Data driven decision making through bio-inspired principles

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Abstract

Architects are constantly facing design challenges that have to be solved efficiently and effectively not only in terms of spatial design but of social behavior and business strategy.

Bio-inspired principles fueled by sets of data collected by users could predict patterns of necessity and trends, ultimately aiding on informed decision making.
Imitating nature has become a recurring approach for contemporary architects, basing design on biological structures that minimize their efforts for specific outcomes, enabled by their improvement over the evolutionary process.

A data driven process can create much more personalized user experiences and identify the essential aspects of a project, visually and functionally, transforming the way space is designed, built and used through widely available and accessible information and emerging types engagement.

This dissertation will define and exemplify, through a set of five projects, the different nomenclatures and functions of bio-inspired design, using decision making techniques such as meta-heuristic optimization algorithms, visual comparison and environmental simulation; Introduce public data collection and its use in architecture, and finally result in a case study on a Feasibility Study platform that uses non-linear, bio-inspired algorithms, directed by user-generated data, to generate building typologies and inform potential development locations.

Key Words: Architecture, Biomimetics, Data, Business Strategy, Ecology

Contents

Introduction

Life informs matter, giving it function, and consequently a form and structure. Applying this concept of nature in different areas of knowledge, such as Architecture, Design and Engineering, are the basic principles that govern biomimetics.
Imitating nature has become a recurring approach for contemporary architects and, especially for those who promote a future that does not compete with nature but coexists with it.

Biological structures perfected over the evolutionary process for 3.8 billion years tend to optimize the use of materials and structural and growth efforts through their spatial configuration. This way, one can use the efficiency of nature, already the result of natural selection, to generate unconventional architectural structures that still meet programmatic needs.

Acquiring and processing data from biological structures on to the architectural field through concepts such as biomimetics, biophilics and biometrics, can result in new design typologies that considers and adapts to the environment.

Data driven design is not an innovation in the field of AEC. Builders and designers have widely used data to inform their decision-making process. However, the amount of data we have today has significantly increased, along with the quantity and quality of tools to analyze them, process it and take action upon it. BIM software, directed to design with data, is now being merged with parametric tools such as Grasshopper, which increases the control and power that architects have on their design, and that is already known to use bio-inspired algorithms such as evolutionary solvers Galapagos and Octopus. With this abundant access to data and the ability to understand it, architects can now create multiple design iterations in less time, facilitating experimentation, and answer questions with much more flexibility such as “where, how and what should we build?”.

1. Biophilic Design

A Biophilic Design is the incorporation of natural phenotypes into the built environment, by considering principles such as Shapes, Forms, Patterns, Landscape and Materials. This approach takes Nature mainly as a geometrical inspiration, without a deep understanding of natural processes or physical characteristics.

By applying this method into contemporary architecture, one can achieve interesting and unexpected design languages, offering new typologies of space and construction.

