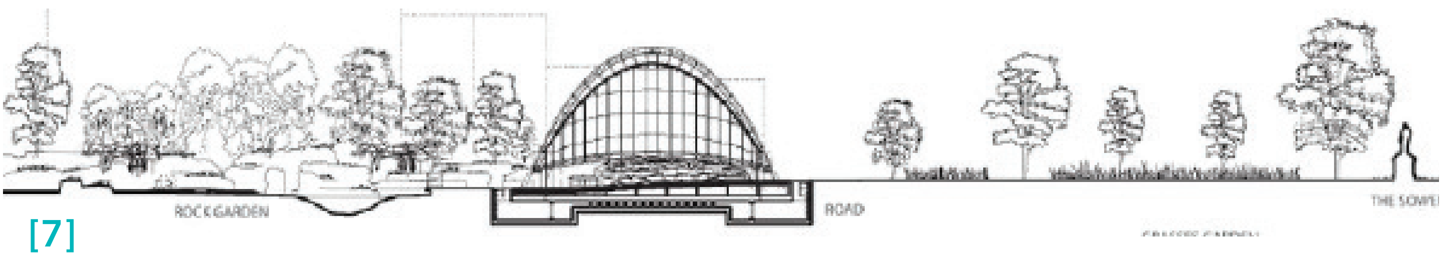
[2] [5] Labyrinth under construction for thermal regulation system used by permission from © Atelier Ten

[3] [4] Ventilation mouths inside the greenhouse used by permission from © Atelier Ten

[6] Blinds going up used by permission from © Joshua Molnar

[7] Elevation of the greenhouse used by permission from © WilkinsonEyre

[6]



[7]

[1]

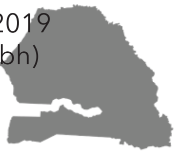
Nianing Chruch, 2019. Senegal

This project is located in Nianing, approximately one hundred kilometers south of Dakar on what is known as the "shell coast". The project takes the shape of a spiral shell as its starting point and develops it architecturally in accordance with the constraints of the brief, the site specifics, and the building's optimal bioclimatic positioning.

In order to put in place an effective passive ventilation, the project is inspired by the functioning of the African termite mound which is an extremely ingenious model of thermal regulation. It is also inspired by the functioning of wind towers in East Africa, which have also been known for centuries for their effectiveness. This crossed approach lays the foundations of a biomimetic approach.

The building closes in the North, to protect itself from the hot and dry winds of the Harmattan, and opens towards the West to welcome the cooling trade winds from the sea. The bell tower functions as a veritable "wind tower" that uses natural convection to bring the trade winds into the building and to create natural ventilation.

Name: Nianing Chrurch
Year of construction: 2017-2019
Climate: Warm semi-arid (Sbh)
City: Nianing
Country: Senegal



Surface: floor area of 457 m²

Cost (€/m²): 1,059799 € (2319/m²)
Project use: cultural building (private)
Renovation: No

IN SITU ARCHITECTURE
EIFFAGE
E.TE.C.S.

Data sheet completed by Estelle Cruz & Tessa Hubert (interview and literature)

Data sheet reviewed by **Nicolas Vernoux Thélot** - contact@insitu-architecture.fr

References

- http://www.insitu-architecture.net/en/projets/12404-church.html#
- https://www.construction21.org/france/articles/fr/24-le-contexte-de-l-eglise-de-nianing.html
- https://awards.re-thinkingthefuture.com/gada-winners-2019/church-nianing-in-situ-architecture/

Biomimetic

Definition
○ Biomimetics
○ Bioinspiration
● Biomimicry

Approach
○ Biology-push
● Technology-pull

Origins of bioinspiration
○ Random opportunities
● Interdisciplinary collaborations
○ Call for projects
○ Other

Targeted performance
● Thermal comfort
● Visual comfort
○ Acoustic comfort
● Air quality
○ Mechanical stress resistance
○ Water regulation

Integration scale of biomimetics
○ Material (facade component)
○ Facade system
● Building

Link to biology

Model kingdom
● Animalia: termites mounds
○ Plantae
○ Fungi
○ Bacteria/Archaea
○ Protozoa
○ Chromista / Ecosystems

Number of models
● One
○ Two
○ More

Type of knowledge
● Existing for general public
○ Existing for specialist
○ Created during the design process

Inputs in biology
● Background of the designer
○ Acquisition during the design
○ Biologists integrated in the process

Design process

Use of design framework
○ Yes
● No

Eco-design approach
● Yes
○ No

Major constraints
○ Lack of funds
○ Use of biomimetic tools
○ Law regulations
○ Technical problems
● Other

Design complexity
○ High (software, design process)
● Low (well-known design)

Outcome

Technology readiness level
○ TRL6 - demonstrated in relevant environment
○ TRL7 - system prototype demonstration in operational environment
○ TRL8 - system complete and qualified
● TRL9 - actual system proven in operational environment

Overtime performance
● Still operating
○ Not operating yet
○ Destroyed

Construction complexity
○ High (new technology)
● Low (existing technology)

Main component of the building envelope
○ Polymers
○ Alloys
○ Textiles
○ Wood
● Concrete
○ Carbon-glass fiber

Level of innovation
○ Breakthrough innovation
● Improvement of existing systems

Adaptable to renovation
○ Yes
● No

Adaptability

Adaptation to stimuli
○ Yes
● No

Type of trigger (input)
○ Mechanical (e.g. wind load)
○ Thermal (e.g. air temperature)
○ Electromagnetic
○ Optical (e.g. daylight level)
○ Air quality (e.g. humidity)
○ Occupancy
○ Other (internet data, BMS, etc.)

Type of actuator (output)
○ Mechanical
○ Pneumatical
○ Electromagnetic
○ Thermal
○ Chemical
○ Other

Control
○ Intrinsic (auto-reactive)
○ Extrinsic (external control)

Response time
○ Seconds
○ Minutes
○ Hours
○ Days
○ Weeks
○ Months

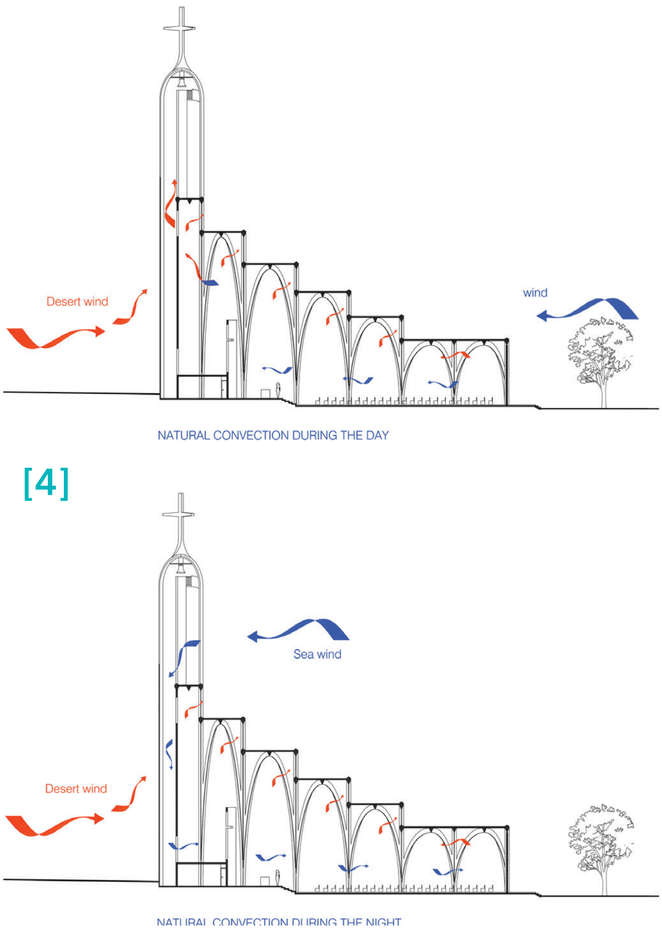
Spatial adaptation
○ Nanometers
○ Micrometers
○ Millimeters
○ Centimeters
○ Meters

Material adaptation
○ Elasticity
○ Inflatable
○ Bi-material
○ Other

Degree of adaptability
○ On-Off
○ Gradual

[2]

[3]



[4]

[5]

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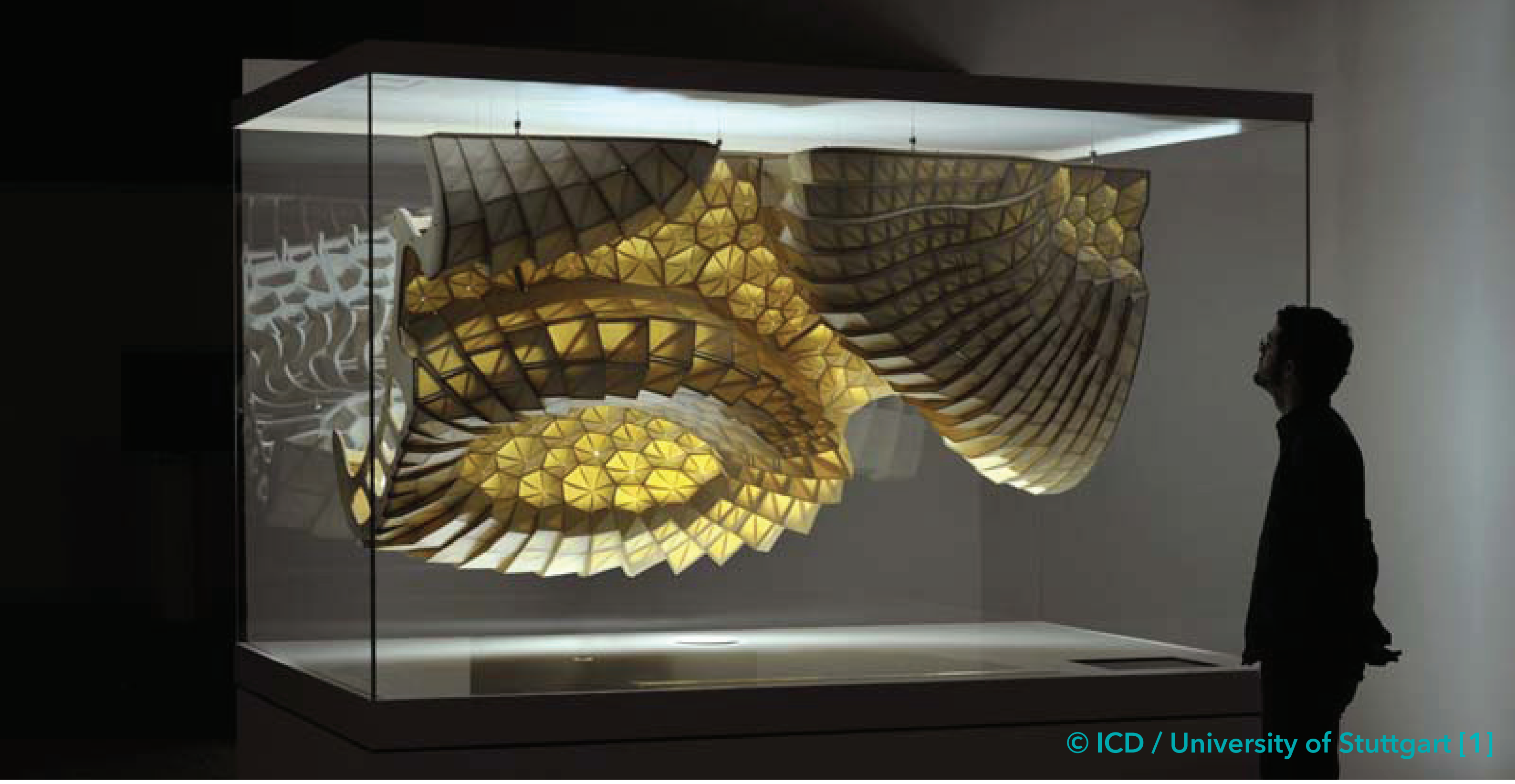
[1] Areal view © Regis L'Hostis
[2] Facade view © Regis L'Hostis
[3] Interior rendering © IN SITU Architecture
[4] Section of ventilation system day and night © IN SITU
[5] Ground floor plan © IN SITU Architecture



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HygroScope, 2012. France

The project explores a novel mode of responsive architecture based on the combination of material inherent behaviour and computational morphogenesis. The dimensional instability of wood in relation to moisture content is employed to construct a climate responsive architectural morphology. Suspended within a humidity controlled glass case the model opens and closes in response to climate changes with no need for any technical equipment or energy. Mere fluctuations in relative humidity trigger the silent changes of material-innate movement. The material structure itself is the machine.

The project is based on more than five years of design research on climate responsive architectural systems that do not require any sensory equipment, motor functions or even energy. Here, the responsive capacity is ingrained in the material's hygroscopic behaviour and anisotropic characteristics. Anisotropy denotes the directional dependence of a material's characteristics, in this case the different physical properties of wood in relation to grain directionality. Hygroscopicity refers to a substance's ability to take in moisture from the atmosphere when dry and yield moisture to the atmosphere when wet, thereby maintaining a moisture content in equilibrium with the surrounding relative humidity.

Name: HygroScope
Year of construction: 2012
Climate: Temperate (Cfb)
City: Paris
Country: France

Surface: 4 m²
Cost (€/m²): na

Project use: pavilion
Renovation: No

ICD Institute for Computational Design and Construction
Transsolar KlimaEngineering
Centre Pompidou
University of Stuttgart Germany

Data sheet completed by Estelle Cruz & Tessa Hubert (literature and interview)

Data sheet reviewed by **Dylan Wood**
dylan-marx.wood@icd.uni-stuttgart.de

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Biomimetic

Definition
- ● Biomimetics
- ○ Bioinspiration
- ○ Biomimicry

Approach
- ● Biology-push
- ○ Technology-pull

Origins of bioinspiration
- ○ Random opportunities
- ● Interdisciplinary collaborations
- ○ Call for projects
- ○ Other

Targeted performance
- ● Thermal comfort
- ● Visual comfort
- ○ Acoustic comfort
- ○ Air quality
- ● Mechanical stress resistance
- ○ Water regulation

Integration scale of biomimetics
- ● Material (facade component)
- ○ Facade system
- ○ Building

Link to biology

Model kingdom
- ○ Animalia
- ● Plantae: pine cone
- ○ Fungi
- ○ Bacteria/Archaea
- ○ Protozoa
- ○ Chromista / Ecosystems

Number of models
- ● One
- ○ Two
- ○ More

Type of knowledge
- ○ Existing for general public
- ● Existing for specialist
- ○ Created during the design process

Inputs in biology
- ○ Background of the designer
- ● Acquisition during the design
- ● Biologists integrated in the process

Design process

Use of design framework
- ○ Yes
- ● No

Eco-design approach
- ○ Yes
- ● No

Major constraints
- ○ Lack of funds
- ○ Use of biomimetic tools
- ○ Law regulations
- ● Technical problems
- ○ Other

Design complexity
- ● High (software, design process)
- ○ Low (well-known design)

Outcome

Technology readiness level
- ○ TRL6 - demonstrated in relevant environment
- ● TRL7 - system prototype demonstration in operational environment
- ○ TRL8 - system complete and qualified
- ○ TRL9 - actual system proven in operational environment

Overtime performance
- ● Still operating
- ○ Not operating yet
- ○ Destroyed

Construction complexity
- ● High (new technology)
- ○ Low (existing technology)

Main component of the building envelope
- ○ Polymers
- ○ Alloys
- ○ Textiles
- ● Wood
- ○ Concrete
- ○ Carbon-glass fiber

Level of innovation
- ● Breakthrough innovation
- ○ Improvement of existing systems

Adaptable to renovation
- ● Yes
- ○ No

Adaptability

Adaptation to stimuli
- ● Yes
- ○ No

Type of trigger (input)
- ○ Mechanical (e.g. wind load)
- ○ Thermal (e.g. air temperature)
- ○ Electromagnetic
- ○ Optical (e.g. daylight level)
- ● Air quality (e.g. humidity)
- ○ Occupancy
- ○ Other (internet data, BMS, etc.)

Type of actuator (output)
- ● Mechanical
- ○ Pneumatical
- ○ Electromagnetic
- ○ Thermal
- ○ Chemical
- ○ Other

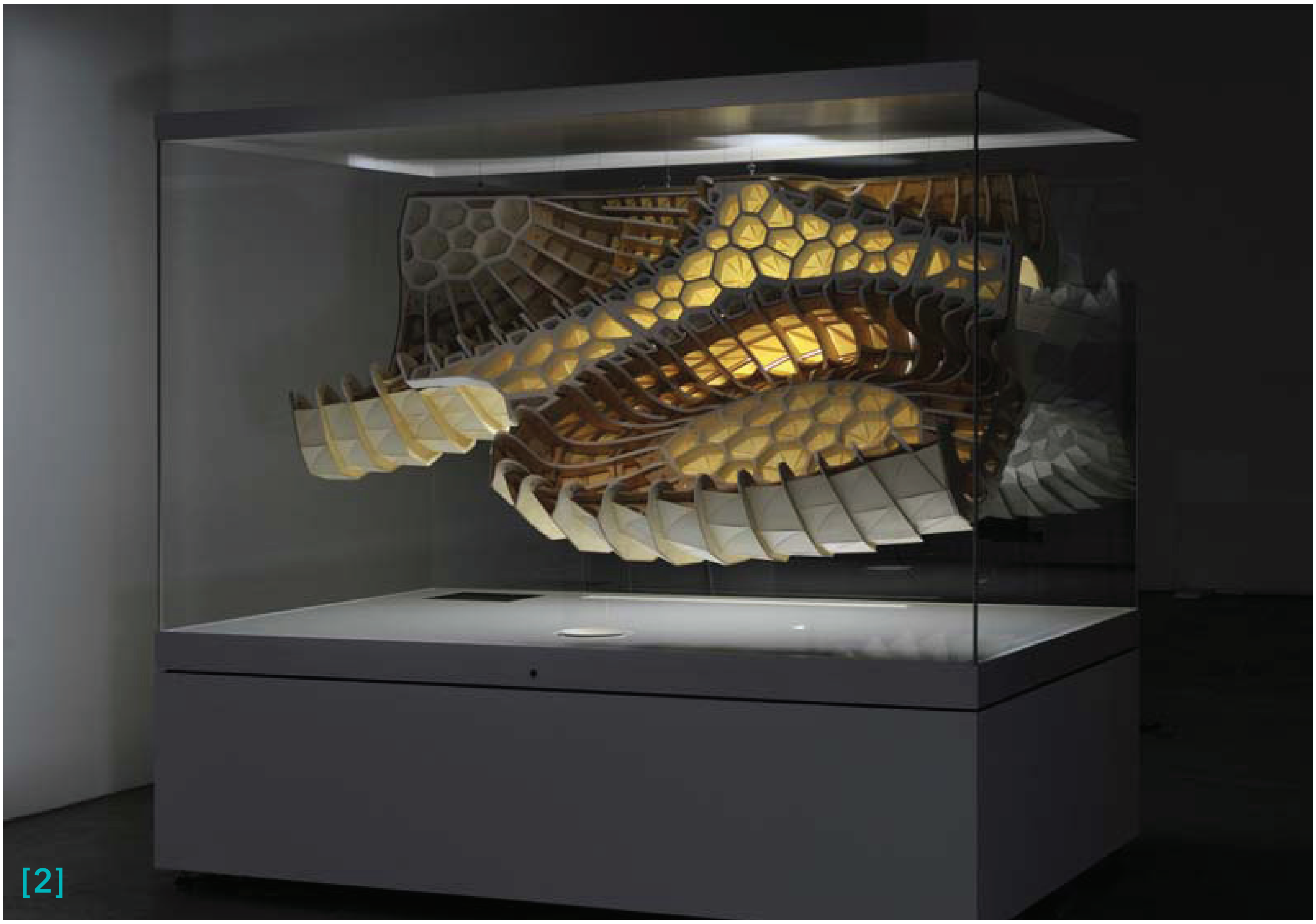
Control
- ● Intrinsic (auto-reactive)
- ○ Extrinsic (external control)

Response time
- ○ Seconds
- ○ Minutes
- ● Hours
- ○ Days
- ○ Weeks
- ○ Months

Spatial adaptation
- ○ Nanometers
- ○ Micrometers
- ○ Millimeters
- ● Centimeters
- ○ Meters

Material adaptation
- ○ Elasticity
- ○ Inflatable
- ● Bi-material
- ○ Other

Degree of adaptability
- ○ On-Off
- ● Gradual



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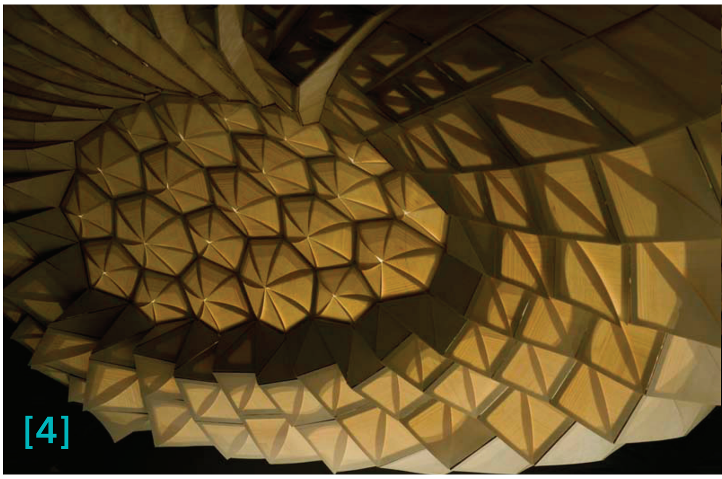

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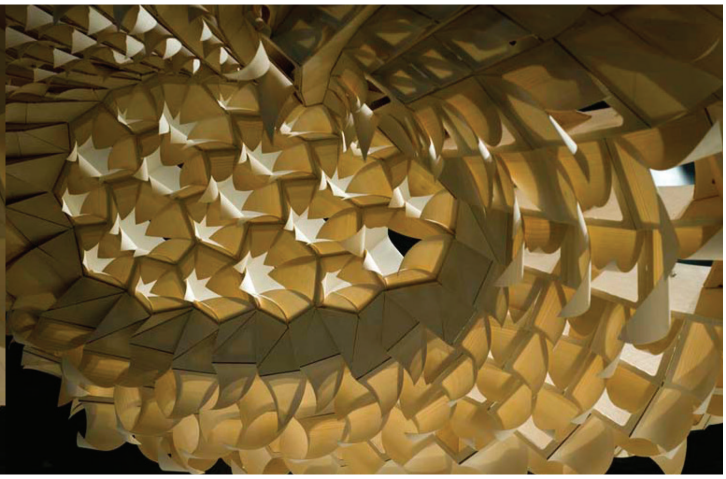

[5]

Pictures and credits ©ICD / University of Stuttgart

[1] [2] Model exhibited at the Centre Pompidou Paris.

[3] [4] Material adaptation: the model opens and closes in response to climate changes

[5] Pine cone opening and closing

[6]

[1] © Florian Kleinefenn, with permission of FRAC

HygroSkin, 2013. France

The project HygroSkin – Meteorosensitive Pavilion explores a novel mode of climate-responsive architecture. The dimensional instability of wood in relation to moisture content is employed to construct a metereosensitive architectural skin. It autonomously opens and closes in response to weather changes but neither requires the supply of operational energy nor any kind of mechanical or electronic control. Here, the material structure itself is the machine.

The travelling pavilion's modular wooden skin is designed and produced utilizing the self-forming capacity of initially planar plywood sheets to form conical surfaces based on the material's elastic behavior. Within the deep, concave surface of each robotically fabricated module a weather-responsive aperture is placed. Materially programming the humidity-responisve behaviour of these apertures opens up the possibility for a strikingly simple yet truly ecologically embedded architecture in constant feedback and interaction with its surrounding environment. The responsive wood-composite skin adjusts the porosity of the pavilion in direct response to changes in ambient relative humidity. These climatic changes – which form part of our everyday live but usually escape our conscious perception – trigger the silent, material-innate movement of the wooden skin.

Name: HygroSkin Pavilion
Year of construction: 2013
Climate: Temperate (Cfb)
City: Orléans
Country: France

Surface: 24 m²
Cost (€/m²): 15 k€

Project use: pavilion
Renovation: No

University of Stuttgart
Germany

Data sheet completed by Estelle Cruz & Tessa Hubert (literature and interview)

Data sheet reviewed by **Dylan Wood**
dylan-marx.wood@icd.uni-stuttgart.de

References

• Schwinn, Tobias, and Oliver David Krieg, eds. 2017. Advancing Wood Architecture: A Computational Approach. London ; New York: Routledge, Taylor & Francis Group.

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Biomimetic

Definition
- ● Biomimetics
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- ○ Biomimicry

Approach
- ● Biology-push
- ○ Technology-pull

Origins of bioinspiration
- ○ Random opportunities
- ● Interdisciplinary collaborations
- ○ Call for projects
- ○ Other

Targeted performance
- ● Thermal comfort
- ● Visual comfort
- ○ Acoustic comfort
- ○ Air quality
- ● Mechanical stress resistance
- ○ Water regulation

Integration scale of biomimetics
- ● Material (facade component)
- ○ Facade system
- ○ Building

Link to biology

Model kingdom
- ○ Animalia
- ● Plantae: pine cone
- ○ Fungi
- ○ Bacteria/Archaea
- ○ Protozoa
- ○ Chromista / Ecosystems

Number of models
- ● One
- ○ Two
- ○ More

Type of knowledge
- ○ Existing for general public
- ● Existing for specialist
- ○ Created during the design process

Inputs in biology
- ○ Background of the designer
- ● Acquisition during the design
- ● Biologists integrated in the process

Design process

Use of design framework
- ○ Yes
- ● No

Eco-design approach
- ○ Yes
- ● No

Major constraints
- ○ Lack of funds
- ○ Use of biomimetic tools
- ○ Law regulations
- ● Technical problems
- ○ Other

Design complexity
- ● High (software, design process)
- ○ Low (well-known design)

Outcome

Technology readiness level
- ○ TRL6 - demonstrated in relevant environment
- ○ TRL7 - system prototype demonstration in operational environment
- ● TRL8 - system complete and qualified
- ○ TRL9 - actual system proven in operational environment

Overtime performance
- ● Still operating
- ○ Not operating yet
- ○ Destroyed

Construction complexity
- ● High (new technology)
- ○ Low (existing technology)

Main component of the building envelope
- ○ Polymers
- ○ Alloys
- ○ Textiles
- ● Wood
- ○ Concrete
- ○ Carbon-glass fiber

Level of innovation
- ● Breakthrough innovation
- ○ Improvement of existing systems

Adaptable to renovation
- ● Yes
- ○ No

Adaptability

Adaptation to stimuli
- ● Yes
- ○ No

Type of trigger (input)
- ○ Mechanical (e.g. wind load)
- ○ Thermal (e.g. air temperature)
- ○ Electromagnetic
- ○ Optical (e.g. daylight level)
- ● Air quality (e.g. humidity)
- ○ Occupancy
- ○ Other (internet data, BMS, etc.)

Type of actuator (output)
- ● Mechanical
- ○ Pneumatical
- ○ Electromagnetic
- ○ Thermal
- ○ Chemical
- ○ Other

Control
- ● Intrinsic (auto-reactive)
- ○ Extrinsic (external control)

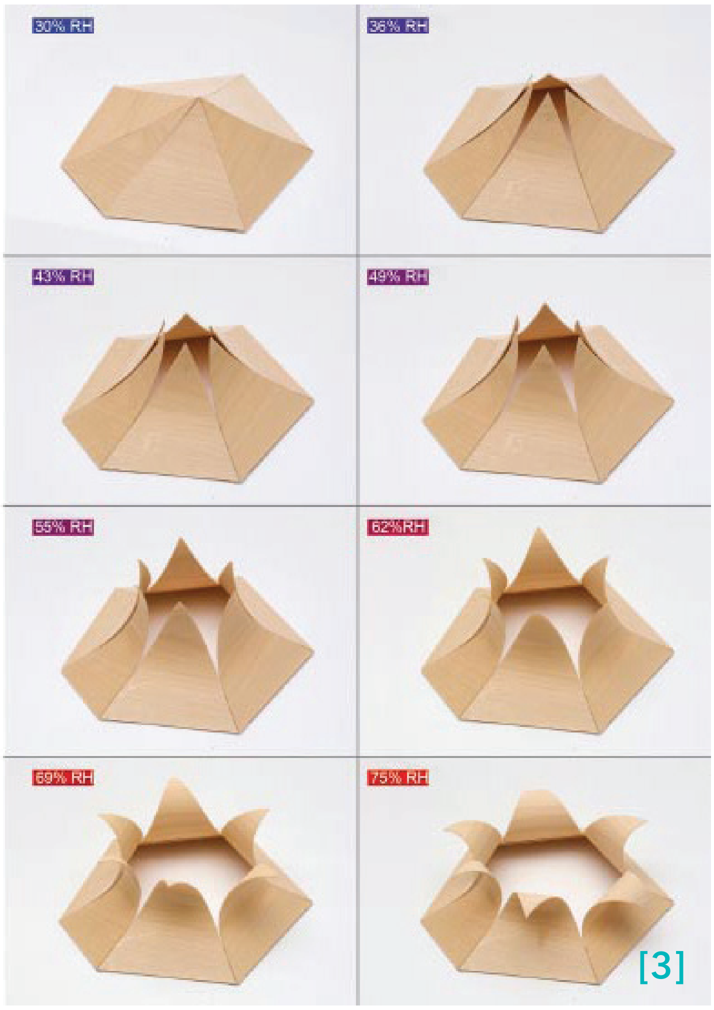
Response time
- ○ Seconds
- ○ Minutes
- ● Hours
- ○ Days
- ○ Weeks
- ○ Months

Spatial adaptation
- ○ Nanometers
- ○ Micrometers
- ○ Millimeters
- ● Centimeters
- ○ Meters

Material adaptation
- ○ Elasticity
- ○ Inflatable
- ● Bi-material
- ○ Other

Degree of adaptability
- ○ On-Off
- ● Gradual

[2]



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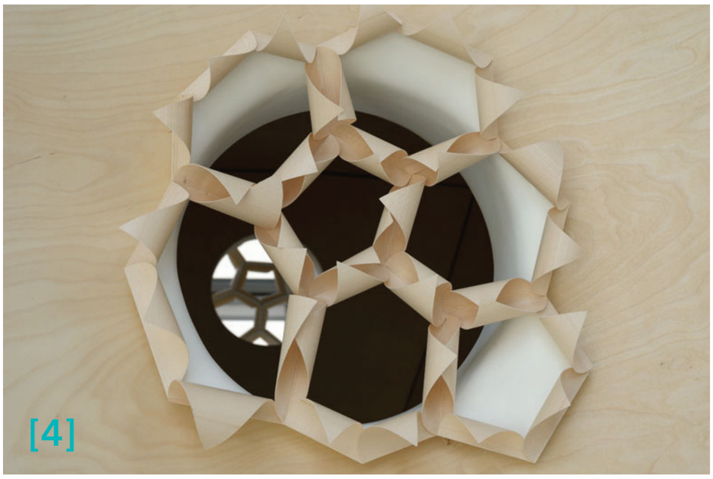

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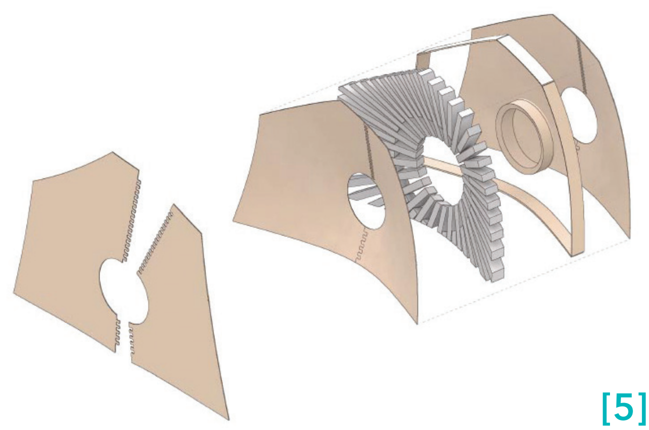

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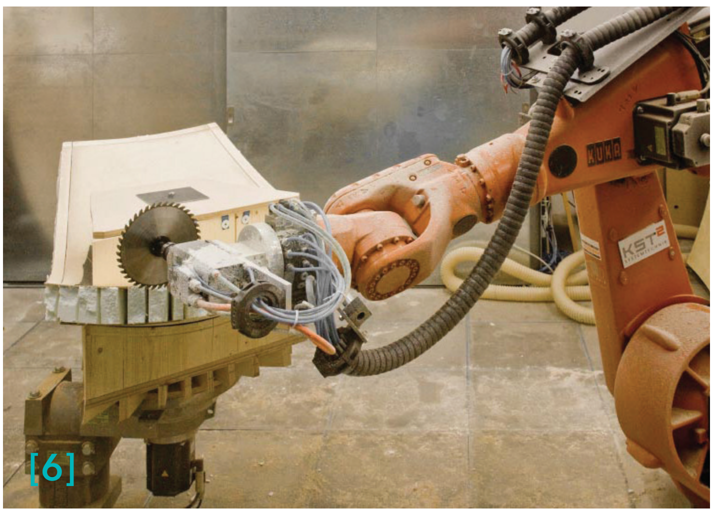


[6]

[1] Exterior facade: close-up photo of a HygroSkin aperture adapting to weather changes: open at low relative humdity

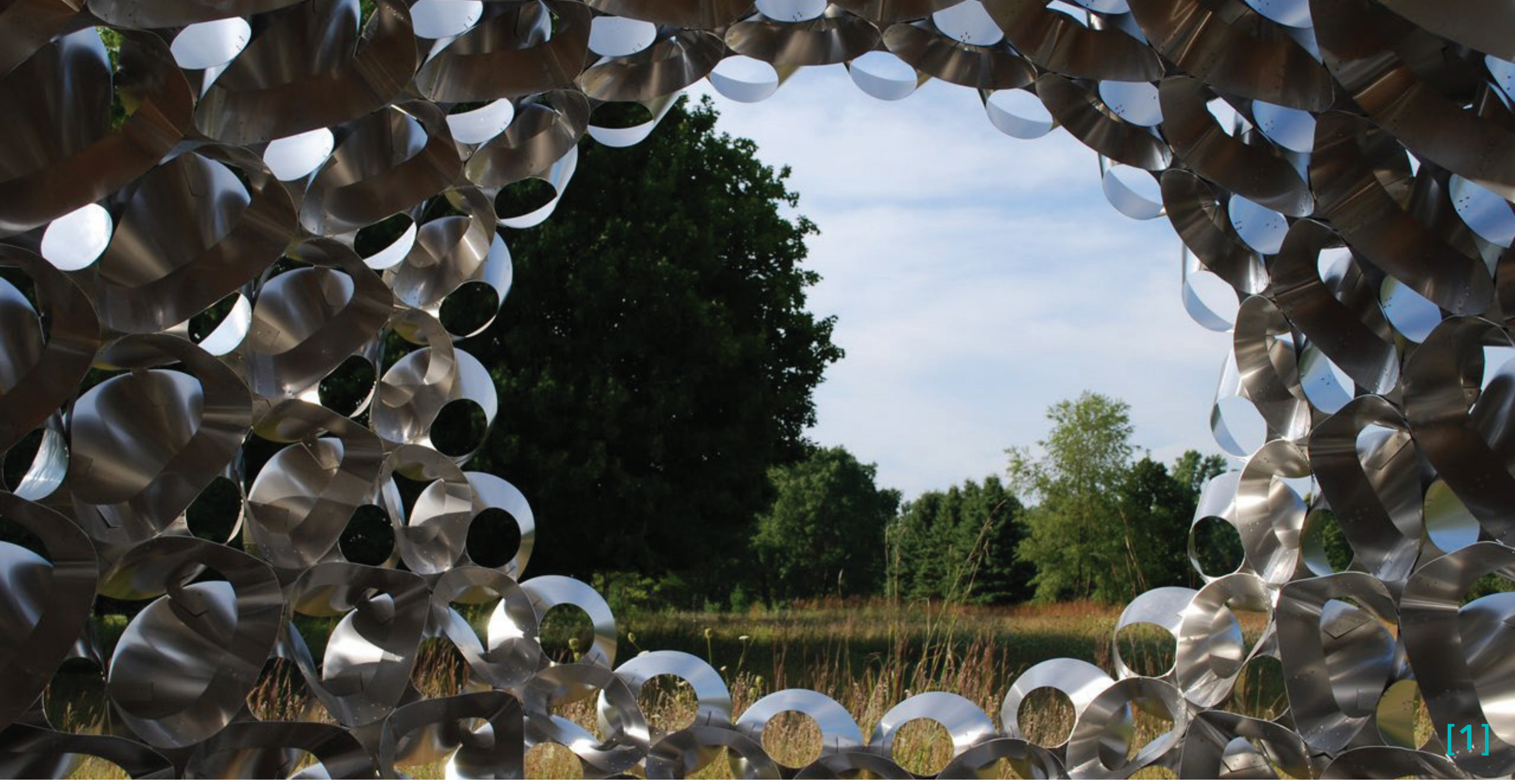
[2] Transfer of the biological principle of shape change induced by hygroscopic and anistropic dimensional change

[3] Photo of HygroSkin – Meteorosensitive Pavilion in Stadt-garten, Stuttgart

[4-5] View and exploded view of a module\'s buildup

[6] Robotic fabrication setup with seven axes

[2,3,5,6] ©ICD / University of Stuttgart
[1,4] © Florian Kleinefenn, with permission of FRAC



Shadow Pavilion, 2009. Michigan

The Shadow Pavilion sits at the University of Michigan Matthaei Botanical Gardens. This perforated structure is made entirely of holes : made with more than one hundred aluminium sheets, laser cut and rolled into cones of various sizes were pre-assembled and then added to a row buried in the ground. The laser cutting process uses the digital design information to precision cut and finish the aluminum cones. The pavilion's surface will maintain the natural aluminum finish and smooth edges resulting from the laser cutter.

The arrangement of the structure is inspired from the concept of phyllotaxis, a phenomenon in biology describing the arrangement of elements in a plant. The cones act to funnel light and sound to the internal space, offering to the visitors a specific view and sound experience and creating a micro-environnement. The structure was designed to be self-supporting with few material, with the use of software to model the shadow patterns or geometric tethering.

Name: Shadow pavilion
Year of construction: 2009
Climate: Continental (D)
City: Ann Arbor
Country: Michigan, USA

Surface: 20 m^2
Cost (€/m²): 18 000 €, (900€ / m2)
Project use: pavilion
Renovation: No

ply architecture

Data sheet completed by Estelle Cruz & Tessa Hubert (literature and emails exchanges)

Data sheet reviewed by **Karl Daubmann -** karl@daub-lab.com

References

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• "Shadow Pavilion / PLY Architecture." 2011. ArchDaily. December 20, 2011. http://www.archdaily.com/192699/shadow-pavilion-ply-architecture/.
• "Shadow Pavilion Informed by Biomimicry / Ply Architecture - EVolo | Architecture Magazine." http://www.evolo.us/shadow-pavilion-informed-by-biomimicry-ply-architecture/.
• "Shadow Pavilion - Daub-Lab." n.d. Accessed October 8, 2019. https://www.daub-lab.com/Shadow-Pavilion.

Biomimetic

Definition
- [ ] Biomimetics
- [x] Bioinspiration
- [ ] Biomimicry

Approach
- [x] Biology-push
- [ ] Technology-pull

Origins of bioinspiration
- [ ] Random opportunities
- [x] Interdisciplinary collaborations
- [ ] Call for projects
- [ ] Other

Targeted performance
- [ ] Thermal comfort
- [x] Visual comfort
- [x] Acoustic comfort (qualitative)
- [ ] Air quality
- [x] Mechanical stress resistance
- [ ] Water regulation

Integration scale of biomimetics
- [x] Material (facade component)
- [ ] Facade system
- [ ] Building

Link to biology

Model kingdom
- [ ] Animalia
- [x] Plantae: phyllotaxis
- [ ] Fungi
- [ ] Bacteria/Archaea
- [ ] Protozoa
- [ ] Chromista / Ecosystems

Number of models
- [x] One
- [ ] Two
- [ ] More

Type of knowledge
- [x] Existing for general public
- [x] Existing for specialist
- [ ] Created during the design process

Inputs in biology
- [ ] Background of the designer
- [ ] Acquisition during the design
- [x] Biologists integrated in the process

Design process

Use of design framework
- [ ] Yes
- [x] No

Eco-design approach
- [x] Yes
- [ ] No

Major constraints
- [x] Lack of funds
- [ ] Use of biomimetic tools
- [ ] Law regulations
- [ ] Technical problems
- [x] Other (schedule management)

Design complexity
- [x] High (software, design process)
- [ ] Low (well-known design)

Outcome

Technology readiness level
- [ ] TRL6 - demonstrated in relevant environment
- [x] TRL7 - system prototype demonstration in operational environment
- [ ] TRL8 - system complete and qualified
- [ ] TRL9 - actual system proven in operational environment

Overtime performance
- [ ] Still operating
- [ ] Not operating yet
- [x] Destroyed (entirely recycled)

Construction complexity
- [x] High (new technology)
- [ ] Low (existing technology)

Main component of the building envelope
- [ ] Polymers
- [x] Alloys (aluminium)
- [ ] Textiles
- [ ] Wood
- [ ] Concrete
- [ ] Carbon-glass fiber

Level of innovation
- [x] Breakthrough innovation
- [ ] Improvement of existing systems

Adaptable to renovation
- [x] Yes
- [ ] No

Adaptability

Adaptation to stimuli
- [ ] Yes
- [x] No

Type of trigger (input)
- [ ] Mechanical (e.g. wind load)
- [ ] Thermal (e.g. air temperature)
- [ ] Electromagnetic
- [ ] Optical (e.g. daylight level)
- [ ] Air quality (e.g. humidity)
- [ ] Occupancy
- [ ] Other (internet data, BMS, etc.)