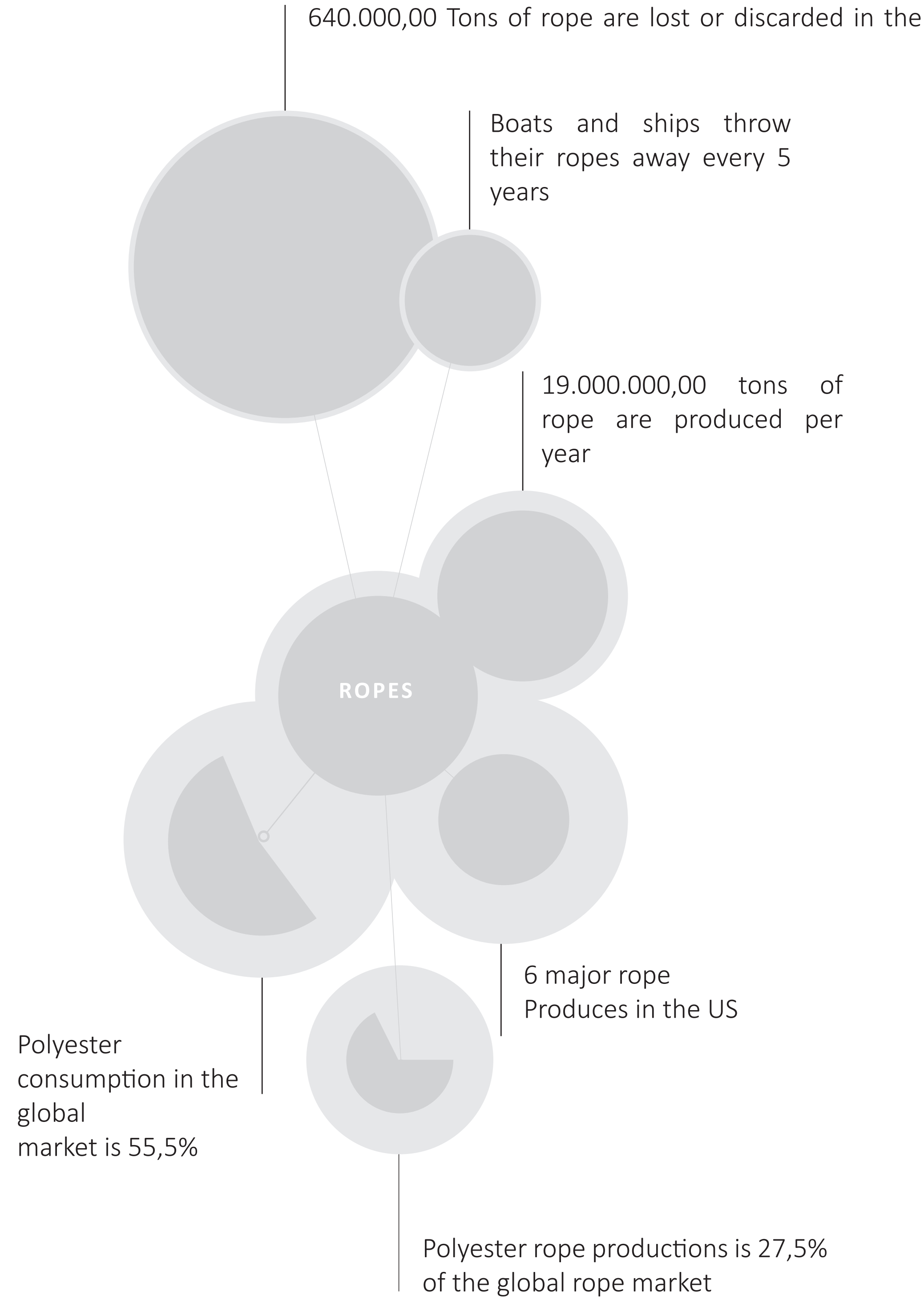
The Knot

Today there are more than 640.000 Tons of rope lost or discarded irregularly at sea by ships and boats worldwide, equivalent to nearly 3,3% of all rope market production. Although this is a serous ecological issue, it can be seen as an opportunity to explore nature-inspired architectural design and construction systems.

By applying the concept of biophilic design, a rope, that is usually used in tension, could have an optimal performance in compression, forming a brick-like module that can be easily assembled and transported.

Braiding and coiling polyester rope based on the visual characteristics of the human “compact bone” structure, form a unique mesh that achieves unexpected structural capabilities and a diverse range of opportunities.

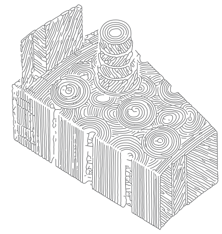
To verify the feasibility of the hypothesis, a rope pavilion was design and simulated using Karambra 3D and Kangaroo in Grasshopper, using Roosevelt Island in New York City as site. The simulation considered the stiffness of the material, as well as its own weight and connection fragilities. In addition to the virtual model, a 1:1 mock-up of the modular system was built, proving that it could withstand similar structural efforts than those predicted through the simulation tools, and demonstrating its design constraints and opportunities.



Concept

Ropes are usually found dirty and tangled.

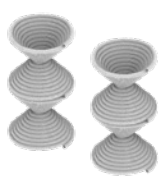
Method



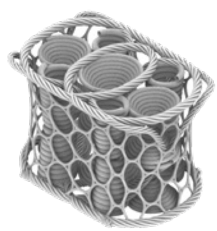
Translate the “Compact Bone” structure from the human bone, to spiral shaped rope structures.

Solution

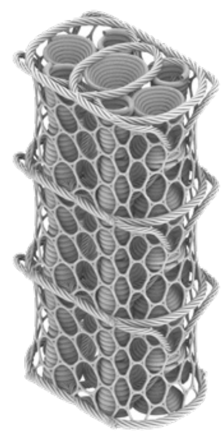
Braiding or twisting could be a solution.



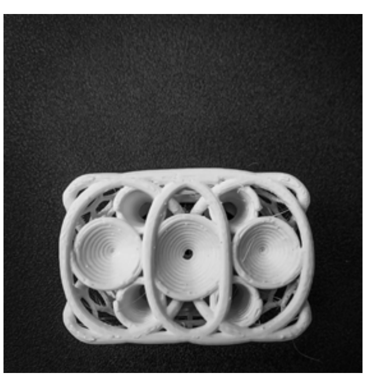
1. Spiral module



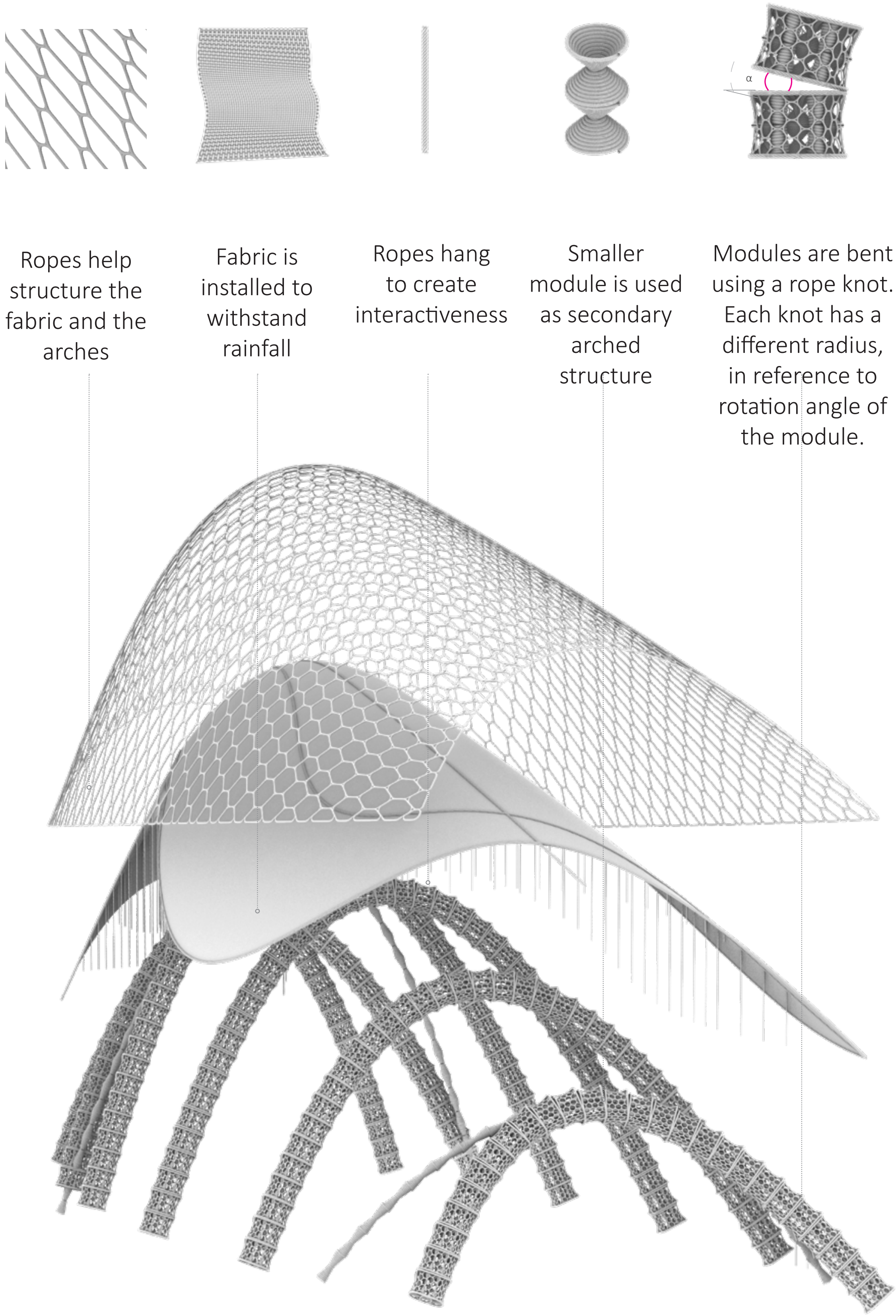
2. Rigid rope “brick”