Type of actuator (output)
- [ ] Mechanical
- [ ] Pneumatical
- [ ] Electromagnetic
- [ ] Thermal
- [ ] Chemical
- [ ] Other

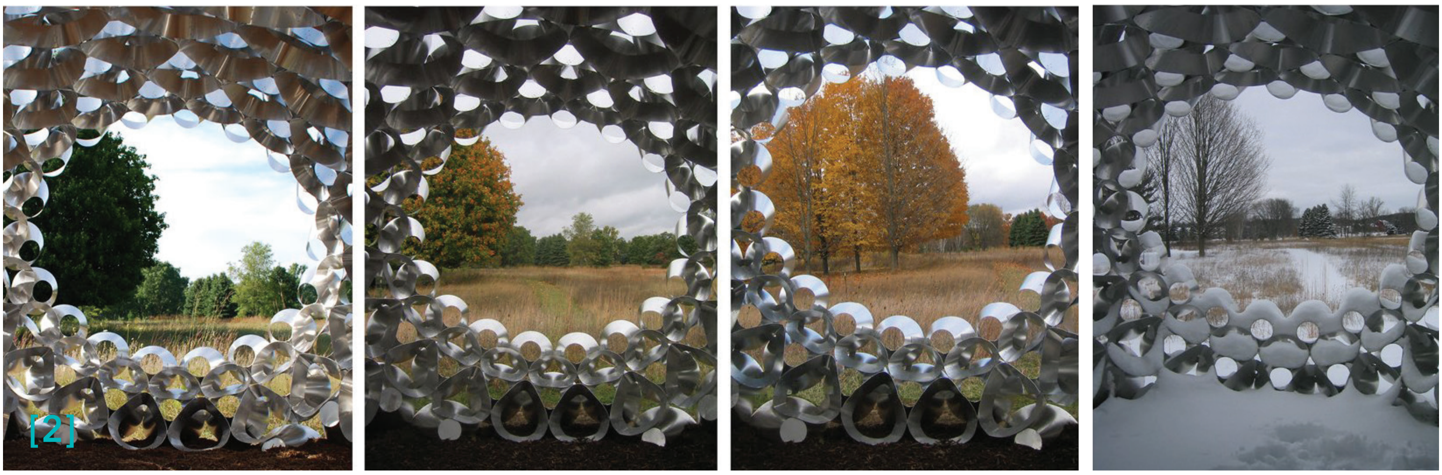
Control
- [ ] Intrinsic (auto-reactive)
- [ ] Extrinsic (external control)

Response time
- [ ] Seconds
- [ ] Minutes
- [ ] Hours
- [ ] Days
- [ ] Weeks
- [ ] Months

Spatial adaptation
- [ ] Nanometers
- [ ] Micrometers
- [ ] Millimeters
- [ ] Centimeters
- [ ] Meters

Material adaptation
- [ ] Elasticity
- [ ] Inflatable
- [ ] Bi-material
- [ ] Other

Degree of adaptability
- [ ] On-Off
- [ ] Gradual



[2]

[3]

[4]

Pictures and credits use by permission from © PLY Architecture

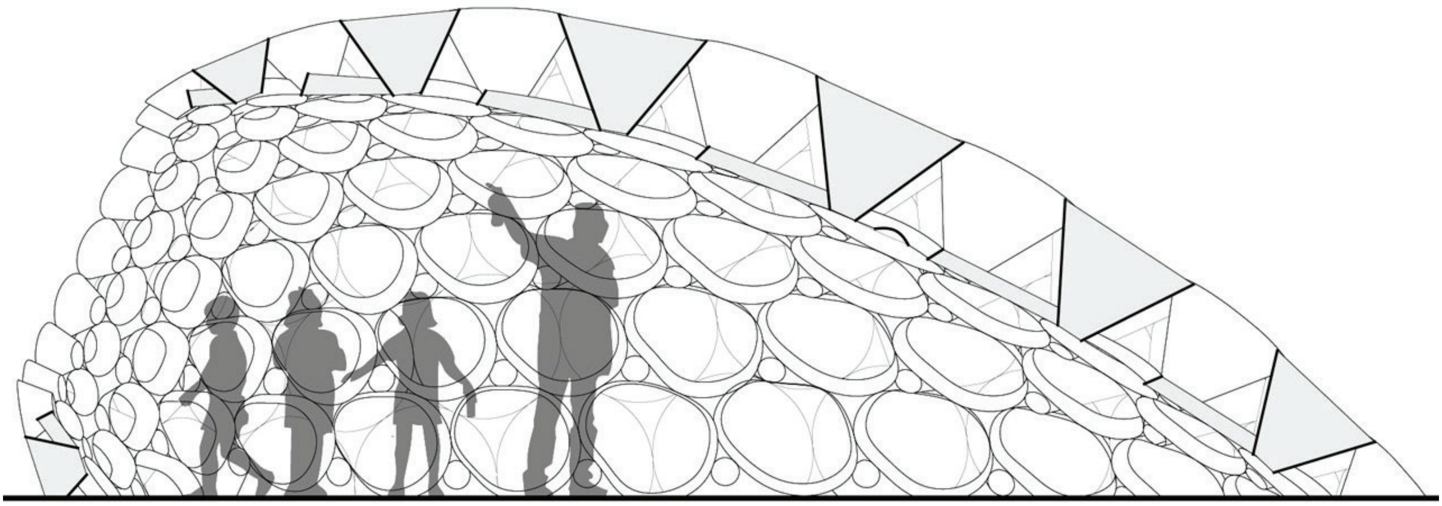
[1] Pavilion

[2] Four seasons

[3] Landscape integration

[4] Aluminium sheets

[5] Section of the pavilion



[5]

[1]

Bloom, 2011. Los Angeles, USA.

"A sun-tracking instrument indexing time and temperature, with a shape alluding to a woman's Victorian-era undergarment, "Bloom" stitches together material experimentation, structural innovation, and computational form and pattern-making into an environmentally responsive form. Made primarily out of a "smart" thermobimetal, a sheet metal that curls when heated (no controls, no energy), the form's responsive surface shades and ventilates specific areas under the shell as the temperature rises. When used on a building's surface, it will reduce the absurd dependency on costly air conditioning and retard the "heat island effect". Adding dynamic thermobimetal to the facade may seem trivial in the big picture of building technology, but the effect on our cultural will be tremendous. The increased complexities of building envelope design with new, smart and dynamic materials will bear careful consideration in the new era of facade aesthetics and urban meaning". Composed of 414 hyperbolic paraboloid-shaped stacked panels, the self-supporting structure also challenges the capability of the materials to perform as a shell. The panels combine a double-ruled surface of bimetal tiles with an interlocking, folded aluminum frame system. The final monocoque structure, lightweight and flexible, is dependent on the overall geometry and combination of materials to provide comprehensive stability.

https://www.dosu-arch.com/bloom

Name: Bloom demonstrator
Year of construction: 2011
Climate: Temperate (Cfb)
City: Los Angeles
Country: USA

Surface: -
Cost (€): 111 000 € (materials only with building cost)
Project use: pavilion
Renovation: No

DO|SU STUDIO ARCHITECTURE

Data sheet completed by Estelle Cruz & Tessa Hubert (literature)

Data sheet reviewed by **Doris Kim Sung -** info@dosu-arch.com

References

• "Bloom | DOSU Studio. https://www.dosu-arch.com/bloom.

• "Doris Kim Sung: Metal That Breathes | TED Talk." n.d. Accessed December 5, 2019. https://www.ted.com/talks/doris_kim_sung_metal_that_breathes.

• BLOOM: Thermally Responsive Surface in Action http://vimeo.com/woodd/bloom-surface

Biomimetic

Definition
○ Biomimetics
● Bioinspiration
○ Biomimicry

Approach
● Biology-push
○ Technology-pull

Origins of bioinspiration
○ Random opportunities
● Interdisciplinary collaborations
○ Call for projects
○ Other

Targeted performance
● Thermal comfort
● Visual comfort
○ Acoustic comfort
○ Air quality
● Mechanical stress resistance
○ Water regulation

Integration scale of biomimetics
● Material (facade component)
● Facade system
○ Building

Link to biology

Model kingdom
● Animalia: human skin
○ Plantae
○ Fungi
○ Bacteria/Archaea
○ Protozoa
○ Chromista / Ecosystems

Number of models
● One
○ Two
○ More

Type of knowledge
● Existing for general public
○ Existing for specialist
○ Created during the design process

Inputs in biology
● Background of the designer
○ Acquisition during the design
○ Biologists integrated in the process

Design process

Use of design framework
○ Yes
● No

Eco-design approach
● Yes
○ No

Major constraints
● Lack of funds
○ Use of biomimetic tools
○ Law regulations
● Technical problems
○ Other

Design complexity
● High (software, design process)
○ Low (well-known design)

Outcome

Technology readiness level
○ TRL6 - demonstrated in relevant environment
● TRL7 - system prototype demonstration in operational environment
○ TRL8 - system complete and qualified
○ TRL9 - actual system proven in operational environment

Overtime performance
● Still operating
○ Not operating yet
○ Destroyed

Construction complexity
● High (new technology)
○ Low (existing technology)

Main component of the building envelope
○ Polymers
● Alloys (thermobimetal)
○ Textiles
○ Wood
○ Concrete
○ Carbon-glass fiber

Level of innovation
● Breakthrough innovation
○ Improvement of existing systems

Adaptable to renovation
● Yes
○ No

Adaptability

Adaptation to stimuli
● Yes
○ No

Type of trigger (input)
○ Mechanical (e.g. wind load)
● Thermal (e.g. air temperature)
○ Electromagnetic
○ Optical (e.g. daylight level)
○ Air quality (e.g. humidity)
○ Occupancy
○ Other (internet data, BMS, etc.)

Type of actuator (output)
● Mechanical
○ Pneumatical
○ Electromagnetic
○ Thermal
○ Chemical
○ Other

Control
● Intrinsic (auto-reactive)
○ Extrinsic (external control)

Response time
○ Seconds
● Minutes
○ Hours
○ Days
○ Weeks
○ Months

Spatial adaptation
○ Nanometers
○ Micrometers
○ Millimeters
● Centimeters
○ Meters

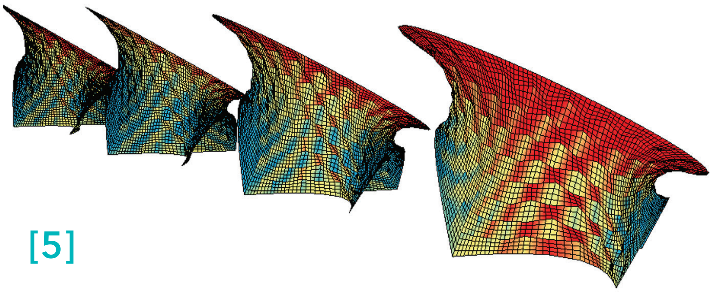
Material adaptation
○ Elasticity
○ Inflatable
● Bi-material
○ Other

Degree of adaptability
○ On-Off
● Gradual

[2]

[3]

[4]



[5]

Pictures and credits

[1] [2] Copyrights Brandon Shigeta

[3] [4] [5] Copyrights DOSU

[6]

[1]

Umbrella Al Hussein Mosque, 2000. Cairo, Egypt

The umbrella systems are the results of 30 years of research on tensile structures (e.g. collaborations with Frei Otto, the world's leading authority on lightweight structures, on the German pavilion at Expo 67 in Montreal or on convertible umbrellas for the 1971 Bundesgartenschau in Cologne), based on the studies of - among others - spider webs for infrastructures.

On the open space in front of the Al Hussein Mosque sit three aligned retractable umbrellas. When they are retracted, the steel frame arms are clad with a sheet metal cladding to protect the PTFE membrane from wind and weather. When opening the umbrellas, the surface tensions are transmitted by edge and radial belts from the arms into the membrane. The systems consist of 4 diagonal arm systems and 4 intermediate arm systems attached to the main frame. The opening is operated by an electro-mechanical drive system with a predicted 30 years of life functioning, for two cycles a day.

Pictures and credits © SL Rasch
[1] Front view of the mosque
[2] [3] Stress distribution
[4] [5] Umbrella opening (right) and closing (left)
[6] [7] Membrane material
[8] [9] Umbrella membrane confectioning

Name: Umbrellas Al Hussein Mosque
Year of construction: 2000
Climate: Tropical desert (Bwh)
City: Cairo
Country: Egypt

Surface: 256 m² per umbralla of shaded area
Cost (€/m²): na
Project use: mosque
Renovation: no

Data sheet completed by Estelle Cruz & Tessa Hubert (literature)

Data sheet reviewed by **Mustafa Rasch -** info@sl-rasch.de

References

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• "Al-Husayn Mosque Canopies | Exterior View of Mosque with Canopies Open." n.d. Archnet. Accessed October 8, 2019. https://archnet.org/sites/5155/media_contents/45407.

Biomimetic

Definition
○ Biomimetics
● Bioinspiration
○ Biomimicry

Approach
○ Biology-push
● Technology-pull

Origins of bioinspiration
○ Random opportunities
● Interdisciplinary collaborations
○ Call for projects
○ Other

Targeted performance
● Thermal comfort
● Visual comfort
○ Acoustic comfort
○ Air quality
○ Mechanical stress resistance
○ Water regulation

Integration scale of biomimetics
○ Material (facade component)
● Facade system
○ Building

Link to biology

Model kingdom
● Animalia: spider web
○ Plantae
○ Fungi
○ Bacteria/Archaea
○ Protozoa
○ Chromista / Ecosystems

Number of models
● One
○ Two
○ More

Type of knowledge
● Existing for general public
○ Existing for specialist
○ Created during the design process

Inputs in biology
● Background of the designer
○ Acquisition during the design
○ Biologists integrated in the process

Design process

Use of design framework
○ Yes
● No

Eco-design approach
○ Yes
● No

Major constraints
○ Lack of funds
○ Use of biomimetic tools
○ Law regulations
○ Technical problems
○ Other

Design complexity
● High (software, design process)
○ Low (well-known design)

Outcome

Technology readiness level
○ TRL6 - demonstrated in relevant environment
○ TRL7 - system prototype demonstration in operational environment
○ TRL8 - system complete and qualified
● TRL9 - actual system proven in operational environment

Overtime performance
● Still operating
○ Not operating yet
○ Destroyed

Construction complexity
● High (new technology)
○ Low (existing technology)

Main component of the building envelope
○ Polymers
○ Alloys
● Textiles
○ Wood
○ Concrete
○ Carbon-glass fiber

Level of innovation
○ Breakthrough innovation
● Improvement of existing systems

Adaptable to renovation
● Yes
○ No

Adaptatibility

Adaptation to stimuli
● Yes
○ No

Type of trigger (input)
○ Mechanical (e.g. wind load)
○ Thermal (e.g. air temperature)
○ Electromagnetic
○ Optical (e.g. daylight level)
○ Air quality (e.g. humidity)
○ Occupancy
● Other (internet data, BMS, etc.)

Type of actuator (output)
● Mechanical
○ Pneumatical
○ Electromagnetic
○ Thermal
○ Chemical
○ Other

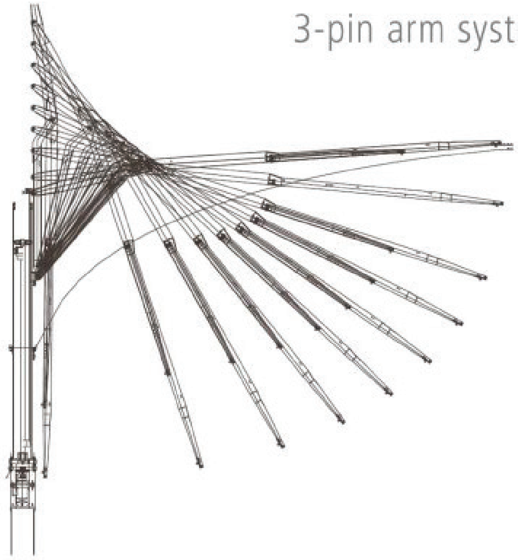
Control
○ Intrinsic (auto-reactive)
● Extrinsic (external control)

Response time
○ Seconds
● Minutes
○ Hours
○ Days
○ Weeks
○ Months

Spatial adaptation
○ Nanometers
○ Micrometers
○ Millimeters
○ Centimeters
● Meters

Material adaptation
○ Elasticity
○ Inflatable
○ Bi-material
○ Other

Degree of adaptability
● On-Off
○ Gradual



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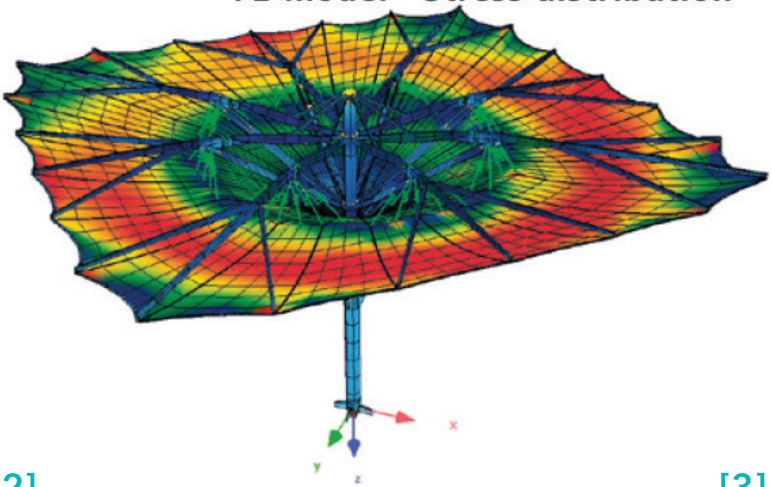
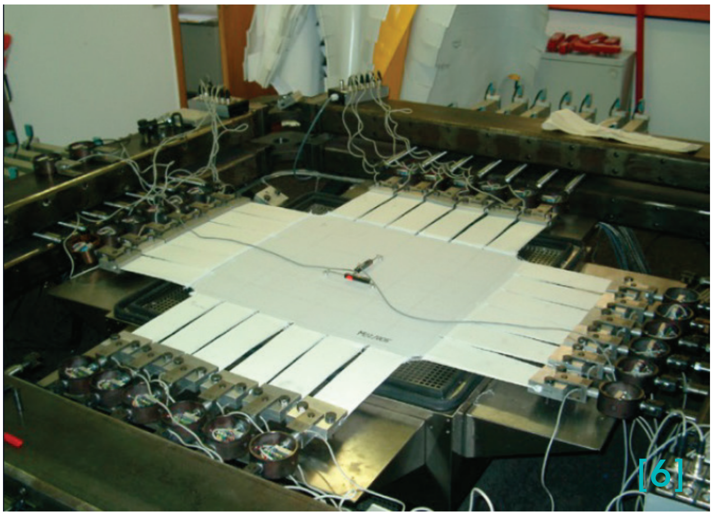


[3]

[4]

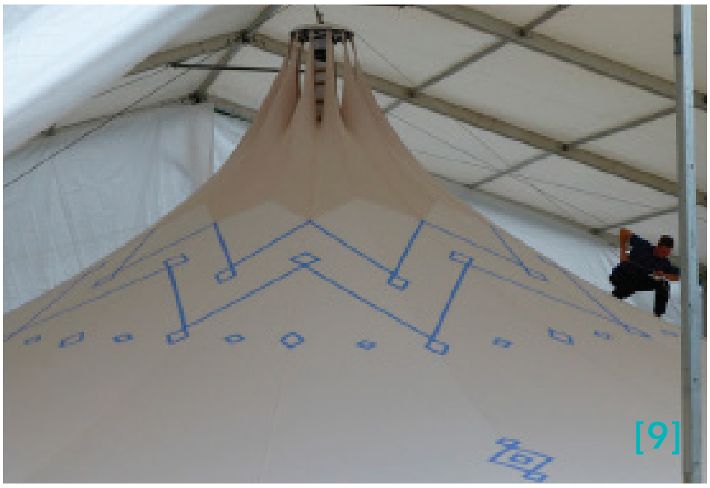
[5]



[6]

[7]

[8]



[9]

© ICD / University of Stuttgart [1]

ICD/ITKE Research Pavilion 2012. Stuttgart, Germany

"In November 2012 the ICD and ITKE at the University of Stuttgart have completed a research pavilion that is entirely robotically fabricated from carbon and glass fibre composites. The research focused on the material and morphological principles of arthropods' exoskeletons as a source of exploration for a new composite construction paradigm in architecture.
At the core of the project is the development of an innovative robotic fabrication process within the context of the building industry based on filament winding of carbon and glass fibres and the related computational design tools and simulation methods. A key aspect of the project was to transfer the fibrous morphology of the biological role model to fibre-reinforced composite materials, the anisotropy of which was integrated from the start into the computer-based design and simulation processes, thus leading to new tectonic possibilities in architecture. The integration of the form generation methods, the computational simulations and robotic manufacturing, specifically allowed the development of a high performance structure: the pavilion requires only a shell thickness of four millimetres of composite laminate while spanning eight metres. The exoskeleton of the lobster (Homarus americanus) was analysed in greater detail for its local material differentiation, which finally served as the biological role model of the project"

Text from https://www.icd.uni-stuttgart.de/projects/icditke-research-pavilion-2012/

Name: Research Pavilion 2012
Year of construction: 2012
Climate: Temperate (Cfb)
City: Stuttgart
Country: Germany

Surface: 30 m2
Cost (€/m²): na
Project use: Pavilion
Renovation: No

itke Institute of Building Structures and Structural Design
ICD Institute for Computational Design and Construction
University of Stuttgart Germany

Data sheet completed by Estelle Cruz & Tessa Hubert during a research exchange of three weeks at ITKE, University of Stuttgart (interview of **Prof Jan Knippers and Axel Körner)**

References

• "ICD/ITKE Research Pavilion 2012 | achimmenges.net." [Online]. Available: http://www.achimmenges.net/?p=5561. [Accessed: 14-Mar-2020]

• J. Knippers, R. La Magna, A. Menges, S. Reichert, T. Schwinn, and F. Waimer, "ICD/ITKE Research Pavilion 2012: Coreless filament winding based on the morphological principles of an arthropod exoskeleton," Archit. Des., vol. 85, no. 5, pp. 48–53, Sep. 2015.

Biomimetic

Definition
- ● Biomimetics
- ○ Bioinspiration
- ○ Biomimicry

Approach
- ○ Biology-push
- ● Technology-pull

Origins of bioinspiration
- ○ Random opportunities
- ● Interdisciplinary collaborations
- ○ Call for projects
- ○ Other

Targeted performance
- ○ Thermal comfort
- ○ Visual comfort
- ○ Acoustic comfort
- ○ Air quality
- ● Mechanical stress resistance
- ○ Water regulation

Integration scale of biomimetics
- ○ Material (facade component)
- ● Facade system
- ○ Building

Link to biology

Model kingdom
- ● Animalia: Homarus americanus (exoskeleton)
- ○ Plantae
- ○ Fungi
- ○ Bacteria/Archaea
- ○ Protozoa

Number of models
- ● One
- ○ Two
- ○ More

Type of knowledge
- ○ Existing for general public
- ● Existing for specialist
- ○ Created during the design process

Inputs in biology
- ○ Background of the designer
- ● Acquisition during the design
- ● Biologists integrated in the process

Design process

Use of design framework
- ○ Yes
- ● No

Eco-design approach
- ○ Yes
- ● No

Major constraints
- ○ Lack of funds
- ○ Use of biomimetic tools
- ○ Law regulations
- ● Technical problems
- ○ Other

Design complexity
- ● High (software, design process)
- ○ Low (well-known design)

Outcome

Technology readiness level
- ○ TRL6 - demonstrated in relevant environment
- ● TRL7 - system prototype demonstration in operational environment
- ○ TRL8 - system complete and qualified
- ○ TRL9 - actual system proven in operational environment

Overtime performance
- ○ Still operating
- ○ Not operating yet
- ● Destroyed

Construction complexity
- ● High (new technology)
- ○ Low (existing technology)

Main component of the building envelope
- ○ Polymers
- ○ Alloys
- ○ Textiles
- ○ Wood
- ○ Concrete
- ● Carbon-glass fiber (structure)

Level of innovation
- ● Breakthrough innovation
- ○ Improvement of existing systems

Adaptable to renovation
- ○ Yes
- ● No

Adaptability

Adaptation to stimuli
- ○ Yes
- ● No

Type of trigger (input)
- ○ Mechanical (e.g. wind load)
- ○ Thermal (e.g. air temperature)
- ○ Electromagnetic
- ○ Optical (e.g. daylight level)
- ○ Air quality (e.g. humidity)
- ○ Occupancy
- ○ Other (internet data, BMS, etc.)

Type of actuator (output)
- ○ Mechanical
- ○ Pneumatical
- ○ Electromagnetic
- ○ Thermal
- ○ Chemical
- ○ Other

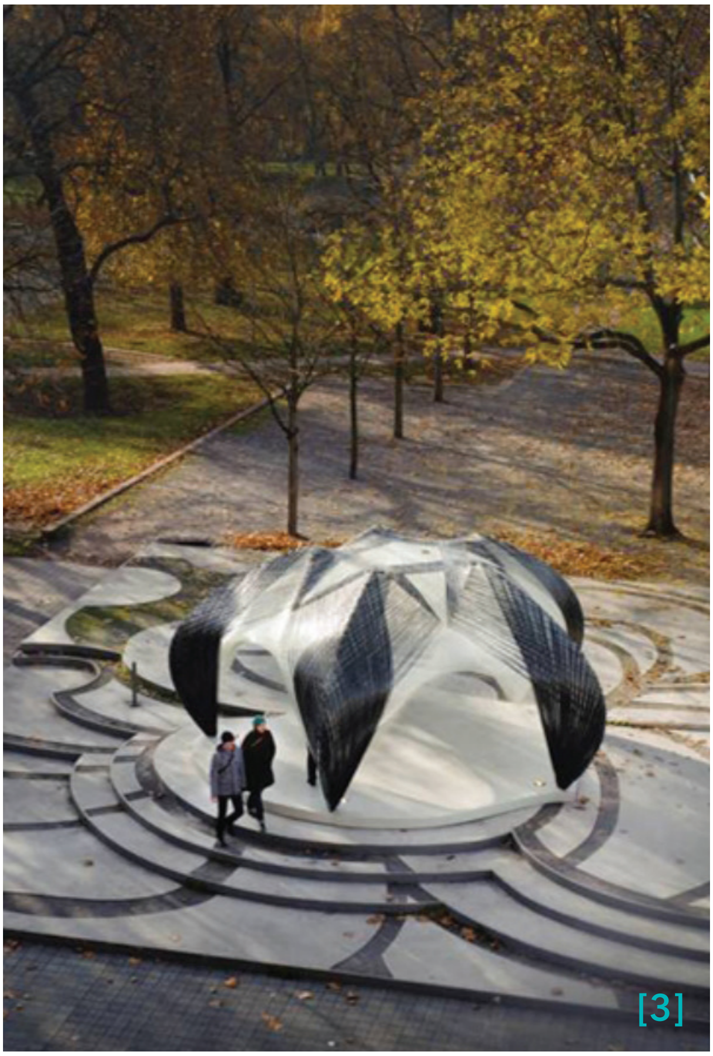
Control
- ○ Intrinsic (auto-reactive)
- ○ Extrinsic (external control)

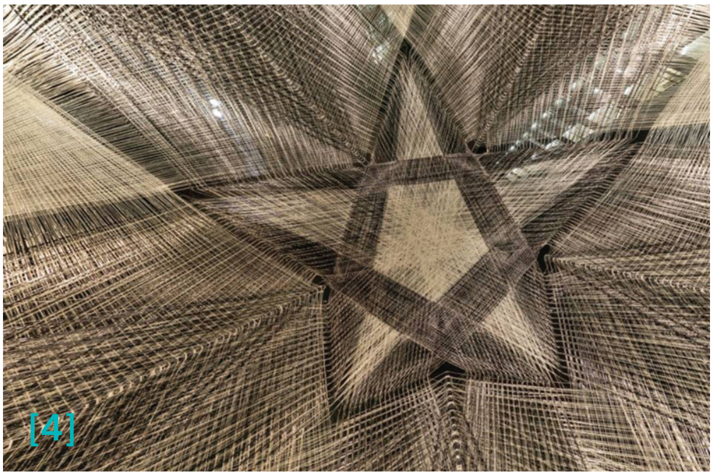
Response time
- ○ Seconds
- ○ Minutes
- ○ Hours
- ○ Days
- ○ Weeks
- ○ Months

Spatial adaptation
- ○ Nanometers
- ○ Micrometers
- ○ Millimeters
- ○ Centimeters
- ○ Meters

Material adaptation
- ○ Elasticity
- ○ Inflatable
- ○ Bi-material
- ○ Other

Degree of adaptability
- ○ On-Off
- ○ Gradual





Pictures and credits
© ICD/ITKE University of Stuttgart

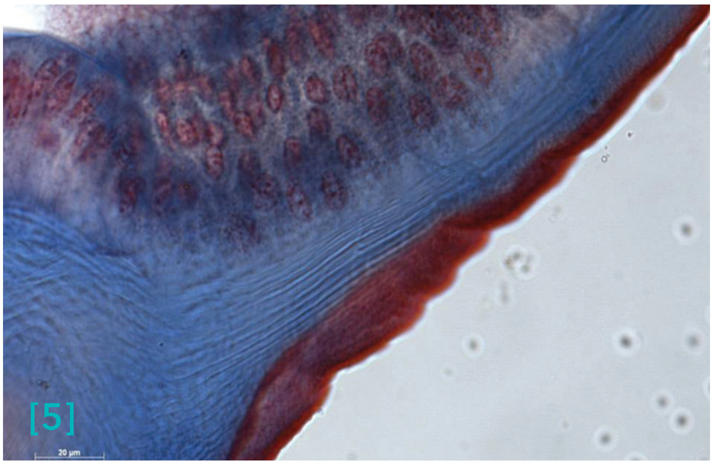
[1] Front view of the pavilion

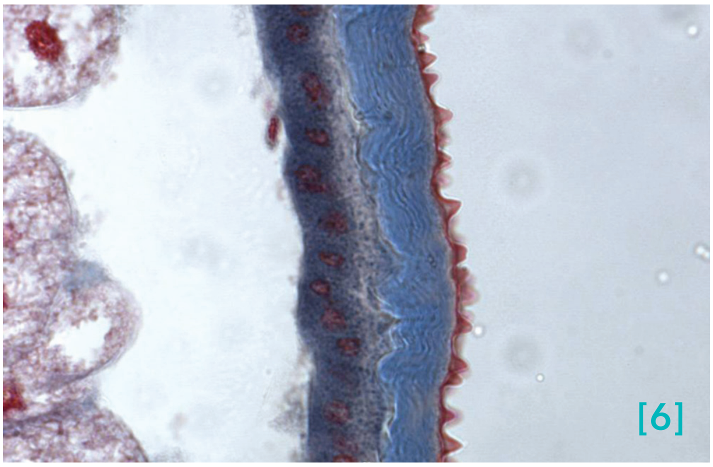
[2] Detail of the exterior envelope

[3] Bird-eye view of the pavilion

[4] Roof of the pavilion

[5] [6] Exoskeleton of the lobster (Homarus americanus)





ICD/ITKE Spider Research Pavilion 2014-15. Stuttgart, Germany

The design concept is based on the study of biological construction processes for fiber-reinforced structures. These processes are relevant for applications in architecture, as they do not require complex formwork and are capable of adapting to the varying demands of the individual constructions. The biological processes form customized fiber-reinforced structures in a highly material-effective and functionally integrated way. In this respect the web building process of the diving bell water spider, (Agyroneda Aquatica) proved to be of particular interest. Thus the web construction process of water spiders was examined and the underlying behavioral patterns and design rules were analyzed, abstracted and transferred into a technological fabrication process.

For the transfer of this biological formation sequence into a building construction application, a process was developed in which an industrial robot is placed within an air supported membrane envelope made of ETFE. This inflated soft shell is initially supported by air pressure, though, by robotically reinforcing the inside with carbon fiber, it is gradually stiffened into a self-supporting monocoque structure. The carbon fibers are only selectively applied where they are required for structural reinforcement, and the pneumatic formwork is simultaneously used as a functionally integrated building skin. This results in a resource efficient construction process.

Name: Research pavilion 2014-15
Year of construction: 2013-14
Climate: Temperate (Cfb)
City: Stuttgart
Country: Germany

Surface: 40 m2
Cost (€): na
Project use: Pavilion
Renovation: No

Data sheet completed by Estelle Cruz & Tessa Hubert during a research exchange of three weeks at ITKE, University of Stuttgart (interview of **Prof Jan Knippers and Axel Körner)**

References

• "ICD/ITKE Research Pavilion 2014-15 | achimmenges.net." [Online]. Available: http://www.achimmenges.net/?p=5814. [Accessed: 14-Mar-2020]

• M. Doerstelmann et al., "ICD/ITKE Research Pavilion 2014-15: Fibre placement on a pneumatic body based on a water spider web," Archit. Des., vol. 85, no. 5, pp. 60-65, Sep. 2015.

Biomimetic

Definition
- ● Biomimetics
- ○ Bioinspiration
- ○ Biomimicry

Approach
- ○ Biology-push
- ● Technology-pull

Origins of bioinspiration
- ○ Random opportunities
- ● Interdisciplinary collaborations
- ○ Call for projects
- ○ Other

Targeted performance
- ○ Thermal comfort
- ○ Visual comfort
- ○ Acoustic comfort
- ○ Air quality
- ● Mechanical stress resistance
- ○ Water regulation

Integration scale of biomimetics
- ○ Material (facade component)
- ● Facade system
- ○ Building

Link to biology

Model kingdom
- ● Animalia: diving bell water spider (Agyroneda Aquatica)
- ○ Plantae
- ○ Fungi
- ○ Bacteria/Archaea
- ○ Protozoa

Number of models
- ● One
- ○ Two
- ○ More

Type of knowledge
- ○ Existing for general public
- ● Existing for specialist
- ○ Created during the design process

Inputs in biology
- ○ Background of the designer
- ● Acquisition during the design
- ● Biologists integrated in the process

Design process

Use of design framework
- ○ Yes
- ● No

Eco-design approach
- ○ Yes
- ● No

Major constraints
- ○ Lack of funds
- ○ Use of biomimetic tools
- ○ Law regulations
- ● Technical problems
- ○ Other

Design complexity
- ● High (software, design process)
- ○ Low (well-known design)

Outcome

Technology readiness level
- ○ TRL6 - demonstrated in relevant environment
- ● TRL7 - system prototype demonstration in operational environment
- ○ TRL8 - system complete and qualified
- ○ TRL9 - actual system proven in operational environment

Overtime performance
- ○ Still operating
- ○ Not operating yet
- ● Destroyed

Construction complexity
- ● High (new technology)
- ○ Low (existing technology)

Main component of the building envelope
- ○ Polymers
- ○ Alloys
- ○ Textiles
- ○ Wood
- ○ Concrete
- ● Carbon-glass fiber (structure)

Level of innovation
- ● Breakthrough innovation
- ○ Improvement of existing systems

Adaptable to renovation
- ○ Yes
- ● No

Adaptability

Adaptation to stimuli
- ○ Yes
- ● No

Type of trigger (input)
- ○ Mechanical (e.g. wind load)
- ○ Thermal (e.g. air temperature)
- ○ Electromagnetic
- ○ Optical (e.g. daylight level)
- ○ Air quality (e.g. humidity)
- ○ Occupancy
- ○ Other (internet data, BMS, etc.)

Type of actuator (output)
- ○ Mechanical
- ○ Pneumatical
- ○ Electromagnetic
- ○ Thermal
- ○ Chemical
- ○ Other

Control
- ○ Intrinsic (auto-reactive)
- ○ Extrinsic (external control)

Response time
- ○ Seconds
- ○ Minutes
- ○ Hours
- ○ Days
- ○ Weeks
- ○ Months

Spatial adaptation
- ○ Nanometers
- ○ Micrometers
- ○ Millimeters
- ○ Centimeters
- ○ Meters

Material adaptation
- ○ Elasticity
- ○ Inflatable
- ○ Bi-material
- ○ Other

Degree of adaptability
- ○ On-Off
- ○ Gradual

Pictures and credits
© ICD/ITKE University of Stuttgart

[1] Front view of the pavilion

[2] Detail of the interior envelope

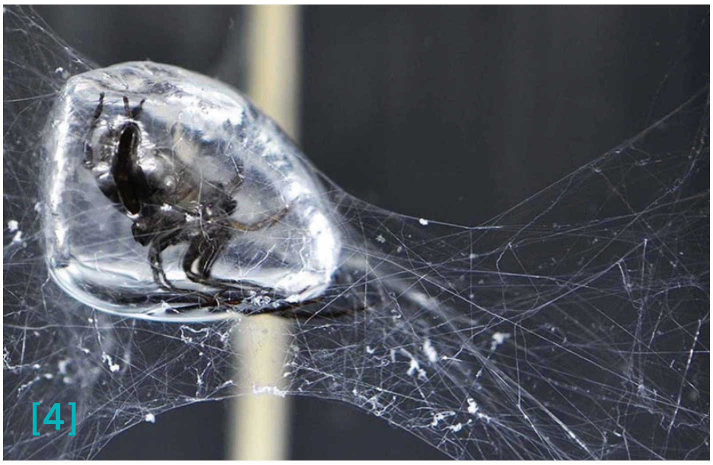
[3] Construction process

[4] Spider web under water

[5] Spider web under microscope

[2]

[3]



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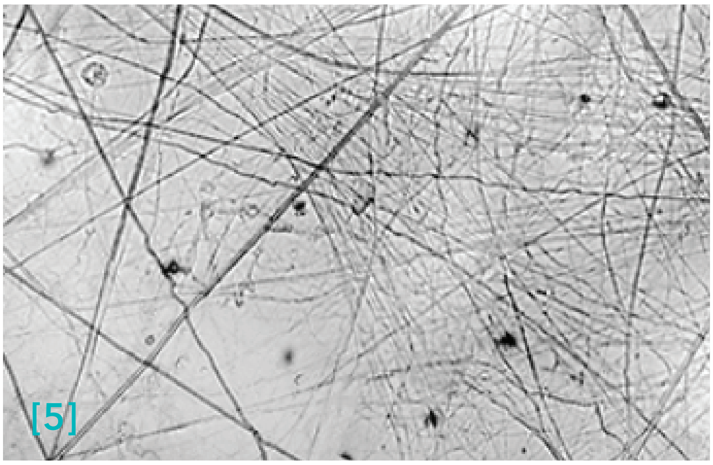

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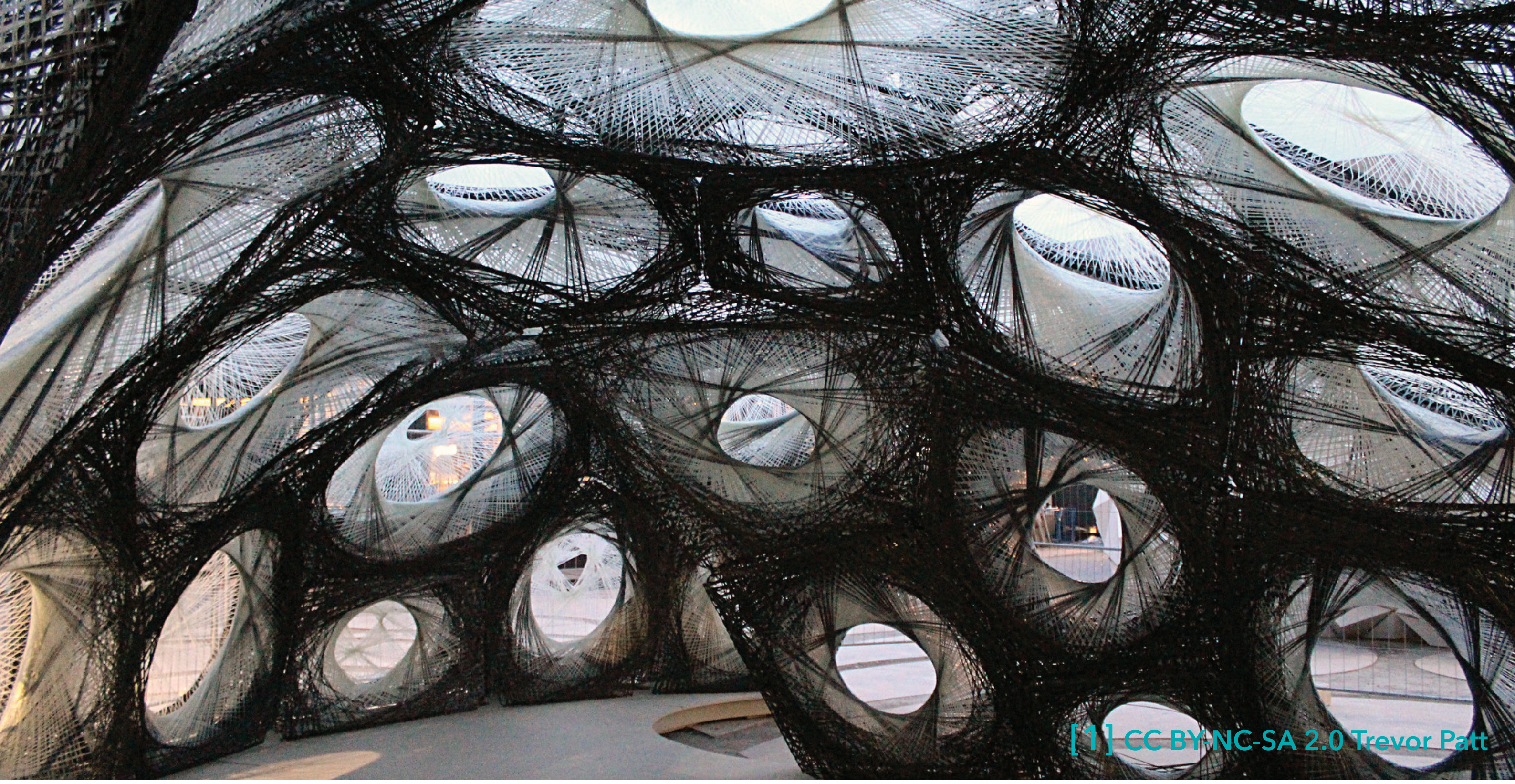
[1] CC BY-NC-SA 2.0 Trevor Patt

ICD/ITKE Elytra I Research Pavilion 2013-14. Stuttgart, Germany

This investigation of natural lightweight structures was conducted in an interdisciplinary cooperation of architects and engineers from Stuttgart University and biologists from Tubingen University. During the investigation, the Elytron, a protective shell for beetles' wings and abdomen, has proved to be a suitable role model for highly material efficient construction. The performance of these lightweight structures relies on the geometric morphology of a double layered system and the mechanical properties of the natural fiber composite. The anisotropic characteristic of this material, which consists of chitin fibers embedded in a protein matrix, allows for locally differentiated material properties.

In total 36 individual elements were fabricated, whose geometries are based on structural principles abstracted from the beetle elytra. Each of them has an individual fiber layout which results in a material efficient load-bearing system. The biggest element has a 2.6 m diameter with a weight of only 24.1 kg. The research pavilion covers a total area of 50 m² and a volume of 122 m³ with a weight of 593 kg.
Altogether the research pavilion shows how the computational synthesis of biological structural principles and the complex reciprocities between material, form and robotic fabrication can lead to the generation of innovative fiber composite construction methods.

Name: Research pavilion Elytra
Year of construction: 2013-14
Climate: Temperate (Cfb)
City: Stuttgart
Country: Germany

Surface: 40 m2
Cost (€/m²): na
Project use: Pavilion
Renovation: No

itke Institute of Building Structures and Structural Design
ICD Institute for Computational Design and Construction
University of Stuttgart Germany

Data sheet completed by Estelle Cruz & Tessa Hubert during a research exchange of three weeks at ITKE, University of Stuttgart (interview of **Prof Jan Knippers and Axel Körner)**

References

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Biomimetic

Definition
- ● Biomimetics
- ○ Bioinspiration
- ○ Biomimicry

Approach
- ○ Biology-push
- ● Technology-pull

Origins of bioinspiration
- ○ Random opportunities
- ● Interdisciplinary collaborations
- ○ Call for projects
- ○ Other

Targeted performance
- ○ Thermal comfort
- ○ Visual comfort
- ○ Acoustic comfort
- ○ Air quality
- ● Mechanical stress resistance
- ○ Water regulation

Integration scale of biomimetics
- ○ Material (facade component)
- ● Facade system
- ○ Building

Link to biology

Model kingdom
- ● Animalia: beetle (wings)
- ○ Plantae
- ○ Fungi
- ○ Bacteria/Archaea
- ○ Protozoa
- ○ Chromista

Number of models
- ● One
- ○ Two
- ○ More

Type of knowledge
- ○ Existing for general public
- ● Existing for specialist
- ● Created during the design process

Inputs in biology
- ○ Background of the designer
- ● Acquisition during the design
- ● Biologists integrated in the process

Design process

Use of design framework
- ○ Yes
- ● No

Eco-design approach
- ○ Yes
- ● No

Major constraints
- ○ Lack of funds
- ○ Use of biomimetic tools
- ○ Law regulations
- ● Technical problems
- ○ Other

Design complexity
- ● High (software, design process)
- ○ Low (well-known design)

Outcome

Technology readiness level
- ○ TRL6 - demonstrated in relevant environment
- ● TRL7 - system prototype demonstration in operational environment
- ○ TRL8 - system complete and qualified
- ○ TRL9 - actual system proven in operational environment

Overtime performance
- ○ Still operating
- ○ Not operating yet
- ● Destroyed

Construction complexity
- ● High (new technology)
- ○ Low (existing technology)

Main component of the building envelope
- ○ Polymers
- ○ Alloys
- ○ Textiles
- ○ Wood
- ○ Concrete
- ● Carbon-glass fiber (structure)

Level of innovation
- ● Breakthrough innovation
- ○ Improvement of existing systems

Adaptable to renovation
- ○ Yes
- ● No

Adaptability

Adaptation to stimuli
- ○ Yes
- ● No

Type of trigger (input)
- ○ Mechanical (e.g. wind load)
- ○ Thermal (e.g. air temperature)
- ○ Electromagnetic
- ○ Optical (e.g. daylight level)
- ○ Air quality (e.g. humidity)
- ○ Occupancy
- ○ Other (internet data, BMS, etc.)