3. Stacking the bricks



Physical Model


Ropes help structure the fabric and the arches
Fabric is installed to withstand rainfall
Ropes hang to create interactiveness
Smaller module is used as secondary arched structure
Modules are bent using a rope knot. Each knot has a different radius, in reference to rotation angle of the module.
α

External Perspective
Rope modules forming main structure

2. Biomimetic Design

A Biomimetic design is a human-made process, system or object that mimics nature not limited by its aesthetic configurations, but is based on nature as a model, measure and mentor, and therefore its construction process, or its geometry and spatiality, must be dynamic, optimized and perhaps adaptable to local conditions resulting in an innovative and efficient architecture.

Initially introduced by Sir William Herschel, of the Civil Service of India in 1858, the term “Biometrics” derived from the Greek “bios”, life, and “metria”, metrics, is the measurement and analysis of a person’s unique physical or behavioral characteristics or object. Today we understand biometrics as a tool to distinguish the identity of a being, whether through facial scanning, or fingerprints.

The science of understanding the fundamentals of nature, the way organisms and ecosystems are formed, and applying them in another field of knowledge, such as architecture, in order to achieve optimized and innovative models, can be defined as, among other terms , Biomimicry, cited in the mid-90s by Janine M. Benyus. Using the concept of Biometrics as a study tool to understand the applicability of Biomimetics, can we then create a new concept of biological identity in architecture?

Biomimetics has been strongly discussed around the world and can be applied in several areas of study, however, one can consider a misuse of the term, to characterize a biophilic approach, which is the simple translation of nature into architecture as an aesthetic element, ignoring the broader value nature-inspired design can add to the field.

Differential Growth Pavilion

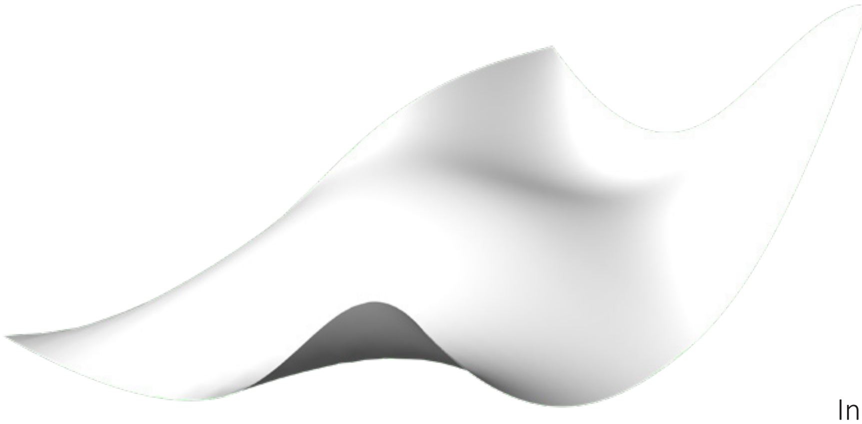
The pavilion is the result of a study on the Differential Growth of plants and the potential applications of physics-based solvers as tools for the generation of a behavior-based form and structure, that when translated into architecture, the bio-inspired algorithm assigns unique formal and structural characteristics to the canopy-shaped geometry.

In order to achieve a truly Biomimetic design approach, it was necessary to study, measure and recreate computationally the growth patterns of plant cells; their measurements, curvatures and density. That way, a full scale prototype could be built with no waste and with full accuracy due to computational simulations.

Starting with a simplified rectangular shape, in order to remove any architectural bias form the design process, the simulation created using Grasshopper and its physics simulation Plug-ins generated more than 100 growth iterations, and had dictated that curves could never touch or overlap each other. The shape was then modified to achieve optimum structural capabilities and a minimum number of supports.

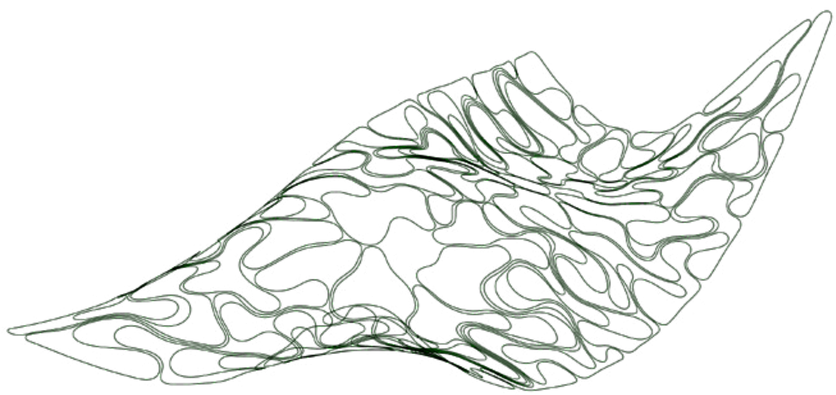
After concluding the computational design, the construction process took two and a half days to be built and suspended, using around 1500 zip ties and 30kg of space graded steel strips.

This pavilion showcased the possibilities of a Biomimetic design, demonstrating not only outstanding structural capabilities but that in generates interesting aesthetic qualities as a consequence of the design process.

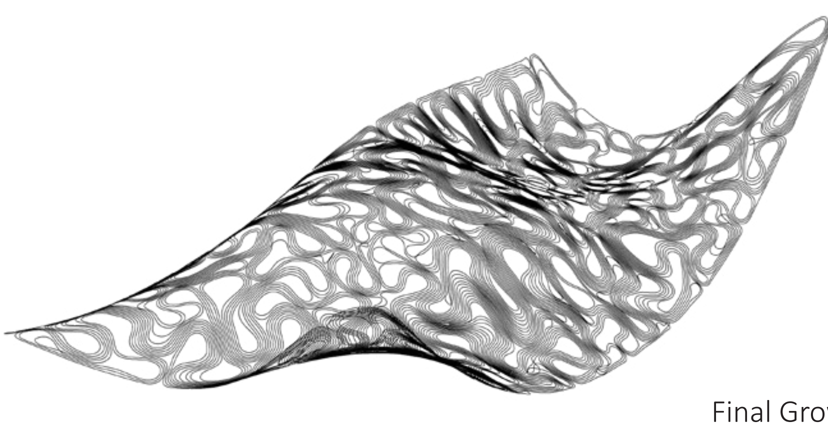


Initial Surface

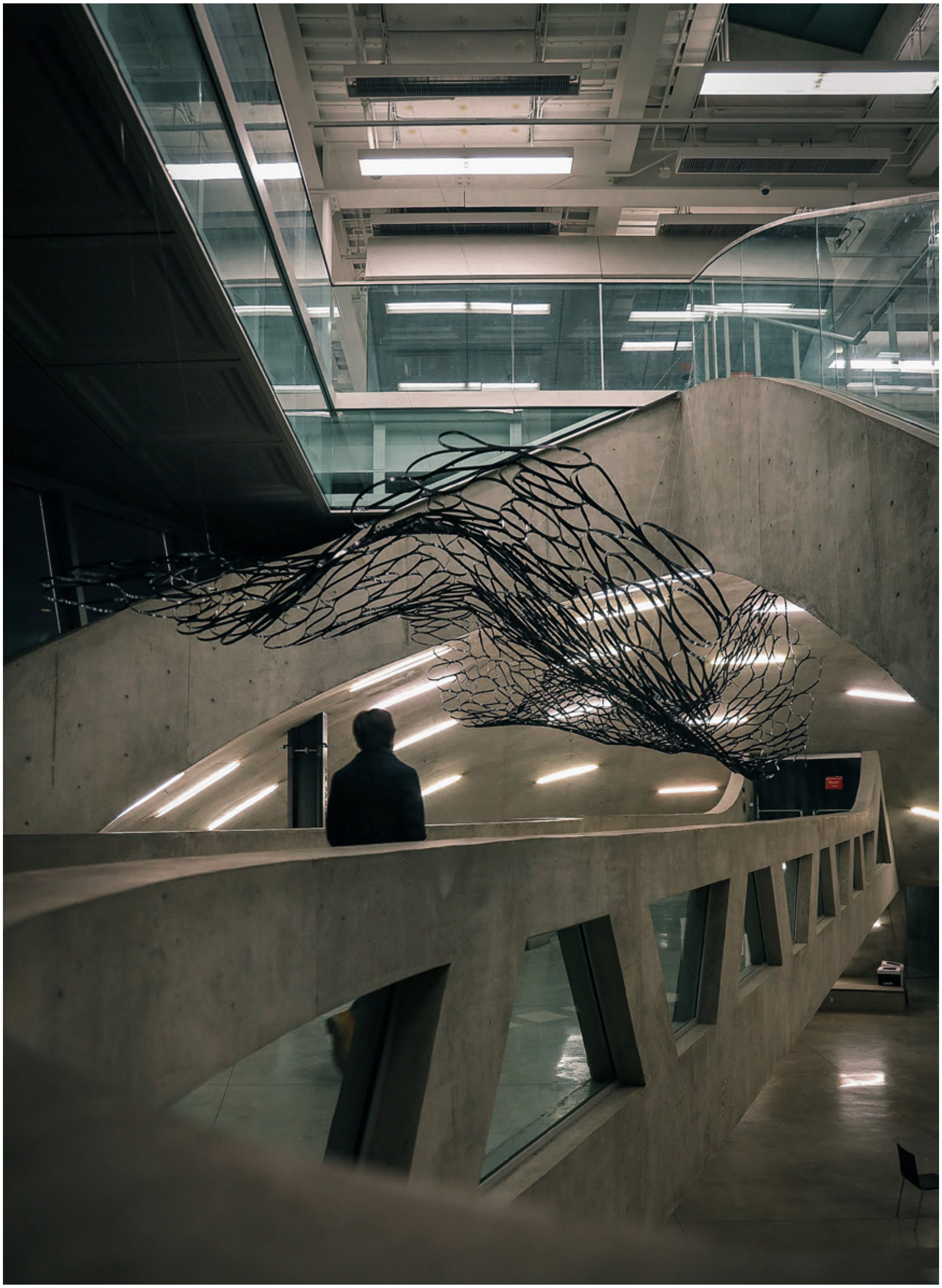
1st Growth Iteration



60th Growth Iteration

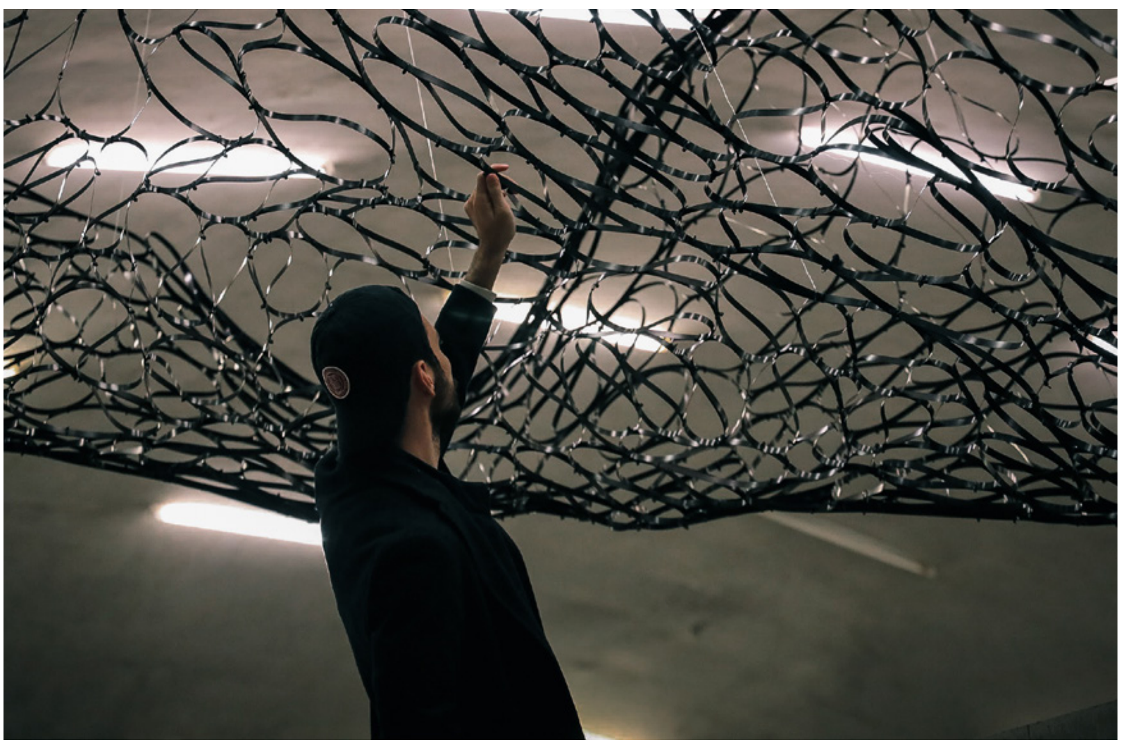


Final Growth Iteration



Walkway View
Students and Faculty can walk underneath the pavilion by the OMA designed walkway.

Front View
View of the unique geometry computationally generated



Pavilion Interaction
The pavilion allows people to interact with it by touching and swinging.

3. Biometric Design

A Biometric design is a purely metric approach, identifying phenotype geometry patterns and unique physiological characteristics. It does not take into account any structural or functional property since it only compares or duplicates data from one object or being, and employs it to an architectural design.