Type of actuator (output)
- ○ Mechanical
- ○ Pneumatical
- ○ Electromagnetic
- ○ Thermal
- ○ Chemical
- ○ Other

Control
- ○ Intrinsic (auto-reactive)
- ○ Extrinsic (external control)

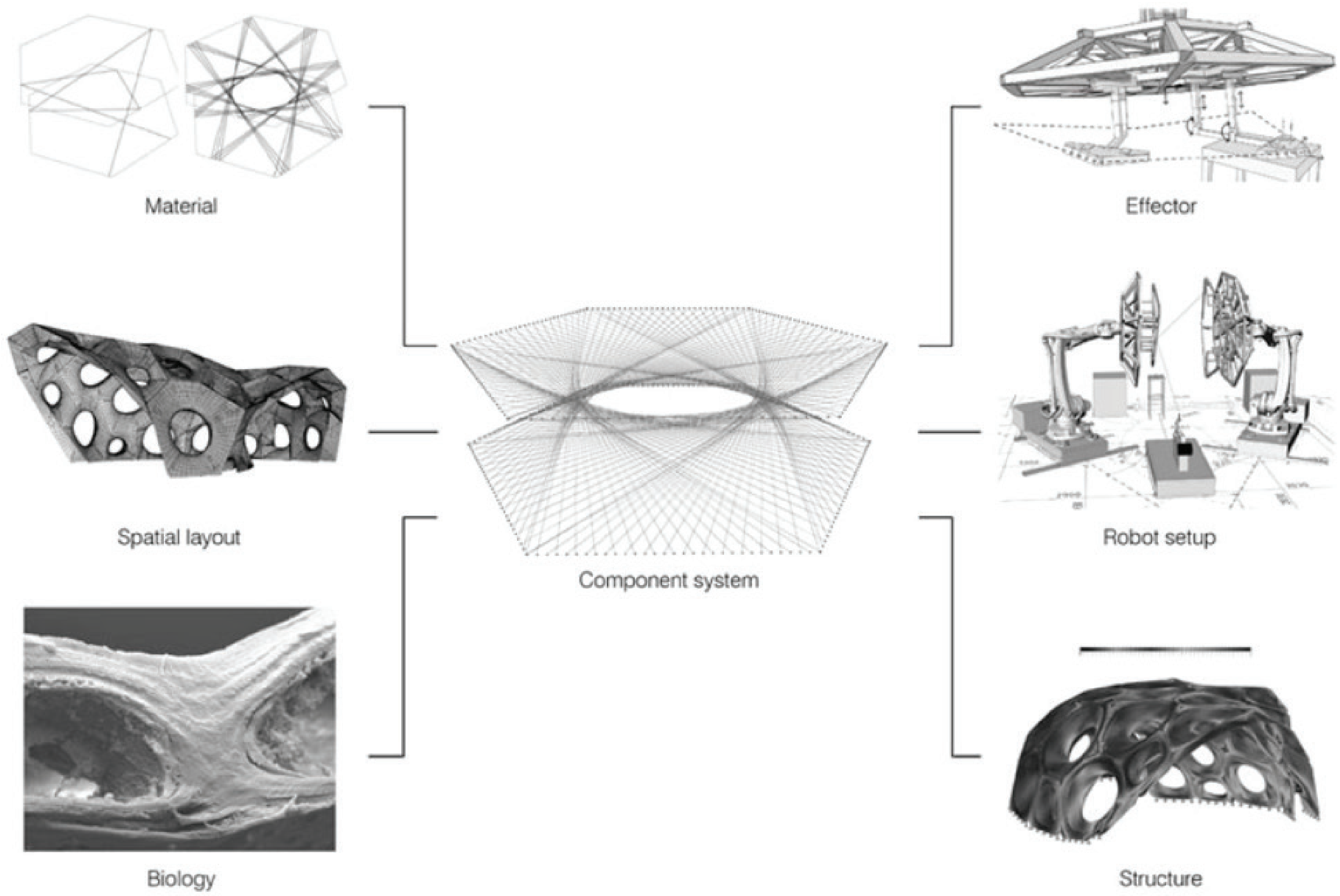
Response time
- ○ Seconds
- ○ Minutes
- ○ Hours
- ○ Days
- ○ Weeks
- ○ Months

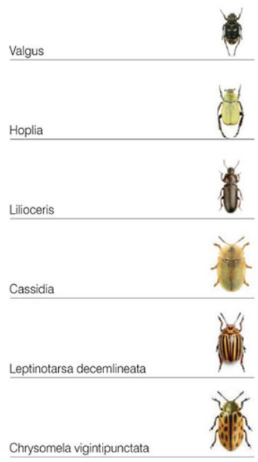
Spatial adaptation
- ○ Nanometers
- ○ Micrometers
- ○ Millimeters
- ○ Centimeters
- ○ Meters

Material adaptation
- ○ Elasticity
- ○ Inflatable
- ○ Bi-material
- ○ Other

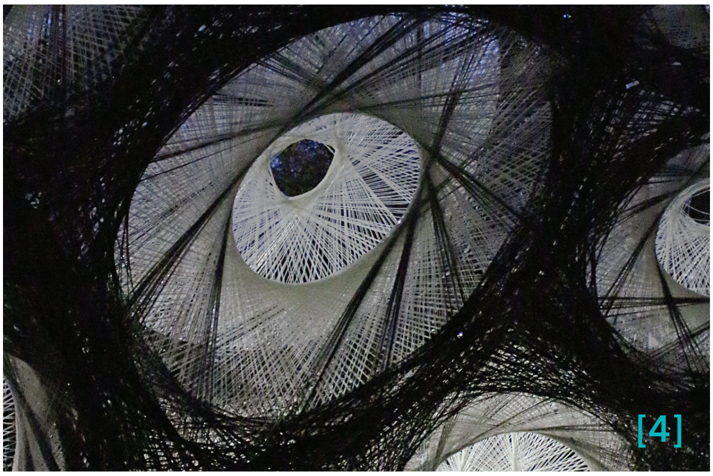
Degree of adaptability
- ○ On-Off
- ○ Gradual

[2]






[3]


[4]

[5]

Credits

[2,3,5] ©ICD/ITKE University of Stuttgart
[1,4] CC BY-NC-SA 2.0 Trevor Patt

[1] Pavilion top view,

[2] Pavilion construction

[3] Beetle test

[4] Pavilion inside view

[5] Beetle wing 3D modelling

[1] CC BY-SA 4.0 MSeses

ICD/ITKE Moth Research Pavilion 2016-17. Stuttgart, Germany

The ICD/ITKE Research Pavilion 2016-17 was created by laying a combined total of 184 km of resin-impregnated glass and carbon fibre. The lightweight material system was employed to create and test a single long spanning cantilever with an overall length of 12 m as an extreme structural scenario. The surface covers an area of about 40 m² and weighs roughly 1000 Kg. The realized structure was manufactured offsite and thus the size was constrained to fit within an allowable transport volume. However, variations of the setup were found suitable for on-site or in situ fabrication, which could be utilized for much longer span and larger fibre composite structures.

The aim was to develop a fibre winding technique over a longer span, which reduces the required formwork to a minimum whilst taking advantage of the structural performance of continuous filament. Two species of leaf miner moths, the Lyonetia clerkella and the Leucoptera erythrinella, whose larvae spin silk "hammocks" stretching between connection points on a bent leaf, were identified as particularly promising for the transfer of morphological and procedural principles for long span fibrous construction.

Name: Research pavilion 2016-17
Year of construction: 2017
Climate: Temperate (Cfb)
City: Stuttgart
Country: Germany

Surface: 5 m2
Cost (€/m²): na
Project use: Pavilion
Renovation: No

Data sheet completed by Estelle Cruz & Tessa Hubert during a research exchange of three weeks at ITKE, University of Stuttgart (interview of **Prof Jan Knippers and Axel Körner)**

References

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Biomimetic

Definition
● Biomimetics
○ Bioinspiration
○ Biomimicry

Approach
○ Biology-push
● Technology-pull

Origins of bioinspiration
○ Random opportunities
● Interdisciplinary collaborations
○ Call for projects
○ Other

Targeted performance
○ Thermal comfort
○ Visual comfort
○ Acoustic comfort
○ Air quality
● Mechanical stress resistance
○ Water regulation

Integration scale of biomimetics
○ Material (facade component)
● Facade system
○ Building

Link to biology

Model kingdom
● Animalia: silk of leaf miner moths
○ Plantae
○ Fungi
○ Bacteria/Archaea
○ Protozoa
○ Chromista

Number of models
● One
○ Two
○ More

Type of knowledge
○ Existing for general public
● Existing for specialist
○ Created during the design process

Inputs in biology
○ Background of the designer
● Acquisition during the design
● Biologists integrated in the process

Design process

Use of design framework
○ Yes
● No

Eco-design approach
○ Yes
● No

Major constraints
○ Lack of funds
○ Use of biomimetic tools
○ Law regulations
● Technical problems
○ Other

Design complexity
● High (software, design process)
○ Low (well-known design)

Outcome

Technology readiness level
○ TRL6 - demonstrated in relevant environment
● TRL7 - system prototype demonstration in operational environment
○ TRL8 - system complete and qualified
○ TRL9 - actual system proven in operational environment

Overtime performance
○ Still operating
○ Not operating yet
● Destroyed

Construction complexity
● High (new technology)
○ Low (existing technology)

Main component of the building envelope
○ Polymers
○ Alloys
○ Textiles
○ Wood
○ Concrete
● Carbon-glass fiber (structure)

Level of innovation
● Breakthrough innovation
○ Improvement of existing systems

Adaptable to renovation
○ Yes
● No

Adaptability

Adaptation to stimuli
○ Yes
● No

Type of trigger (input)
○ Mechanical (e.g. wind load)
○ Thermal (e.g. air temperature)
○ Electromagnetic
○ Optical (e.g. daylight level)
○ Air quality (e.g. humidity)
○ Occupancy
○ Other (internet data, BMS, etc.)

Type of actuator (output)
○ Mechanical
○ Pneumatical
○ Electromagnetic
○ Thermal
○ Chemical
○ Other

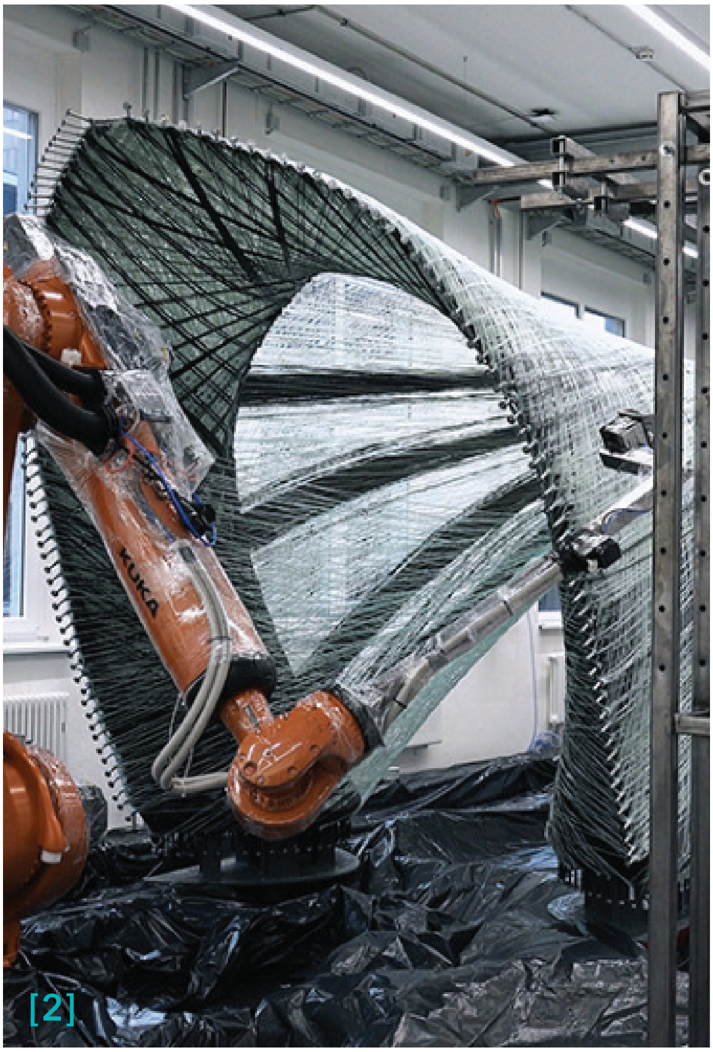
Control
○ Intrinsic (auto-reactive)
○ Extrinsic (external control)

Response time
○ Seconds
○ Minutes
○ Hours
○ Days
○ Weeks
○ Months

Spatial adaptation
○ Nanometers
○ Micrometers
○ Millimeters
○ Centimeters
○ Meters

Material adaptation
○ Elasticity
○ Inflatable
○ Bi-material
○ Other

Degree of adaptability
○ On-Off
○ Gradual



[2]

[4]

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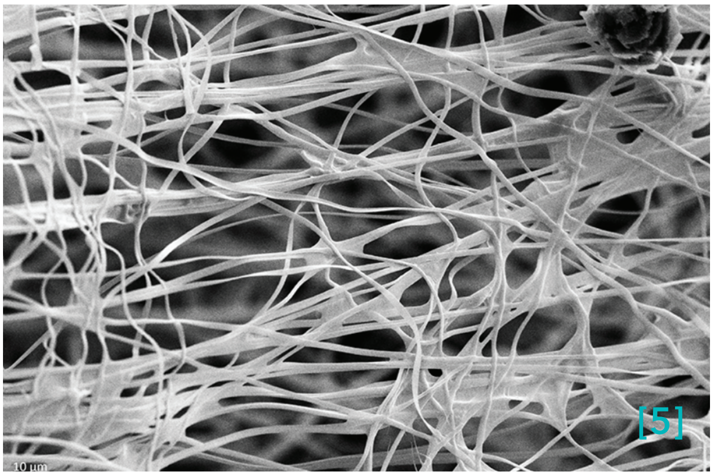


[5]

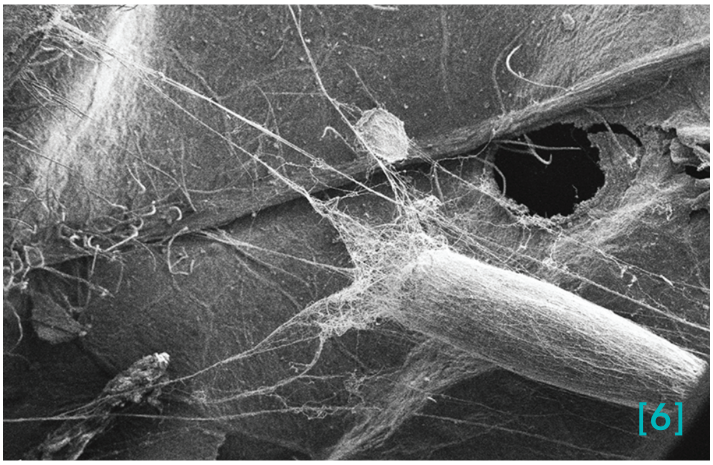
Pictures and credits
[2,4-6] © ICD/ITKE University of Stuttgart
[1] CC BY-SA 4.0 MSeses

[1] Pavilion face view

[2] Building process

[3] [4] Moth habitat

[5] [6] Moth microscope



[6]

ICD/ITKE BUGA Fibre Pavilion, 2019. Heilbronn, Germany

The pavilion demonstrates how combining cutting-edge computational technologies with constructional principles found in nature enables the development of truly novel and genuinely digital building systems. The pavilion's load-bearing structure is robotically produced from advanced fibre composites only. This globally unique structure is not only highly effective and exceptionally lightweight, but it also provides a distinctive yet authentic architectural expression and an extraordinary spatial experience.

In biology most load-bearing structures are fibre composites. They are made from fibres, as for example cellulose, chitin or collagen, and a matrix material that supports them and maintains their relative position. The astounding performance and unrivalled resource efficiency of biological structures stem from these fibrous systems. Their organization, directionality and density is finely tuned and locally varied in order to ensure that material is only placed where it is needed.

The BUGA Fibre Pavilion aims to transfer this biological principle of load-adapted and thus highly differentiated fibre composite systems into architecture. Manmade composites, such as the glass- or carbon-fibre-reinforced plastics that were used for this building, are ideally suited for such an approach because they share their fundamental characteristics with natural composites.

Name:
Year of construction: 2019
Climate: Temperate (Cfb)
City: Heilbronn
Country: Germany

Surface: 70 m²
Cost (€/m²): na
Project use: pavilion
Renovation: No

itke Institute of Building Structures and Structural Design
ICD Institute for Computational Design and Construction
FibR reinventing composites
BUGA HEILBRONN 2019
University of Stuttgart Germany

Data sheet completed by Estelle Cruz & Tessa Hubert during a research exchange of three weeks at ITKE, University of Stuttgart (interview of **Prof Jan Knippers and Axel Körner)**

References
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Biomimetic

Definition
● Biomimetics
○ Bioinspiration
○ Biomimicry

Approach
○ Biology-push
● Technology-pull

Origins of bioinspiration
○ Random opportunities
● Interdisciplinary collaborations
○ Call for projects
○ Other

Targeted performance
○ Thermal comfort
○ Visual comfort
○ Acoustic comfort
○ Air quality
● Mechanical stress resistance
○ Water regulation

Integration scale of biomimetics
○ Material (facade component)
● Facade system
○ Building

Link to biology

Model kingdom
● Animalia: beetle (wings)
○ Plantae
○ Fungi
○ Bacteria/Archaea
○ Protozoa
○ Chromista

Number of models
● One
○ Two
○ More

Type of knowledge
○ Existing for general public
● Existing for specialist
○ Created during the design process

Inputs in biology
○ Background of the designer
● Acquisition during the design
● Biologists integrated in the process

Design process

Use of design framework
○ Yes
● No

Eco-design approach
○ Yes
● No

Major constraints
○ Lack of funds
○ Use of biomimetic tools
○ Law regulations
● Technical problems
○ Other

Design complexity
● High (software, design process)
○ Low (well-known design)

Outcome

Technology readiness level
○ TRL6 - demonstrated in relevant environment
○ TRL7 - system prototype demonstration in operational environment
● TRL8 - system complete and qualified
○ TRL9 - actual system proven in operational environment

Overtime performance
● Still operating
○ Not operating yet
○ Destroyed

Construction complexity
● High (new technology)
○ Low (existing technology)

Main component of the building envelope
● Polymers (envelope)
○ Alloys
○ Textiles
○ Wood
○ Concrete
● Carbon-glass fiber (structure)

Level of innovation
● Breakthrough innovation
○ Improvement of existing systems

Adaptable to renovation
○ Yes
● No

Adaptability

Adaptation to stimuli
○ Yes
● No

Type of trigger (input)
○ Mechanical (e.g. wind load)
○ Thermal (e.g. air temperature)
○ Electromagnetic
○ Optical (e.g. daylight level)
○ Air quality (e.g. humidity)
○ Occupancy
○ Other (internet data, BMS, etc.)

Type of actuator (output)
○ Mechanical
○ Pneumatical
○ Electromagnetic
○ Thermal
○ Chemical
○ Other

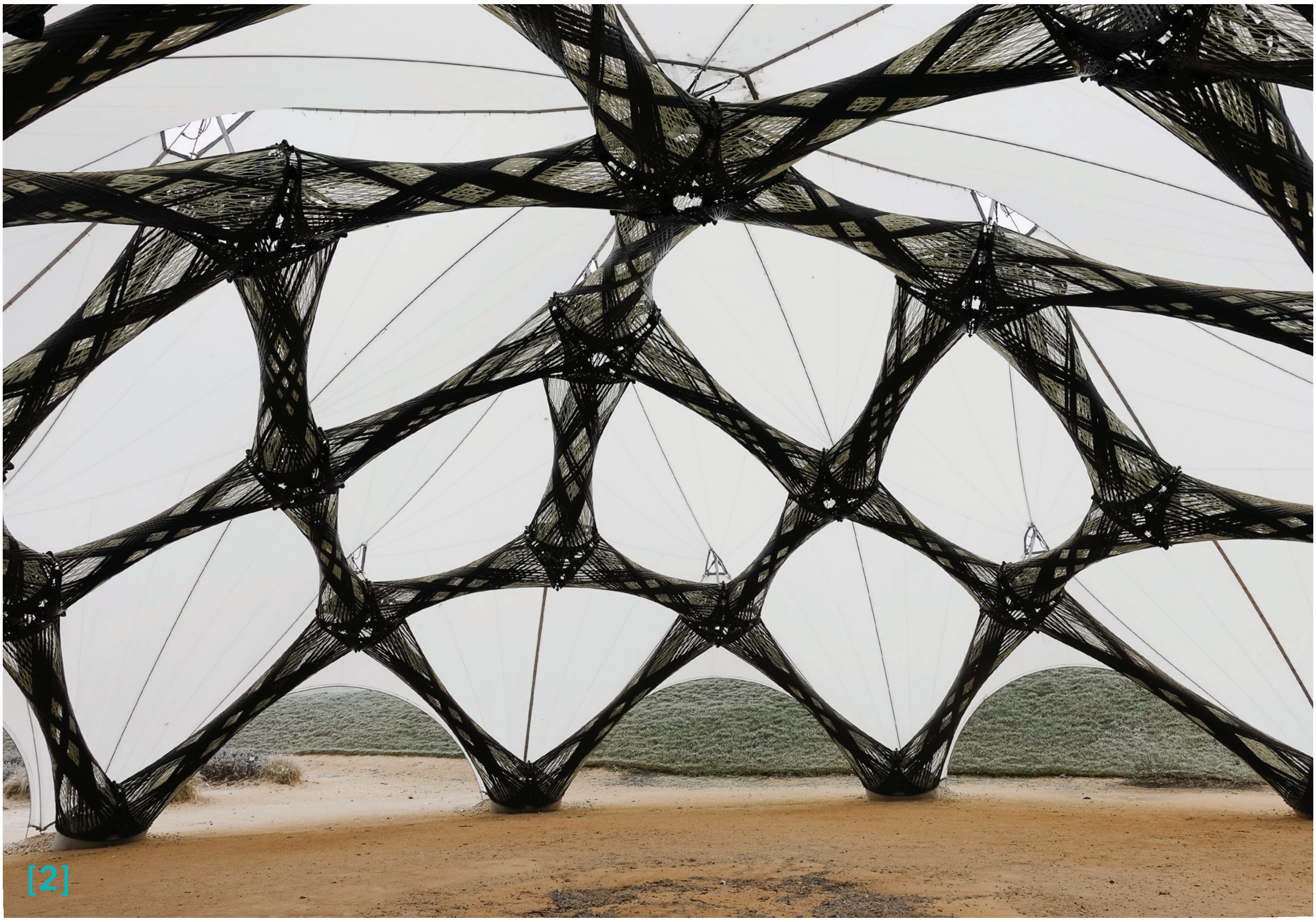
Control
○ Intrinsic (auto-reactive)
○ Extrinsic (external control)

Response time
○ Seconds
○ Minutes
○ Hours
○ Days
○ Weeks
○ Months

Spatial adaptation
○ Nanometers
○ Micrometers
○ Millimeters
○ Centimeters
○ Meters

Material adaptation
○ Elasticity
○ Inflatable
○ Bi-material
○ Other

Degree of adaptability
○ On-Off
○ Gradual



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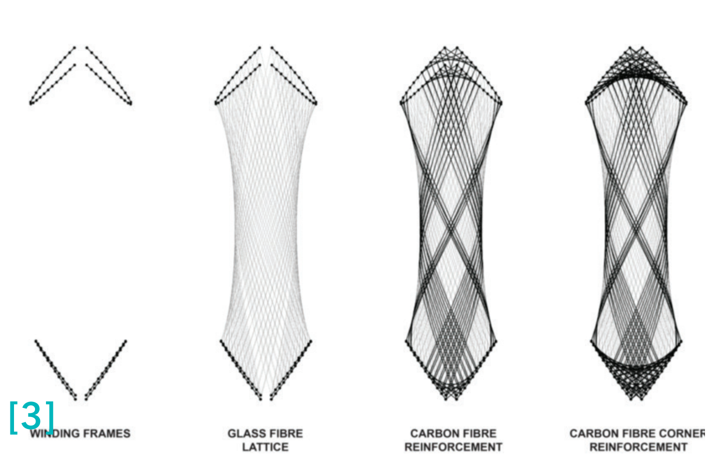
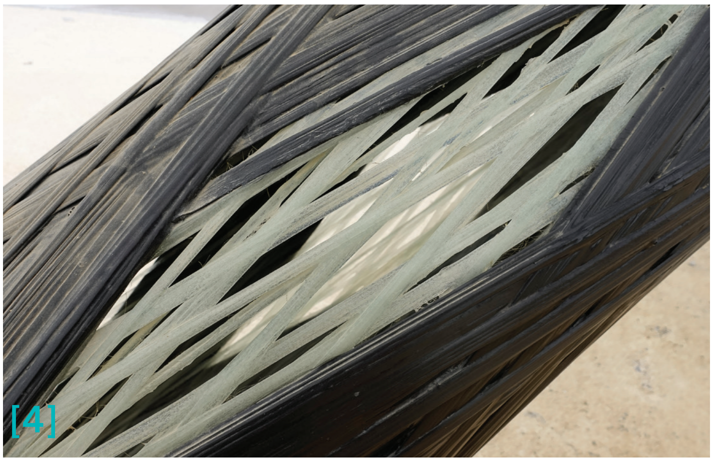
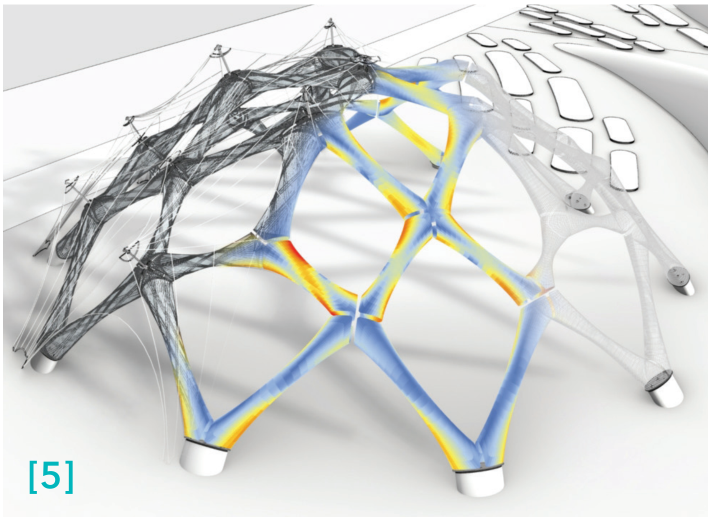


[3]



[4]



[5]

Credits

[3, 5] © ICD/ITKE University of Stuttgart
[1, 2, 4] CC BY SA Axel Larsson

[1] Pavilion external view

[2] Pavilion internal view - roof

[3] Module detail

[4] Detail of the structure

[5] Pavilion 3D modelling

[1] CC BY-SA 4.0 MSeses

ICD/ITKE Sand Dollar Research Pavilion, 2011. Stuttgart, Germany

This bionic research pavilion is made of wood at the intersection of teaching and research. The project explores the architectural transfer of biological principles of the sea urchin's plate skeleton morphology by means of novel computer-based design and simulation methods, along with computer-controlled manufacturing methods for its building implementation.

The focus was set on the development of a modular system which allows a high degree of adaptability and performance due to the geometric differentiation of its plate components and robotically fabricated finger joints. The plate skeleton morphology of the sand dollar, a sub-species of the sea urchin (Echinoidea), became of particular interest and subsequently provided the basic principles of the bionic structure that was realized. The skeletal shell of the sand dollar is a modular system of polygonal plates, which are linked together at the edges by finger-like calcite protrusions. High load bearing capacity is achieved by the particular geometric arrangement of the plates and their joining system. Therefore, the sand dollar serves as a most fitting model for shells made of prefabricated elements. Similarly, the traditional finger-joints typically used in carpentry as connection elements, can be seen as the technical equivalent of the sand dollar's calcite protrusions.

Text from http://www.achimmenges.net/?p=5123

Name: Research Pavilion 2011
Year of construction: 2011
Climate: Temperate (Cfb)
City: Stuttgart
Country: Germany

Surface: 40 m2
Cost: na
Project use: pavilion
Renovation: no

itke Institute of Building Structures and Structural Design
ICD Institute for Computational Design and Construction
University of Stuttgart Germany

Data sheet completed by Estelle Cruz & Tessa Hubert during a research exchange of three weeks at ITKE, University of Stuttgart (interview of **Prof Jan Knippers and Axel Körner**).

References

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Biomimetic

Definition
- ● Biomimetics
- ○ Bioinspiration
- ○ Biomimicry

Approach
- ○ Biology-push
- ○ Technology-pull

Origins of bioinspiration
- ○ Random opportunities
- ● Interdisciplinary collaborations
- ○ Call for projects
- ○ Other

Targeted performance
- ○ Thermal comfort
- ○ Visual comfort
- ○ Acoustic comfort
- ○ Air quality
- ● Mechanical stress resistance
- ○ Water regulation

Integration scale of biomimetics
- ○ Material (facade component)
- ● Facade system
- ○ Building

Link to biology

Model kingdom
- ● Animalia: sand dollar
- ○ Plantae
- ○ Fungi
- ○ Bacteria/Archaea
- ○ Protozoa
- ○ Chromista

Number of models
- ● One
- ○ Two
- ○ More

Type of knowledge
- ○ Existing for general public
- ● Existing for specialist
- ● Created during the design process

Inputs in biology
- ○ Background of the designer
- ● Acquisition during the design
- ● Biologists integrated in the process

Design process

Use of design framework
- ○ Yes
- ● No

Eco-design approach
- ○ Yes
- ● No

Major constraints
- ○ Lack of funds
- ○ Use of biomimetic tools
- ○ Law regulations
- ● Technical problems
- ○ Other

Design complexity
- ● High (software, design process)
- ○ Low (well-known design)

Outcome

Technology readiness level
- ○ TRL6 - demonstrated in relevant environment
- ● TRL7 - system prototype demonstration in operational environment
- ○ TRL8 - system complete and qualified
- ○ TRL9 - actual system proven in operational environment

Overtime performance
- ○ Still operating
- ○ Not operating yet
- ● Destroyed

Construction complexity
- ● High (new technology)
- ○ Low (existing technology)

Main component of the building envelope
- ○ Polymers
- ○ Alloys
- ○ Textiles
- ● Wood
- ○ Concrete
- ○ Carbon-glass fiber

Level of innovation
- ● Breakthrough innovation
- ○ Improvement of existing systems

Adaptable to renovation
- ○ Yes
- ● No

Adaptability

Adaptation to stimuli
- ○ Yes
- ● No

Type of trigger (input)
- ○ Mechanical (e.g. wind load)
- ○ Thermal (e.g. air temperature)
- ○ Electromagnetic
- ○ Optical (e.g. daylight level)
- ○ Air quality (e.g. humidity)
- ○ Occupancy
- ○ Other (internet data, BMS, etc.)

Type of actuator (output)
- ○ Mechanical
- ○ Pneumatical
- ○ Electromagnetic
- ○ Thermal
- ○ Chemical
- ○ Other

Control
- ○ Intrinsic (auto-reactive)
- ○ Extrinsic (external control)

Response time
- ○ Seconds
- ○ Minutes
- ○ Hours
- ○ Days
- ○ Weeks
- ○ Months

Spatial adaptation
- ○ Nanometers
- ○ Micrometers
- ○ Millimeters
- ○ Centimeters
- ○ Meters

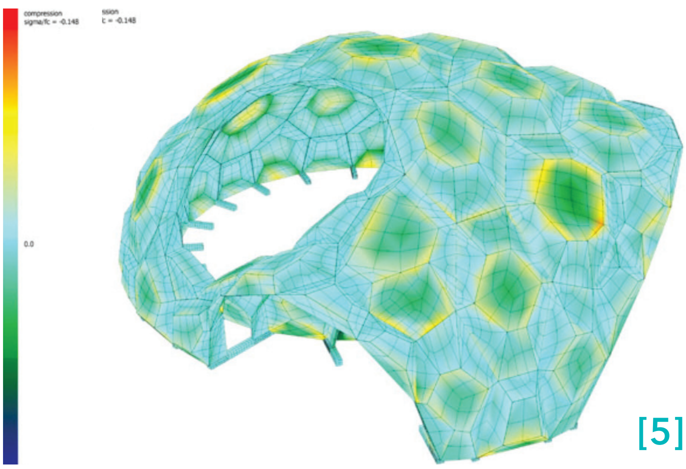
Material adaptation
- ○ Elasticity
- ○ Inflatable
- ○ Bi-material
- ○ Other

Degree of adaptability
- ○ On-Off
- ○ Gradual

[2]

[3]

[4]



[5]

Credits

[2-5] © ICD/ITKE University of Stuttgart
[1] CC BY-SA 4.0 MSeses

[1] Front view of the pavilion

[2] View from the inside of the pavilion

[3] Detail of the figer joint

[4] Manufacturing process

[5] Numerical modeling of the structural constraints

© ICD / University of Stuttgart [1]

ICD/ITKE Sand Dollar II Research Pavilion, 2015-16. Stuttgart.

The pavilion is the first of its kind to employ industrial sewing of wood elements on an architectural scale. The project was designed and realized by students and researchers within a multi-disciplinary team of architects, engineers, biologists, and palaeontologists.

The project commenced with the analysis of the constructional morphology of sand dollars. At the same time, a fabrication technique was developed that enables the production of elastically bent, double-layered segments made from custom-laminated, robotically sewn beech plywood. Introducing textile connection methods in timber construction enables extremely lightweight and performative segmented timber shells.

Previous studies on sea urchins by the research partners already led to the transfer of constructional principles and the development of new construction methods for timber plate shells. Together with the University of Tübingen, pictures and SEM scans (scanning electron microscopy) were performed on several species in order to understand the intricate internal structures of sea urchins and sand dollars.

https://www.icd.uni-stuttgart.de/projects/icditke-research-pavilion-2015-16/

Name: Research Pavilion 2015-16
Year of construction: 2015-16
Climate: Temperate (Cfb)
City: Stuttgart
Country: Germany

Surface: 85 m2
Cost (€): na
Project use: pavilion
Renovation: No

itke Institute of Building Structures and Structural Design
ICD Institute for Computational Design and Construction

University of Stuttgart
Germany

Data sheet completed by Estelle Cruz & Tessa Hubert during a research exchange of three weeks at ITKE, University of Stuttgart.

Data sheet reviewed by **Daniel-Alexander Sonntag** - daniel-alexander.sonntag@itke.uni-stuttgart.de

References

• O. D. Krieg, K. Dierichs, S. Reichert, T. Schwinn, and A. Menges, "Performative Architectural Morphology Robotically manufactured biomimetic finger-joined plate structures," 2011.

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Biomimetic

Definition
- ● Biomimetics
- ○ Bioinspiration
- ○ Biomimicry

Approach
- ○ Biology-push
- ● Technology-pull

Origins of bioinspiration
- ○ Random opportunities
- ● Interdisciplinary collaborations
- ○ Call for projects
- ○ Other

Targeted performance
- ○ Thermal comfort
- ○ Visual comfort
- ○ Acoustic comfort
- ○ Air quality
- ● Mechanical stress resistance
- ○ Water regulation

Integration scale of biomimetics
- ○ Material (facade component)
- ● Facade system
- ○ Building

Link to biology

Model kingdom
- ● Animalia: sand dollar
- ○ Plantae
- ○ Fungi
- ○ Bacteria/Archaea
- ○ Protozoa
- ○ Chromista

Number of models
- ● One
- ○ Two
- ○ More

Type of knowledge
- ○ Existing for general public
- ● Existing for specialist
- ● Created during the design process

Inputs in biology
- ○ Background of the designer
- ● Acquisition during the design
- ● Biologists integrated in the process

Design process

Use of design framework
- ○ Yes
- ● No

Eco-design approach
- ○ Yes
- ● No

Major constraints
- ○ Lack of funds
- ○ Use of biomimetic tools
- ○ Law regulations
- ● Technical problems
- ○ Other

Design complexity
- ● High (software, design process)
- ○ Low (well-known design)

Outcome

Technology readiness level
- ○ TRL6 - demonstrated in relevant environment
- ● TRL7 - system prototype demonstration in operational environment
- ○ TRL8 - system complete and qualified
- ○ TRL9 - actual system proven in operational environment

Overtime performance
- ○ Still operating
- ○ Not operating yet
- ● Destroyed

Construction complexity
- ● High (new technology)
- ○ Low (existing technology)

Main component of the building envelope
- ○ Polymers
- ○ Alloys
- ○ Textiles
- ● Wood
- ○ Concrete
- ○ Carbon-glass fiber

Level of innovation
- ● Breakthrough innovation
- ○ Improvement of existing systems

Adaptable to renovation
- ○ Yes
- ● No

Adaptability

Adaptation to stimuli
- ○ Yes
- ● No

Type of trigger (input)
- ○ Mechanical (e.g. wind load)
- ○ Thermal (e.g. air temperature)
- ○ Electromagnetic
- ○ Optical (e.g. daylight level)
- ○ Air quality (e.g. humidity)
- ○ Occupancy
- ○ Other (internet data, BMS, etc.)

Type of actuator (output)
- ○ Mechanical
- ○ Pneumatical
- ○ Electromagnetic
- ○ Thermal
- ○ Chemical
- ○ Other

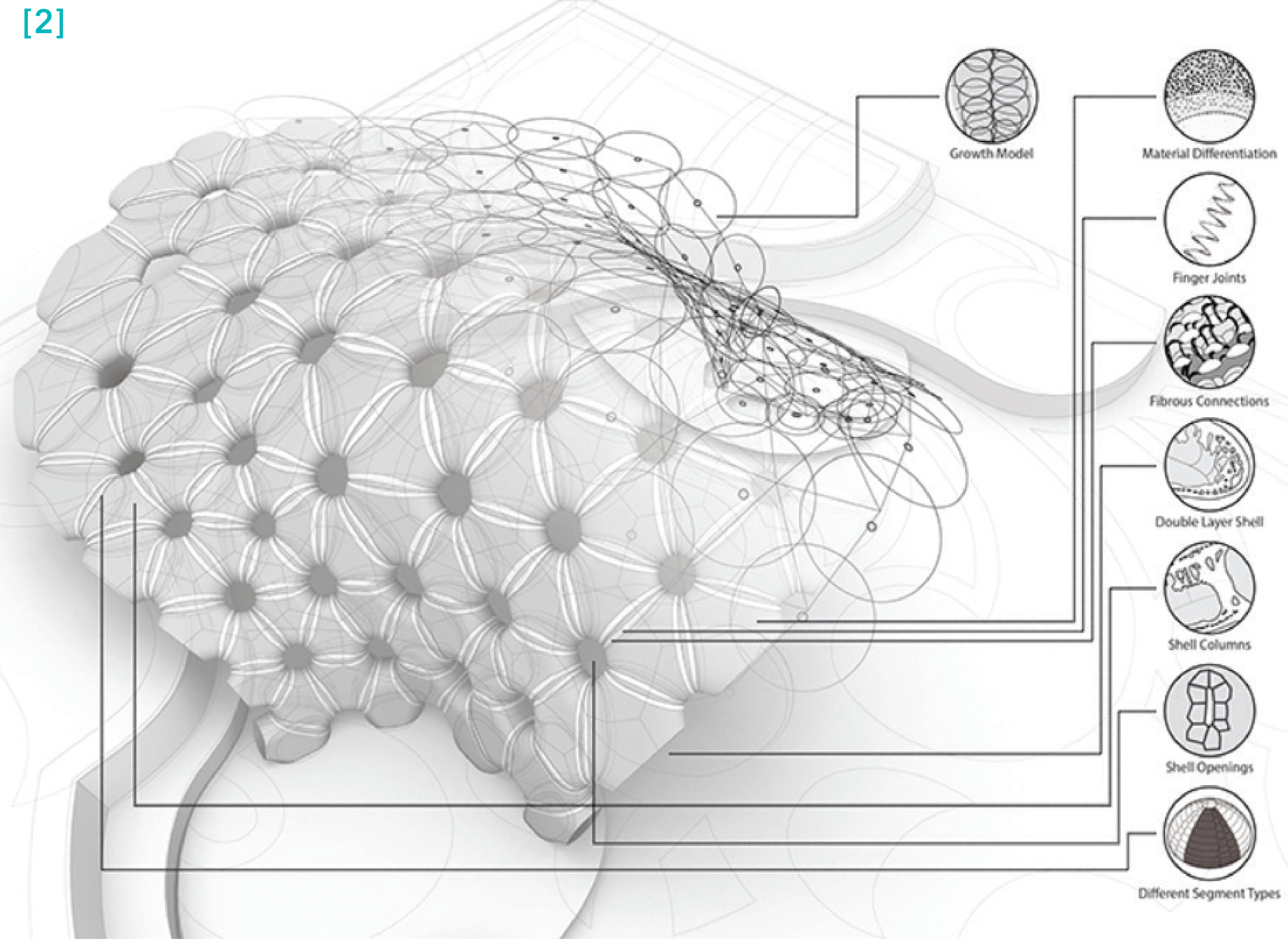
Control
- ○ Intrinsic (auto-reactive)
- ○ Extrinsic (external control)

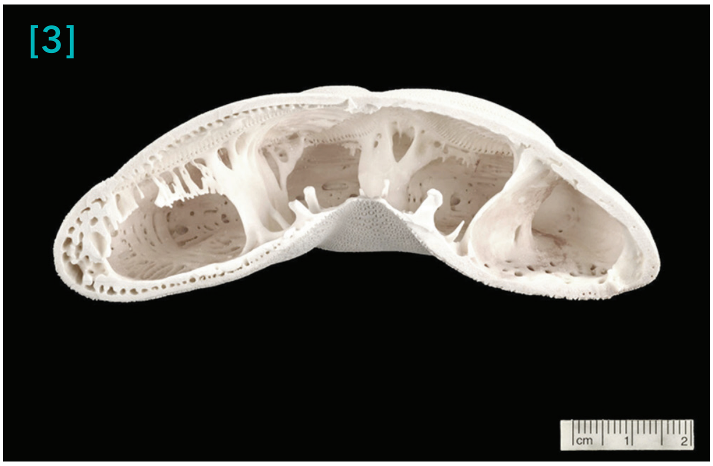
Response time
- ○ Seconds
- ○ Minutes
- ○ Hours
- ○ Days
- ○ Weeks
- ○ Months

Spatial adaptation
- ○ Nanometers
- ○ Micrometers
- ○ Millimeters
- ○ Centimeters
- ○ Meters

Material adaptation
- ○ Elasticity
- ○ Inflatable
- ○ Bi-material
- ○ Other

Degree of adaptability
- ○ On-Off
- ○ Gradual





Pictures and credits ©ICD/ITKE University of Stuttgart

[1] Front view of the pavilion

[2] Numerical modelling of the pavilion

[3] SEM scans (scanning electron microscopy) of the sand dollars to understand the intricate internal structures.