By identifying key aspects of a natural element, using mathematics and statistics to the study of biology, there is the possibility to create databases and discretize its components, process sets of information and control these characteristics in order to create architecture.

Meditation Pod

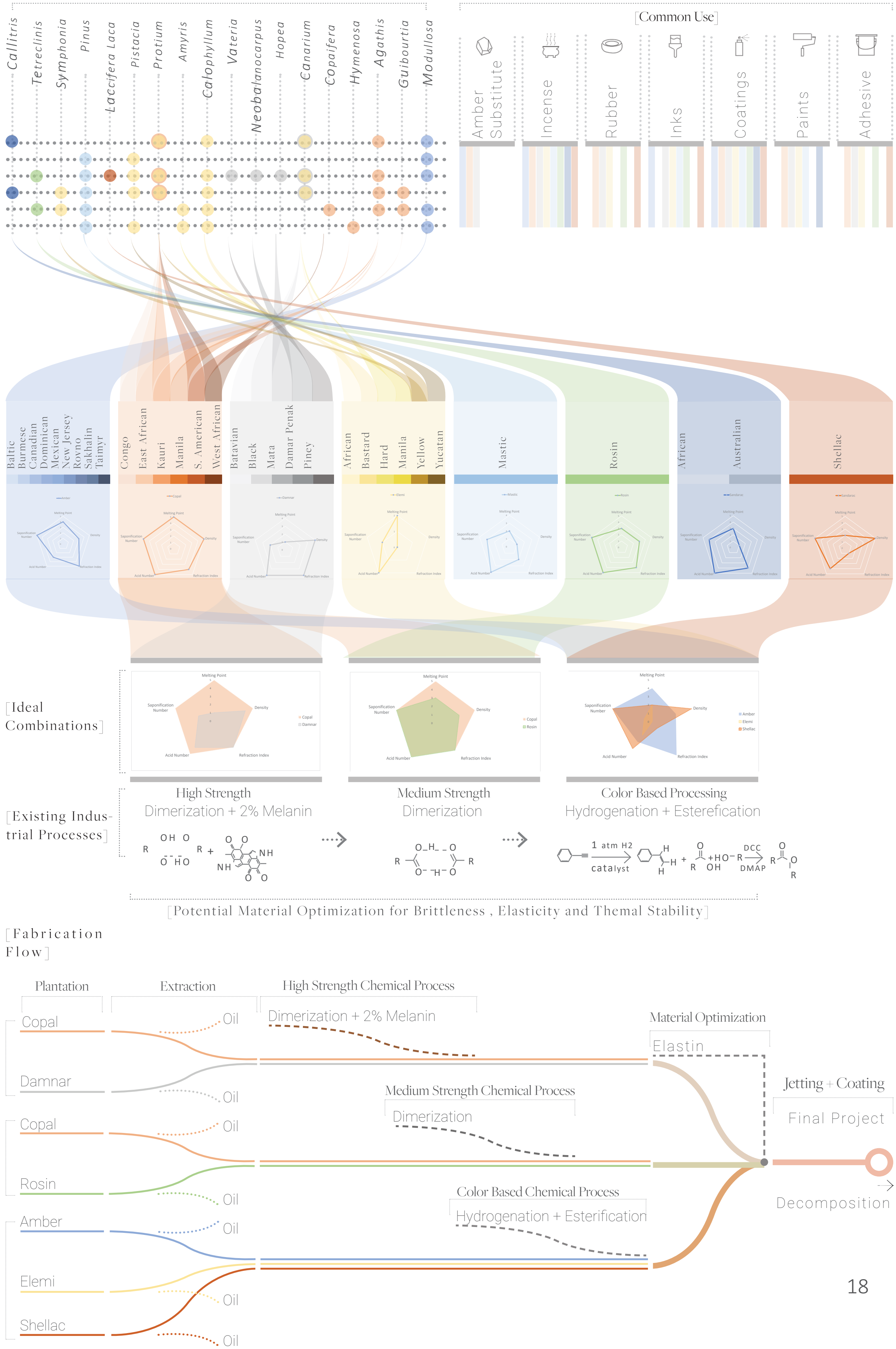
Nature has evolved through millions of years under selection pressure. Extracting knowledge and understanding some of the properties found in natural elements can provide opportunities to innovate, and lead to new material applications. Natural resins, which are characterized as any natural organic compound consisting of a noncrystalline or viscous liquid substance, may possess underlying properties suitable for the architectural industry.