[4] [5] Façade module


© ICD / University of Stuttgart [1]

ICD/ITKE LAGA Research Pavilion, 2014. Stuttgart, Germany

The Landesgartenschau Exhibition Hall is an architectural prototype building and a showcase for the current developments in computational design and robotic fabrication for lightweight timber construction. The building is the first to have its primary structure entirely made of robotically prefabricated beech plywood plates. The newly developed timber construction offers not only innovative architectural possibilities; it is also highly resource efficient, with the load bearing plate structure being just 50 mm thin. This is made possible through integrative computational design.

In comparison to man-made constructions natural biological constructions exhibit a significantly higher degree of morphological differentiation. This differentiation in form and structure is a key aspect for their performance and resource efficiency, achieving "less material" through "more from". In the context of the Exhibition Hall, natural plate shells are of particular interest as they are a performative construction system made of individual elements. The skeleton of sea urchins is such a modular system made of calcium carbonate plates that are joined by microscopic interlocking projections along the plate edges that are very similar to man-made finger joints.

https://www.icd.uni-stuttgart.de/projects/landesgartenschau-exhibition-hall/

Name:
Year of construction: 2014
Climate: Temperate (Cfb)
City: Stuttgart
Country: Germany

Surface: 125 m2
Cost (€): na
Project use: Pavilion
Renovation: No

itke Institute of Building Structures and Structural Design
ICD Institute for Computational Design and Construction
University of Stuttgart Germany

Data sheet completed by Estelle Cruz & Tessa Hubert during a research exchange of three weeks at ITKE, University of Stuttgart.

Data sheet reviewed by **Pr. Knippers**
stuttgart@knippershelbig.com

References

• "Landesgartenschau Exhibition Hall | Institute for Computational Design and Construction | University of Stuttgart." [Online]. Available: https://www.icd.uni-stuttgart.de/projects/landesgartenschau-exhibition-hall/. [Accessed: 14-Mar-2020]

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Biomimetic

Definition
● Biomimetics
○ Bioinspiration
○ Biomimicry

Approach
○ Biology-push
● Technology-pull

Origins of bioinspiration
○ Random opportunities
● Interdisciplinary collaborations
○ Call for projects
○ Other

Targeted performance
○ Thermal comfort
○ Visual comfort
○ Acoustic comfort
○ Air quality
● Mechanical stress resistance
○ Water regulation

Integration scale of biomimetics
○ Material (facade component)
● Facade system
○ Building

Link to biology

Model kingdom
● Animalia: sea urchins (skeleton)
○ Plantae
○ Fungi
○ Bacteria/Archaea
○ Protozoa
○ Chromista

Number of models
● One
○ Two
○ More

Type of knowledge
○ Existing for general public
● Existing for specialist
● Created during the design process

Inputs in biology
○ Background of the designer
● Acquisition during the design
● Biologists integrated in the process

Design process

Use of design framework
○ Yes
● No

Eco-design approach
○ Yes
● No

Major constraints
○ Lack of funds
○ Use of biomimetic tools
○ Law regulations
● Technical problems
○ Other

Design complexity
● High (software, design process)
○ Low (well-known design)

Outcome

Technology readiness level
○ TRL6 - demonstrated in relevant environment
○ TRL7 - system prototype demonstration in operational environment
● TRL8 - system complete and qualified
○ TRL9 - actual system proven in operational environment

Overtime performance
● Still operating
○ Not operating yet
○ Destroyed

Construction complexity
● High (new technology)
○ Low (existing technology)

Main component of the building envelope
○ Polymers
○ Alloys
○ Textiles
● Wood
○ Concrete
○ Carbon-glass fiber

Level of innovation
● Breakthrough innovation
○ Improvement of existing systems

Adaptable to renovation
○ Yes
● No

Adaptability

Adaptation to stimuli
○ Yes
● No

Type of trigger (input)
○ Mechanical (e.g. wind load)
○ Thermal (e.g. air temperature)
○ Electromagnetic
○ Optical (e.g. daylight level)
○ Air quality (e.g. humidity)
○ Occupancy
○ Other (internet data, BMS, etc.)

Type of actuator (output)
○ Mechanical
○ Pneumatical
○ Electromagnetic
○ Thermal
○ Chemical
○ Other

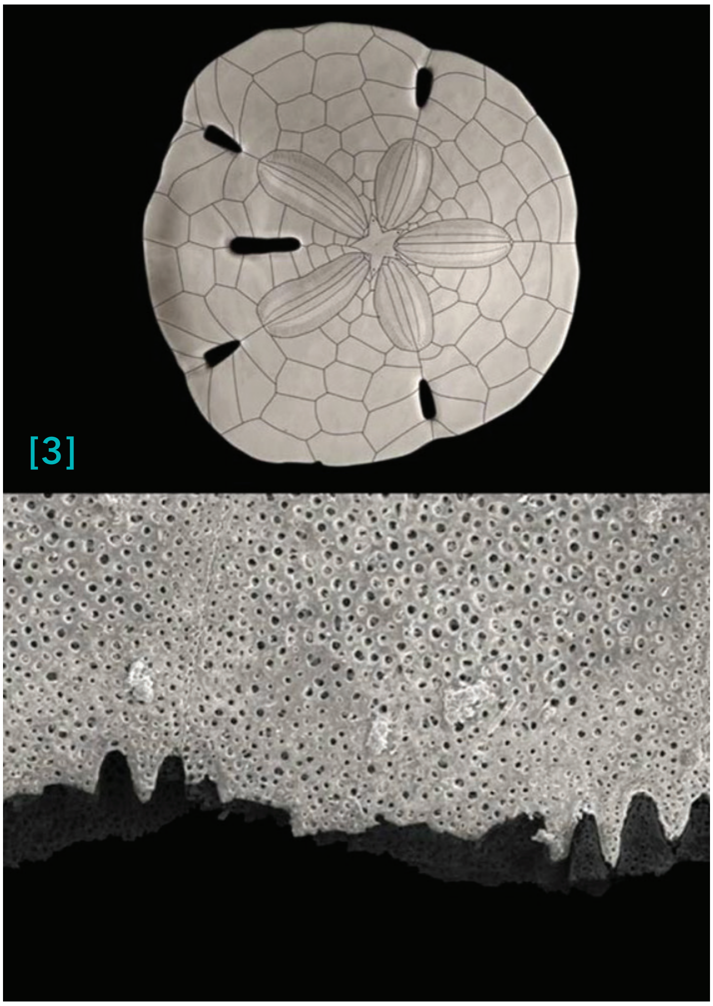
Control
○ Intrinsic (auto-reactive)
○ Extrinsic (external control)

Response time
○ Seconds
○ Minutes
○ Hours
○ Days
○ Weeks
○ Months

Spatial adaptation
○ Nanometers
○ Micrometers
○ Millimeters
○ Centimeters
○ Meters

Material adaptation
○ Elasticity
○ Inflatable
○ Bi-material
○ Other

Degree of adaptability
○ On-Off
○ Gradual



Pictures and credits
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[1] Front view of the pavilion

[2] View from the inside of the pavilion

[3] Photograph of a sand dollar and microscopic view of a plate connection, © Gerber & Nebelsick / Nebelsick & Grun, University of Tubingen, used with permission.

[4] Robotic fabrication of plywood plates

ICD/ITKE BUGA Wood Pavilion, 2019. Heilbronn, 2019.

"The BUGA Wood Pavilion is made of 376 unique plate segments with 17 000 different finger joints. The pavilion's loadbearing wood shell achieves a column-free span of 30 meters, but weighs only 38kg/m².

Its segmented wood shell is based on biological principles found in the plate skeleton of sea urchins, which have been studied by the Institute for ICD and ITKE at the University of Stuttgart for almost a decade.

As part of the project, a robotic manufacturing platform was developed for the automated assembly and milling of the pavilion's 376 bespoke hollow wood segments. This fabrication process ensures that all segments fit together with sub-millimetre precision like a big, three-dimensional puzzle. The stunning wooden roof spans 30 meters over one of BUGA's main event and concert venues, using a minimum amount of material while also generating a unique architectural space. With the same small amount of wood per square meter as in the LAGA project, is it possible to build a shell that reaches triple the span. The biomimetic principle of using less material by having more form".

Http://www.achimmenges.net/?p=20987

Name: BUGA Wood
Year of construction: 2019
Climate: Temperate (Cfb)
City: Heilbronn
Country: Germany

Surface: 70
Cost (€/m²): na
Project use: Pavilion
Renovation: No

itke Institute of Building Structures and Structural Design
ICD Institute for Computational Design and Construction
University of Stuttgart Germany

Data sheet completed by Estelle Cruz & Tessa Hubert during a research exchange of three weeks at ITKE, University of Stuttgart.

Data sheet reviewed by **Daniel-Alexander Sonntag** and **Monika Göbel** daniel-alexander.sonntag@itke.uni-stuttgart.de // monika.goebel@icd.uni-stuttgart.de

References

• "BUGA Wood Pavilion 2019 | achimmenges.net." [Online]. Available: http://www.achimmenges.net/?p=20987. [Accessed: 14-Mar-2020].

• D. Sonntag, L. Aldinger, ... S. B.-P. of I., and undefined 2019, "Lightweight segmented timber shell for the Bundesgartenschau 2019 in Heilbronn," ingentaconnect.com.

Biomimetic

Definition
- ● Biomimetics
- ○ Bioinspiration
- ○ Biomimicry

Approach
- ○ Biology-push
- ● Technology-pull

Origins of bioinspiration
- ○ Random opportunities
- ● Interdisciplinary collaborations
- ○ Call for projects
- ○ Other

Targeted performance
- ○ Thermal comfort
- ○ Visual comfort
- ○ Acoustic comfort
- ○ Air quality
- ● Mechanical stress resistance
- ○ Water regulation

Integration scale of biomimetics
- ○ Material (facade component)
- ● Facade system
- ○ Building

Link to biology

Model kingdom
- ● Animalia: *plate skeleton of sea urchins*
- ○ Plantae
- ○ Fungi
- ○ Bacteria/Archaea
- ○ Protozoa
- ○ Chromista

Number of models
- ● One
- ○ Two
- ○ More

Type of knowledge
- ○ Existing for general public
- ● Existing for specialist
- ● Created during the design process

Inputs in biology
- ○ Background of the designer
- ● Acquisition during the design
- ● Biologists integrated in the process

Design process

Use of design framework
- ○ Yes
- ● No

Eco-design approach
- ○ Yes
- ● No

Major constraints
- ○ Lack of funds
- ○ Use of biomimetic tools
- ○ Law regulations
- ● Technical problems
- ○ Other

Design complexity
- ● High (software, design process)
- ○ Low (well-known design)

Outcome

Technology readiness level
- ○ TRL6 - demonstrated in relevant environment
- ○ TRL7 - system prototype demonstration in operational environment
- ● TRL8 - system complete and qualified
- ○ TRL9 - actual system proven in operational environment

Overtime performance
- ● Still operating
- ○ Not operating yet
- ○ Destroyed

Construction complexity
- ● High (new technology)
- ○ Low (existing technology)

Main component of the building envelope
- ○ Polymers
- ○ Alloys
- ○ Textiles
- ● Wood
- ○ Concrete
- ○ Carbon-glass fiber

Level of innovation
- ● Breakthrough innovation
- ○ Improvement of existing systems

Adaptable to renovation
- ○ Yes
- ● No

Adaptatibility

Adaptation to stimuli
- ○ Yes
- ● No

Type of trigger (input)
- ○ Mechanical (e.g. wind load)
- ○ Thermal (e.g. air temperature)
- ○ Electromagnetic
- ○ Optical (e.g. daylight level)
- ○ Air quality (e.g. humidity)
- ○ Occupancy
- ○ Other (internet data, BMS, etc.)

Type of actuator (output)
- ○ Mechanical
- ○ Pneumatical
- ○ Electromagnetic
- ○ Thermal
- ○ Chemical
- ○ Other

Control
- ○ Intrinsic (auto-reactive)
- ○ Extrinsic (external control)

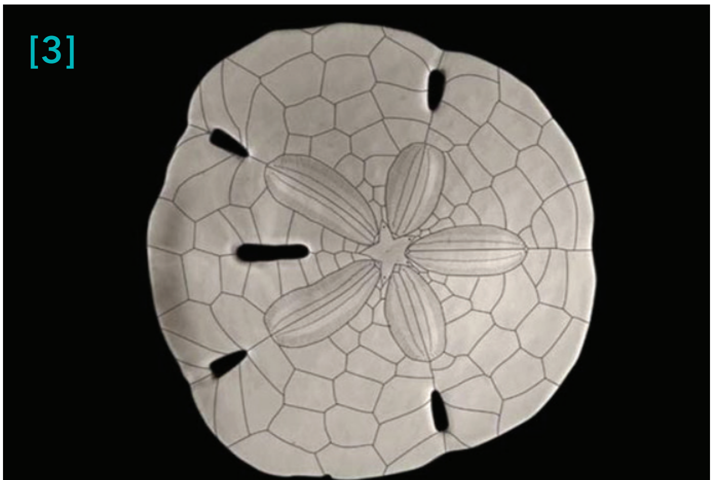
Response time
- ○ Seconds
- ○ Minutes
- ○ Hours
- ○ Days
- ○ Weeks
- ○ Months

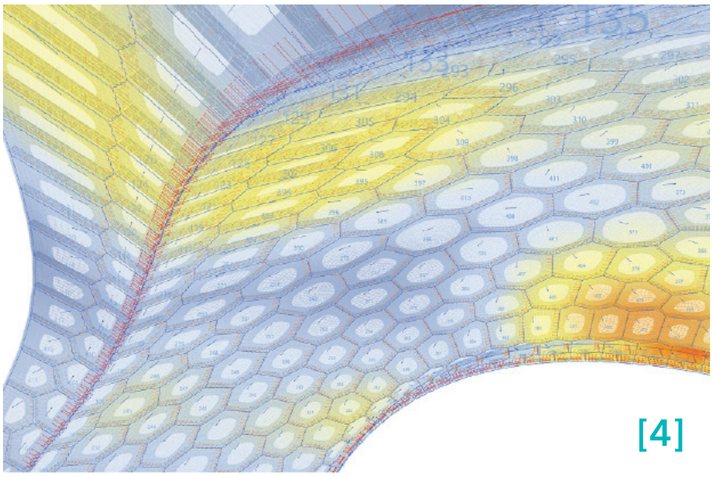
Spatial adaptation
- ○ Nanometers
- ○ Micrometers
- ○ Millimeters
- ○ Centimeters
- ○ Meters

Material adaptation
- ○ Elasticity
- ○ Inflatable
- ○ Bi-material
- ○ Other

Degree of adaptability
- ○ On-Off
- ○ Gradual


[2]


[3]


[4]


[5]

Credits [2-4]© ICD/ITKE University of Stuttgar
[1] CC BY-SA 4.0 Axel Larsson

[1] South-View of BUGA Wood Pavilion

[2] Inside view

[3] Microscopic view of the plate edge of a sand dollar used with permission from © James Nebelsick

[4] Numerical modelling of the structure

[5] Photograph of a sand dollar and microscopic view of a plate connection, © Gerber & Nebelsick / Nebelsick & Grun, University of Tubingen.

[1]

Flectofin®, 2011. Germany

The Flectofin® is a hinge-less flapping mechanism inspired by a deformation principle found in the Bird-Of- Paradise flower. Its valvular pollination mechanism functions with non-autonomous plant movement which was analyzed to understand the underlying principles responsible for the plant's mechanical performance.

The product Flectofin® is based on elastic deflection. The advantage of replacing local hinges with elastic deformation is in the fusion of all mechanical elements within an all-in-one pliable component. As a result, fully functional mechanical systems can be constructed in one production step without the need for assembly.

The successful product development of the Flectofin® Lamella, for example, proves the feasibility of this approach and reflects the potential of advanced fabrication processes. Furthermore, using the lamella as part of a Flectofin® Facade shows the concept's adaptability to an architectural scale and taps into new market niches.

Name: Flectofin®
Year of construction: 2011
Climate: Temperate (Cfb)
City: Stuttgart, Freiburg
Country: Germany

Dimension: 2 m (length), 0.25 m (height), 5 mm (hickness in the backbone), 2 mm (thickness in the wing)
Cost (€/m²): na
Project use: Pavilion
Renovation: No

itke Institute of Building Structures and Structural Design

UNI FREIBURG

University of Stuttgart Germany

Data sheet completed by Estelle Cruz & Tessa Hubert during a research exchange of three weeks at ITKE, University of Stuttgart.

Data sheet reviewed by **Pr. Knippers**
j.knippers@itke.uni-stuttgart.de

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Biomimetic

Definition
● Biomimetics
○ Bioinspiration
○ Biomimicry

Approach
● Biology-push
○ Technology-pull

Origins of bioinspiration
○ Random opportunities
● Interdisciplinary collaborations
○ Call for projects
○ Other

Targeted performance
● Thermal comfort
● Visual comfort
○ Acoustic comfort
○ Air quality
● Mechanical stress resistance
○ Water regulation

Integration scale of biomimetics
○ Material (facade component)
● Facade system
○ Building

Link to biology

Model kingdom
○ Animalia
● Plantae: *Strelitzia reginae*
○ Fungi
○ Bacteria/Archaea
○ Protozoa
○ Chromista / Ecosystems

Number of models
● One
○ Two
○ More

Type of knowledge
○ Existing for general public
● Existing for specialist
● Created during the design process

Inputs in biology
○ Background of the designer
○ Acquisition during the design
● Biologists integrated in the process

Design process

Use of design framework
○ Yes
● No

Eco-design approach
○ Yes
● No

Major constraints
○ Lack of funds
○ Use of biomimetic tools
○ Law regulations
○ Technical problems
● Other

Design complexity
● High (software, design process)
○ Low (well-known design)

Outcome

Technology readiness level
○ TRL6 - demonstrated in relevant environment
● TRL7 - system prototype demonstration in operational environment
○ TRL8 - system complete and qualified
○ TRL9 - actual system proven in operational environment

Overtime performance
● Still operating
○ Not operating yet
○ Destroyed

Construction complexity
● High (new technology)
○ Low (existing technology)

Main component of the building envelope
○ Polymers
○ Alloys
● Textiles
○ Wood
○ Concrete
○ Carbon-glass fiber

Level of innovation
● Breakthrough innovation
○ Improvement of existing systems

Adaptable to renovation
● Yes
○ No

Adaptability

Adaptation to stimuli
● Yes
○ No

Type of trigger (input)
○ Mechanical (e.g. wind load)
○ Thermal (e.g. air temperature)
○ Electromagnetic
○ Optical (e.g. daylight level)
○ Air quality (e.g. humidity)
○ Occupancy
● Other (internet data, BMS, etc.)

Type of actuator (output)
● Mechanical
○ Pneumatical
○ Electromagnetic
○ Thermal
○ Chemical
○ Other

Control
○ Intrinsic (auto-reactive)
● Extrinsic (external control)

Response time
● Seconds
● Minutes
○ Hours
○ Days
○ Weeks
○ Months

Spatial adaptation
○ Nanometers
○ Micrometers
○ Millimeters
● Centimeters
● Meters

Material adaptation
● Elasticity
○ Inflatable
○ Bi-material
○ Other

Degree of adaptability
○ On-Off
● Gradual


[2]

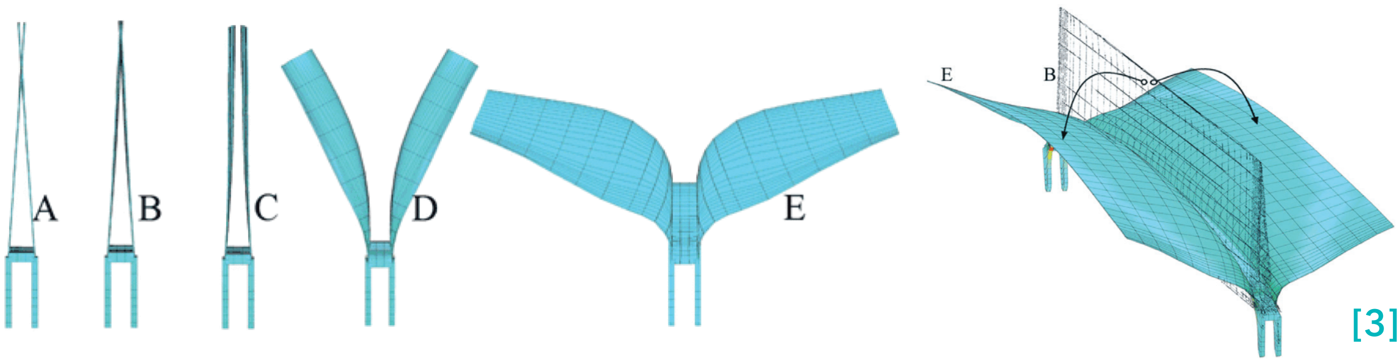
Pictures and credits

[1] Full-scale prototype of the Flectofin®. Façade produced with the industrial partner Clauss Martisem. The lower support the FRP lamellas can be moved vertically and thus cause the eccentrically attached backbone. Source: International Bionic-Award 2012.

[2] Full scale prototype of the Flectofin®. Source: International Bionic-Award 2012.

[3] Illustration of a double Flectofin®. (A) Theoretical position of the planar wings, (B) real position of the wings pushing against each other and (C)–(F) opening of the wings due to bending of the backbone. Source: Lienhard et al. 2011

[4] Bird paradise flower. Source: https://vimeo.com/48374174



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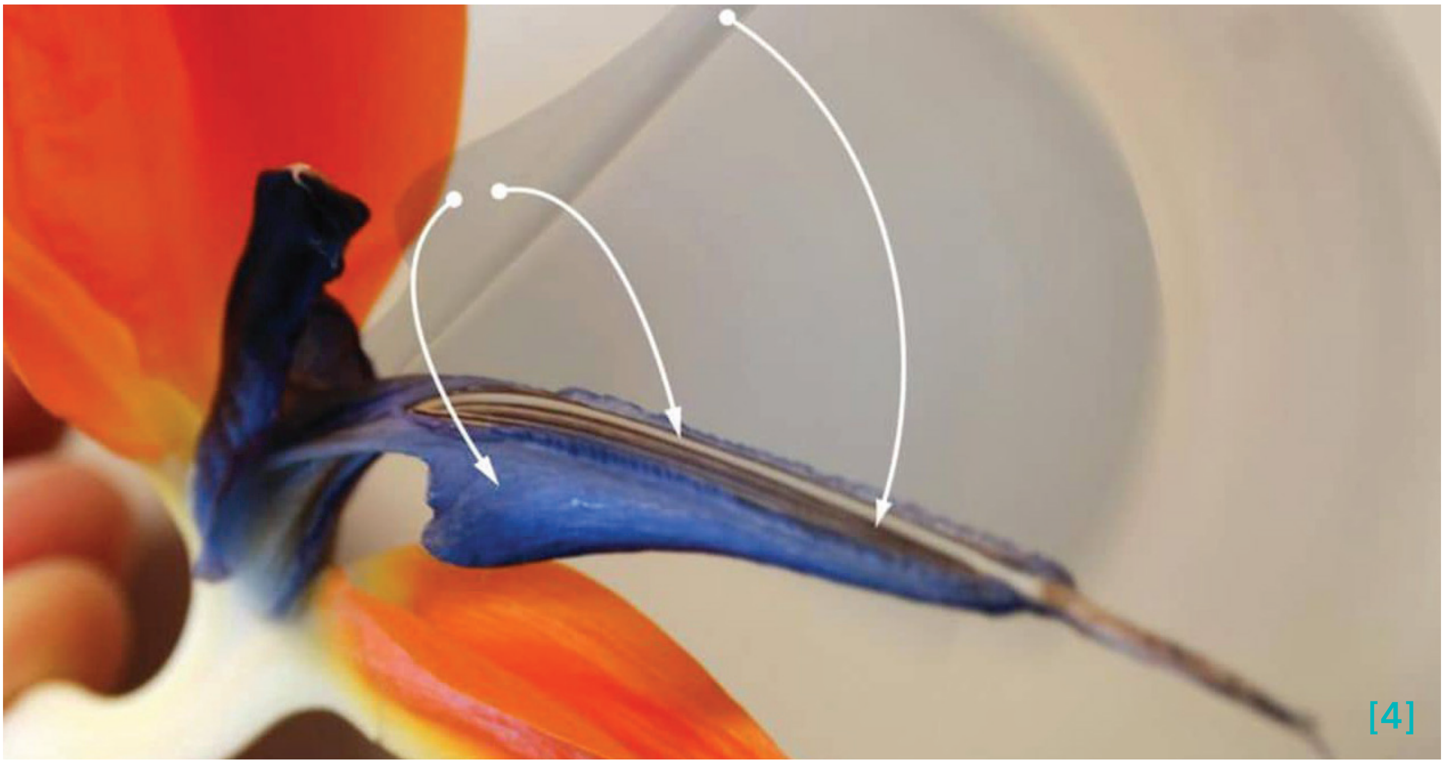
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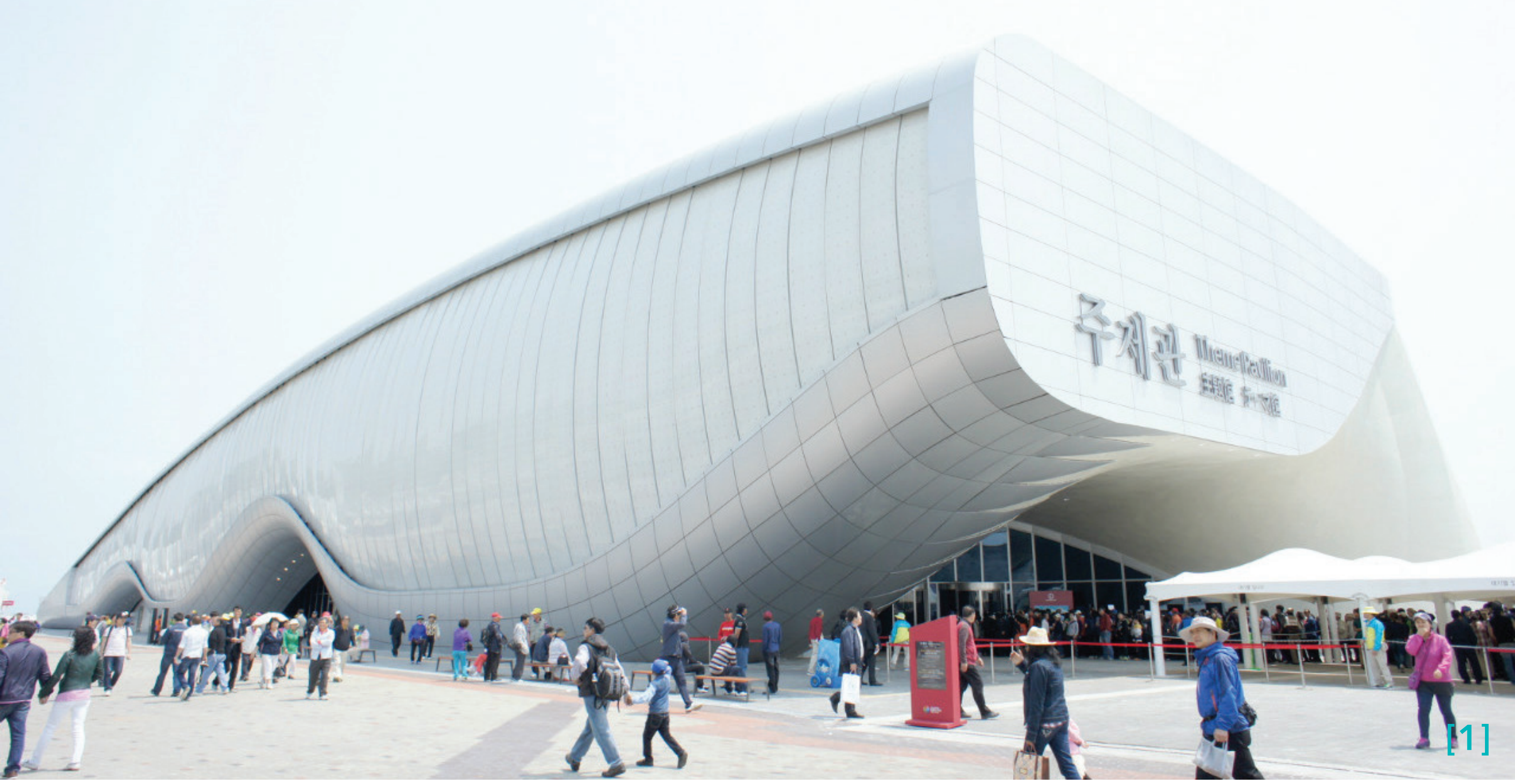

[1]

One Ocean, 2012. Yoesu, South Korea.

Yoesu Pavilion experiments with the concept of adaptive envelope. The facade is 140 meters long, ranging from 3 to 13 high, incorporating shutters that control the light input. They move individually thanks to actuators positioned at the ends which create a deformation of the slats.

This mechanism is inspired by the opening and closing system of the stamen of the Bird-Of- Paradise flower. By day, the moveable lamellas of the kinetic facade control the entry of light into the foyer and the Best Practice Area. Individually controlled, opening and closing these in succession allows choreography of wave-like patterns to be created along the entire length of the building.

The lamellas of the facade are manufactured with glass fibre reinforced polymer and make use of its material properties for the movement process. Initially, it was attempted to scale Flectofin® to the size of the facade. However, it did not meet all expected structural and aesthetic requirements, even though technically possible.

Name: One Ocean German Pavilion
Year of construction: 2012
Climate: Temperate (Cfa)
City: Yoesu
Country: South Korea
Surface (m²): 5 700 m²
Cost (€/m²): na
Project use: Tertiary public building
Renovation: No

Knippers Helbig
Advanced Engineering

soma

itke
Institute of Building Structures and Structural Design

Data sheet completed by Estelle Cruz & Tessa Hubert during a research exchange of three weeks at ITKE, University of Stuttgart.

Data sheet reviewed by **Pr. Knippers** and **SOMA Architecture** -
stuttgart@knippershelbig.com
office@soma-architecture.com

References

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Biomimetic

Definition
- ● Biomimetics
- ○ Bioinspiration
- ○ Biomimicry

Approach
- ● Biology-push
- ○ Technology-pull

Origins of bioinspiration
- ○ Random opportunities
- ● Interdisciplinary collaborations
- ○ Call for projects
- ○ Other

Targeted performance
- ● Thermal comfort
- ● Visual comfort
- ○ Acoustic comfort
- ○ Air quality
- ● Mechanical stress resistance
- ○ Water regulation

Integration scale of biomimetics
- ○ Material (facade component)
- ● Facade system
- ○ Building

Link to biology

Model kingdom
- ○ Animalia
- ● Plantae: *Strelitzia reginae*
- ○ Fungi
- ○ Bacteria/Archaea
- ○ Protozoa
- ○ Chromista / Ecosystems

Number of models
- ● One
- ○ Two
- ○ More

Type of knowledge
- ○ Existing for general public
- ● Existing for specialist
- ● Created during the design process

Inputs in biology
- ○ Background of the designer
- ○ Acquisition during the design
- ● Biologists integrated in the process

Design process

Use of design framework
- ○ Yes
- ● No

Eco-design approach
- ○ Yes
- ● No

Major constraints
- ○ Lack of funds
- ○ Use of biomimetic tools
- ○ Law regulations
- ○ Technical problems
- ● Other

Design complexity
- ● High (software, design process)
- ○ Low (well-known design)

Outcome

Technology readiness level
- ○ TRL6 - demonstrated in relevant environment
- ○ TRL7 - system prototype demonstration in operational environment
- ○ TRL8 - system complete and qualified
- ● TRL9 - actual system proven in operational environment

Overtime performance
- ○ Still operating
- ● Not operating yet
- ○ Destroyed

Construction complexity
- ● High (new technology)
- ○ Low (existing technology)

Main component of the building envelope
- ○ Polymers
- ○ Alloys
- ○ Textiles
- ○ Wood
- ○ Concrete
- ● Carbon-glass fiber

Level of innovation
- ● Breakthrough innovation
- ○ Improvement of existing systems

Adaptable to renovation
- ● Yes
- ○ No

Adaptability

Adaptation to stimuli
- ● Yes
- ○ No

Type of trigger (input)
- ○ Mechanical (e.g. wind load)
- ○ Thermal (e.g. air temperature)
- ○ Electromagnetic
- ○ Optical (e.g. daylight level)
- ○ Air quality (e.g. humidity)
- ○ Occupancy
- ● Other (internet data, BMS, etc.)

Type of actuator (output)
- ● Mechanical
- ○ Pneumatical
- ○ Electromagnetic
- ○ Thermal
- ○ Chemical
- ○ Other

Control
- ○ Intrinsic (auto-reactive)
- ● Extrinsic (external control)

Response time
- ● Seconds
- ● Minutes
- ○ Hours
- ○ Days
- ○ Weeks
- ○ Months

Spatial adaptation
- ○ Nanometers
- ○ Micrometers
- ○ Millimeters
- ○ Centimeters
- ● Meters

Material adaptation
- ○ Elasticity
- ○ Inflatable
- ○ Bi-material
- ○ Other

Degree of adaptability
- ○ On-Off
- ● Gradual

Pictures and credits

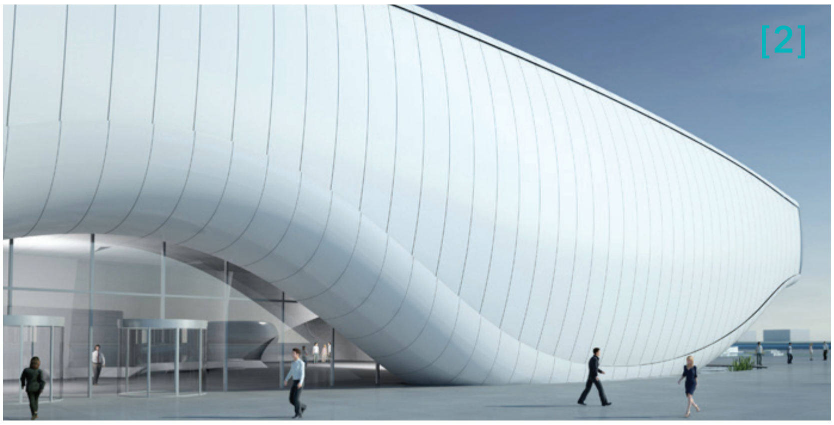
[1] Exterior view of the façade used with permission from © SOMA

[2] [3] Exterior rendering and [6] areal view used with permission from © Isochrom

[4] Louvers used with permission from © Kim Yong-kwan

[5] Bird paradise flower (Creative Commons CC0)

[6] Bird eye view © Isochrom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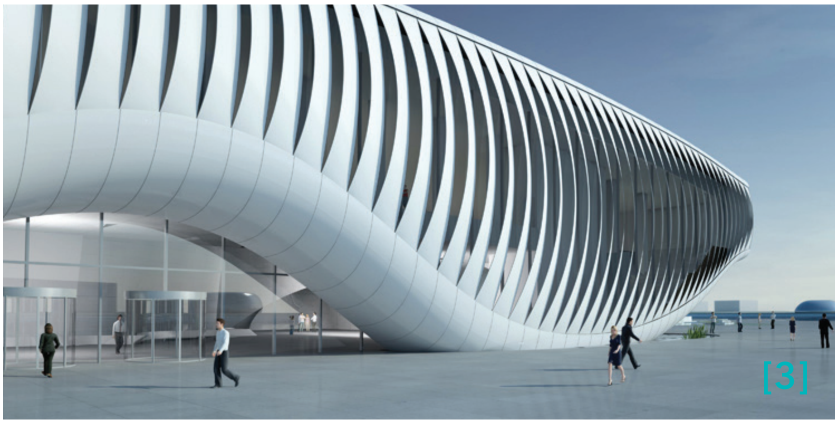
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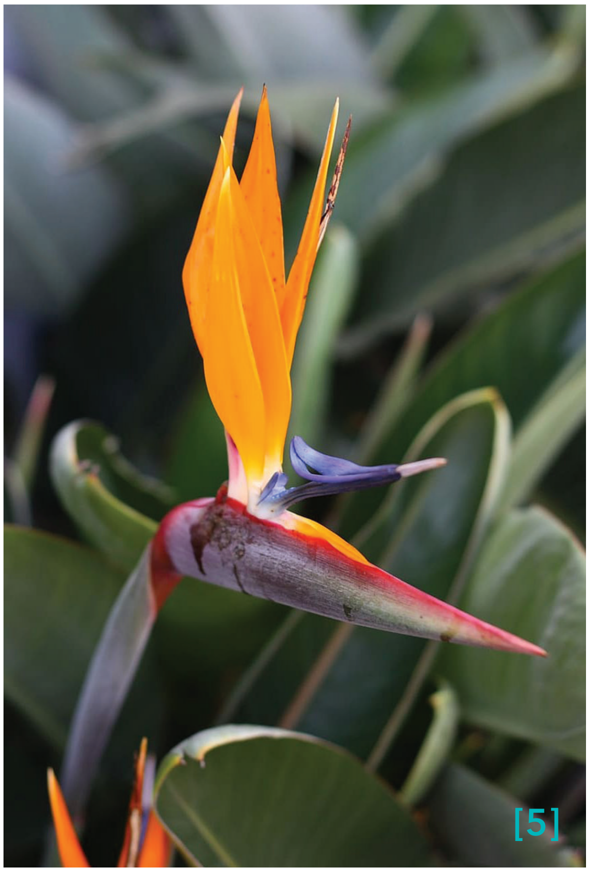
[5]


[6]

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ITECH Research Demonstrator, 2018-19. Stuttgart, Germany

The ITECH research demonstrator 2018/19 investigates large-scale compliant architecture inspired by the folding mechanisms of the Coleoptera coccinellidae (Ladybug) wings. The demonstrator is composed of two adaptive folding elements made of carbon and glass fibre-reinforced plastic.

The demonstrator is first to employ industrial tape-laying technology for an automated fabrication of large-scale compliant mechanisms. Their kinetic behaviour is achieved through distinct compliant hinge zones with integrated pneumatic actuators. An interactive control system, consisting of integrated sensors, online communication, and backend computational processing, facilitates interactive and user-controlled adaptation.

https://www.itke.uni-stuttgart.de/research/icd-itke-research-pavilions/itech-research-demonstrator-2018-19/

Name: Research Pavilion ITECH
Year of construction: 2018/2019
Climate: Temperate (Cfb)
City: Stuttgart
Country: Germany
Surface (m²): < 2 m²
Cost (€): na
Project use: Pavilion
Renovation: No

University of Stuttgart
Germany

Data sheet completed by Estelle Cruz & Tessa Hubert during a research exchange of three weeks at ITKE, University of Stuttgart.

Data sheet reviewed by **Axel Körner**
axel.koerner@itke.uni-stuttgart.de

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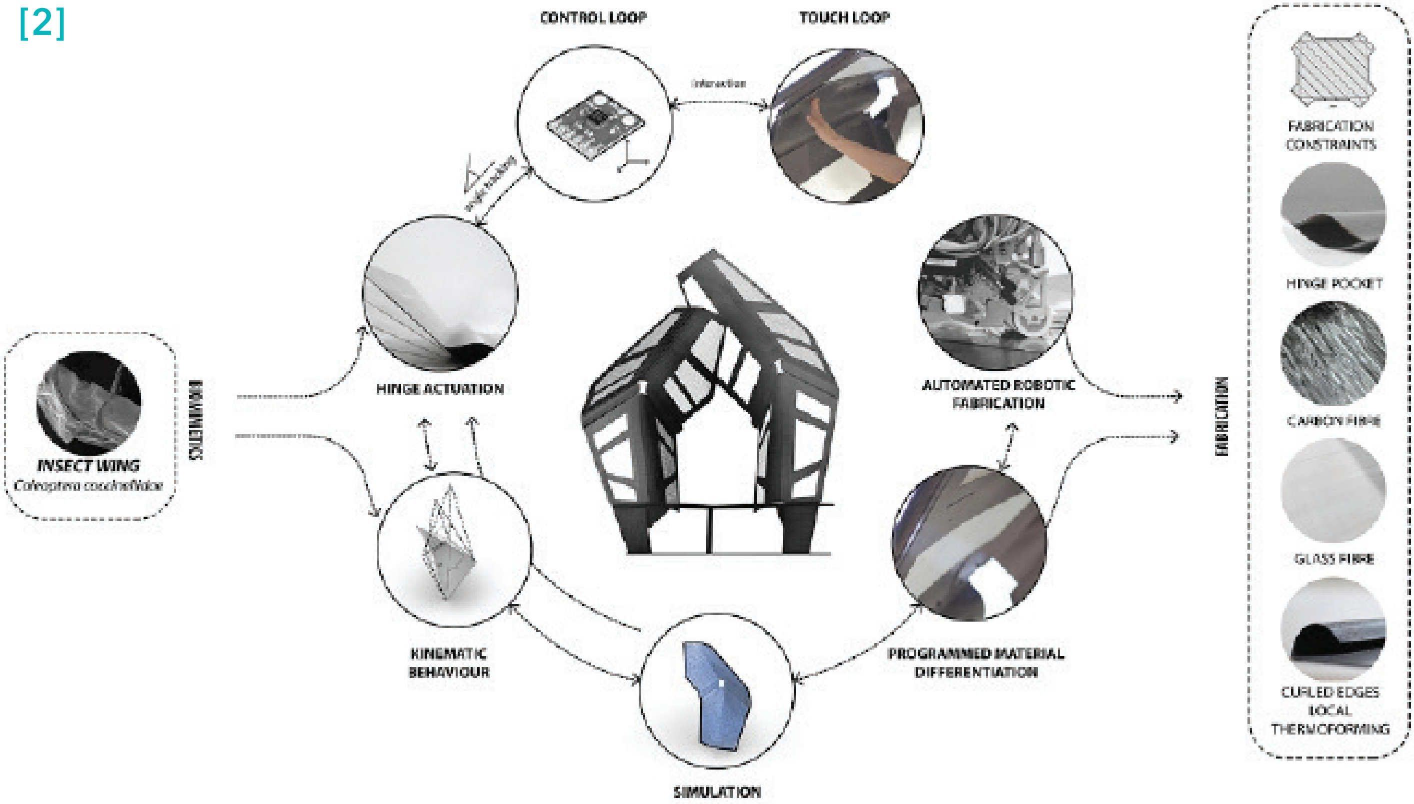
[2]



Pictures and credits
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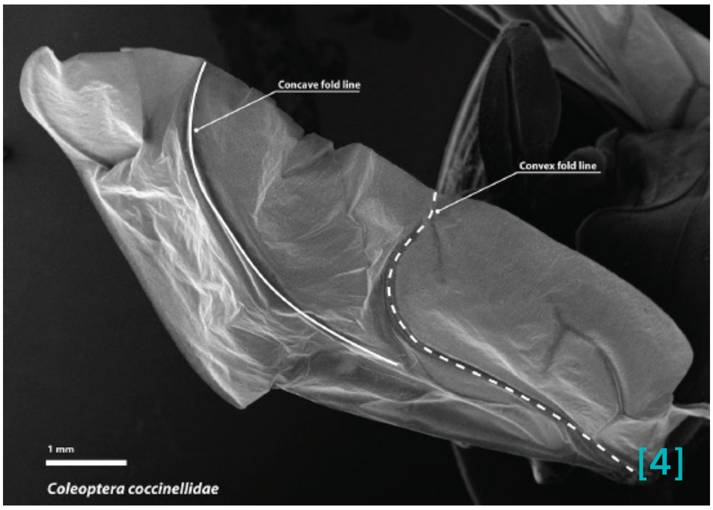
[1] ITECH Research Demonstrator
[2] Design framework
[3] Removable sun-shading
[4] Wings of Coleoptera coccinellidae
[5] Manufacture process

[3]



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[5]