3D printing processes, known to use mainly plastics and other carbon intense materials, are seeing a shift towards the use of organic and other degradable materials. This offers the possibility of exploring new techniques and building typologies that take into account sustainability issues and material life cycle.

The benefits of the Jetting process, one of the 3d printing techniques, include the production of smooth parts with high dimensional accuracy, as well as homogeneous or controllable mechanical and thermal properties.

Its multi-material capabilities enables the creation of accurate visual and haptic prototypes, although it is known for its high cost, making some applications not viable.

By undergoing the resin into several chemical processes such as dimmerization, hydrogenation, esterification and the addition of melanin, it is possible to achieve a printable natural resin that has structural capabilities for architectural application, considering its life cycle and decomposition.

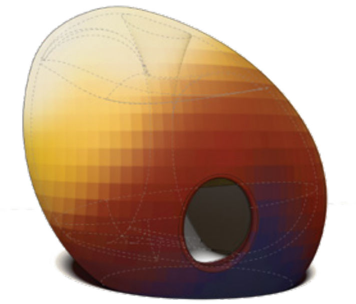

Callitris
Tetreclinis
Symphonia
Pinus
Laccifera Laca
Pistacia
Protium
Amyris
Calophyllum
Vateria
Neobalanocarpus
Hopea
Canarium
Copaifera
Hymenosa
Agathis
Guibourtia
Modullosa
[Common Use]
Amber Substitute
Incense
Rubber
Inks
Coatings
Paints
Adhesive
Baltic
Burmese
Canadian
Dominican
Mexican
New Jersey
Rovno
Sakhalin
Taimyr
Congo
East African
Kauri
Manila
S. American
West African
Batavian
Black
Mata
Damar Penak
Piney
African
Bastard
Hard
Manila
Yellow
Yucatan
Mastic
Rosin
African
Australian
Shellac
[Ideal Combinations]
[Existing Industrial Processes]
High Strength
Dimerization + 2% Melanin
Medium Strength
Dimerization
Color Based Processing
Hydrogenation + Esterefication
1 atm H2
catalyst
DCC
DMAP
[Potential Material Optimization for Brittleness , Elasticity and Themal Stability]
[Fabrication Flow]
Plantation
Extraction
High Strength Chemical Process
Copal
Oil
Dimerization + 2% Melanin
Material Optimization
Elastin
Damnar
Oil
Jetting + Coating
Medium Strength Chemical Process
Dimerization
Final Project
Copal
Oil
Rosin
Oil
Color Based Chemical Process
Hydrogenation + Esterification
Decomposition
Amber
Oil
Elemi
Oil
Shellac
Oil

Color Map

Yellow =
sandarac
Orange:
rosin
Red:
shellac

Each resin has a natural color spectrum that varies with the age of the tree and the extraction process.

Light Map



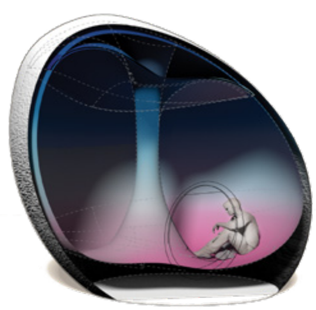
Average refraction:

resin 1.55

glass=1.4

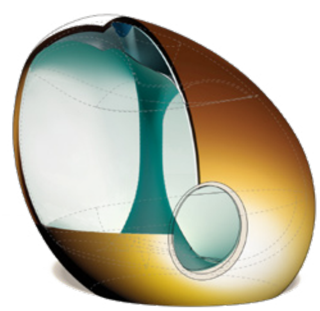
diamond 2.45

Deformation

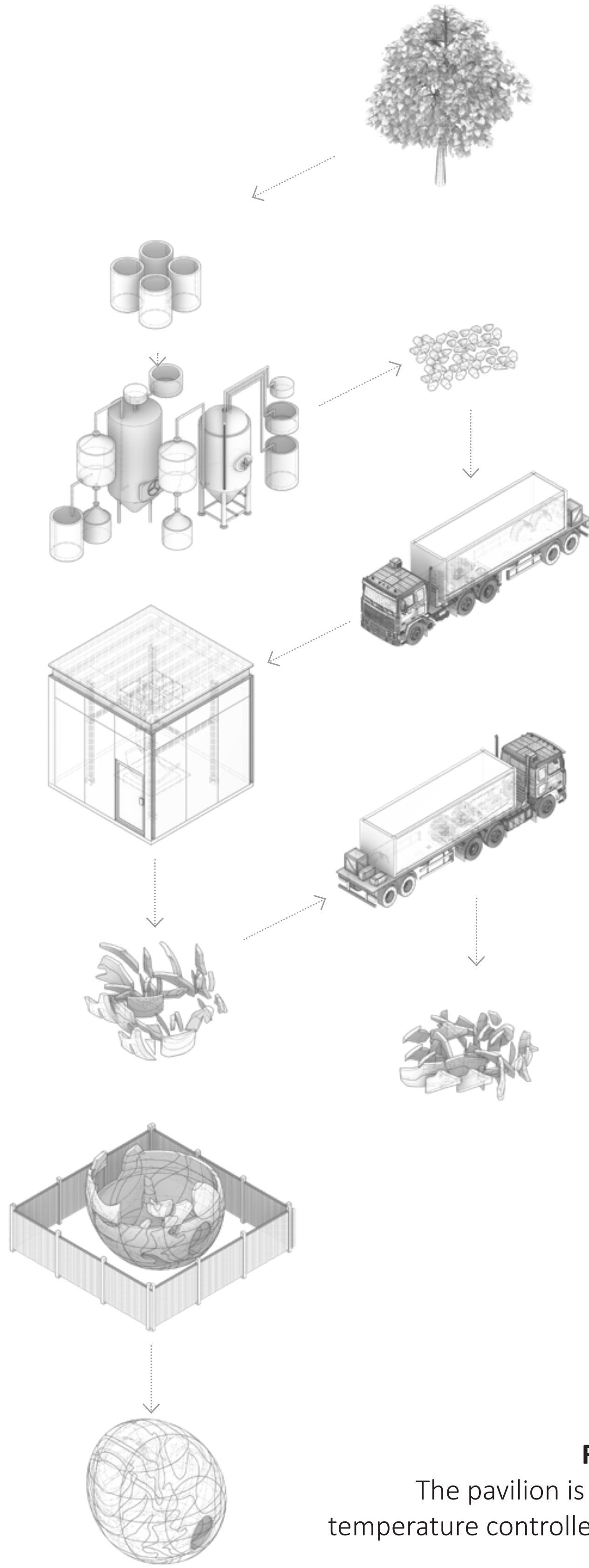


Standing: 12,850 Pa
Sitting: 3,469 Pa
Laying down: 1,542 Pa
The material adapts its shape to the human body pressure to guarantee the most comfortable posture.

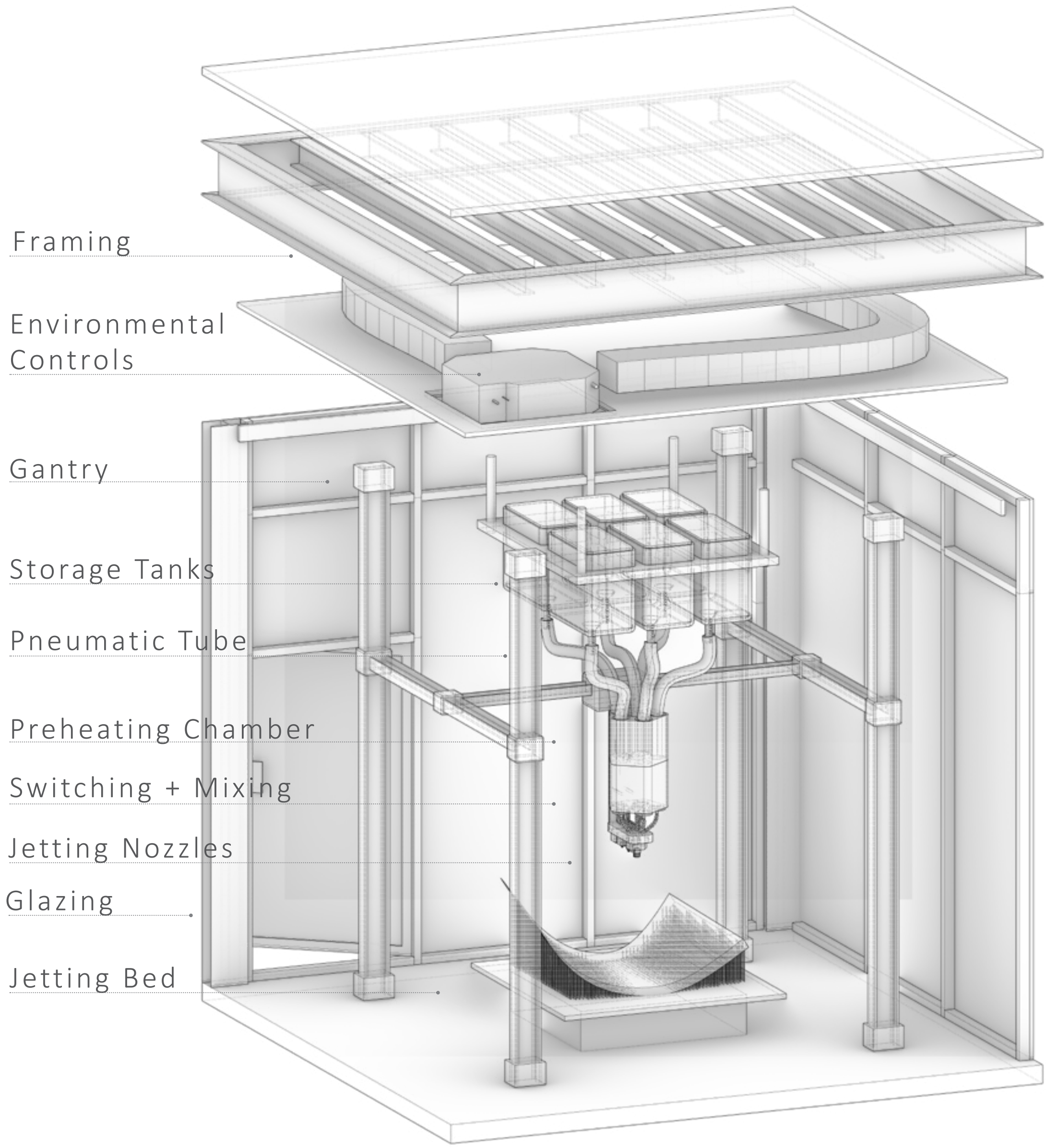
Odor Map



Two main aromas are obtained by a series of combinations between the initial eight resins: pine and citrus.
The meditation pod has a strong pine odor on the outside to enhance people's curiosity and a fresh and relaxing citrus odor on the inside.



Fabrication Process
The pavilion is pre-fabricated on a temperature controlled environment and assembled on site.



Fabrication Room
A custom jetting nosel is created to
extrude the natural resin

Central Park Intervention
The translucent characteristics of natural resin allow incredible aesthetic properties

High Line Intervention
The pavilion would be exposed and open to anyone willing to interact with it

4. Computational Design and Data Collection

Computational design has already changed how architecture is perceived, designed and fabricated, offering a diverse range of tools to control, iterate and process concepts. It has also transformed how architects predict cultural, social and economical patterns that surround it.

Utilizing cross-disciplinary approaches and emerging technologies accelerates the potential for innovation, using widely available data, through value chains to increase situational awareness.

Data sources provides information in a variety of technical formats, thus creating a necessity of converting sets of data into an homogeneous function. In architecture, GIS data can be merged with social media and in turn linked to zoning laws, creating a data mesh that can be used to inform new development areas and building typology.

The quality of data is also an important factor. Not all data is good data. Designers have to be aware of what reliable sources of data are available, so that their concepts can be developed with seriousness and precision. Climatic sensors, GPS signals, building component data, and simulation tools provide valuable information that architects can use in order to create a safer, faster, and more precise design, minimizing error and maximizing opportunity.

Gathered data and real time data can inform how people occupy spaces and different infrastructures, allowing a better understanding of user necessities, a wider range of experimentation and prototyping and finally a designing spaces that truly meet these needs, reducing operational cost, optimizing maintenance, and enhancing flow and circulation.

Rochester Masterplan

As part of an exploration in VR as a design tool, and data-driven design using procedural design and bio-inspired collective decision-making in network dynamics such as migration, this project is a master-plan for the Browns Race region in Rochester, NY. By gathering GIS, pedestrian flow pattern data, and defining a series of rules to transform the predominantly industrial area into a livable and workable area permeable to the public, the new urban plan uses evolutionary algorithms to process collected data and create a series of iterations that encompasses program distribution, user necessity trends and multi-modal transportation connectivity.

Three main buildings were designed to serve as connection hubs for the incoming visiting population: A museum, a Tram station, and a Hotel, as well as other eight proposed building volumes. The area is historically known by its wood and brick factories, scattered along Browns Race street.

The design of each of the three main buildings took these characteristics into consideration, by infusing data sets into the design with the end goal of creating building typologies that integrated seamlessly on the historical fabric and met the needs of the current population, prioritizing pedestrian flow, and increasing visibility.

A range of tools were used to make this project possible: as mentioned previously, GIS data was collected, creating a model that could be easily iterated, then adding BIM to control building components and landscape design. The process was an unconventional exploration on how designing with multi-platform connection can be successful, mixing Virtual Reality, with procedural modeling, coding with Python, and real time visualization through Enscape 3D and Unreal Engine, in order to facilitate decision making in a conscious and informed way.

Drone Exploration

As an analysis and visual exploration tool, drones were used in order to understand the site’s intrincicacies in a different and more detailed manner.

Virtual Reality Immersion

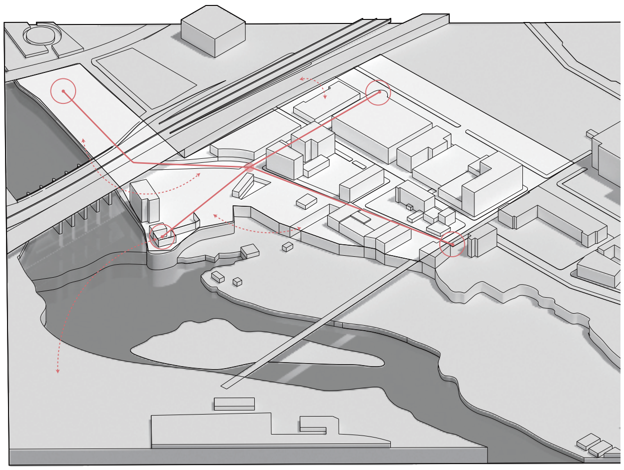
Virtual Reality was used as an essential part of the design process, from concept design to materiality definition.
The tools used were: Unreal Engine, City Engine VR and Enscape 3D, creating a multivalence of medias of immersion and representation

Two-Dimmensional Diagraming

Apart from digital design and analysis, conventional 2D drawings served as a bridge between the different medias used, unfolding the creative experience in a more explicit and practical way.

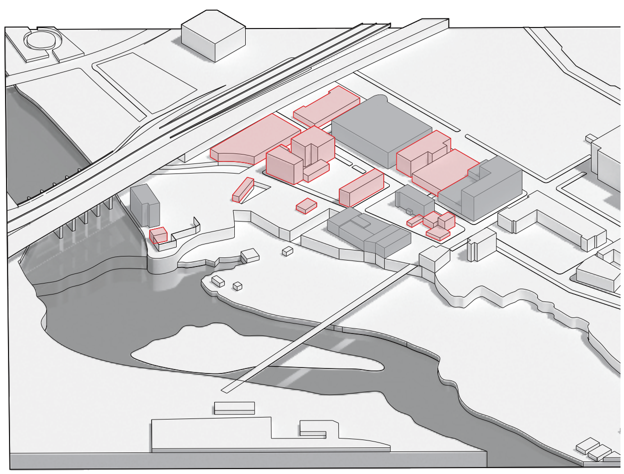
Computational Design

3D modeling software such as Rhino, Revit and Sketchup and their plug-ins such as Dynamo BIM and Grasshopper were used to rapidly document changes perceived in Virtual Reality, as well as creating solar studies, volumetric iterations and facilitate the conversion of data and file types.



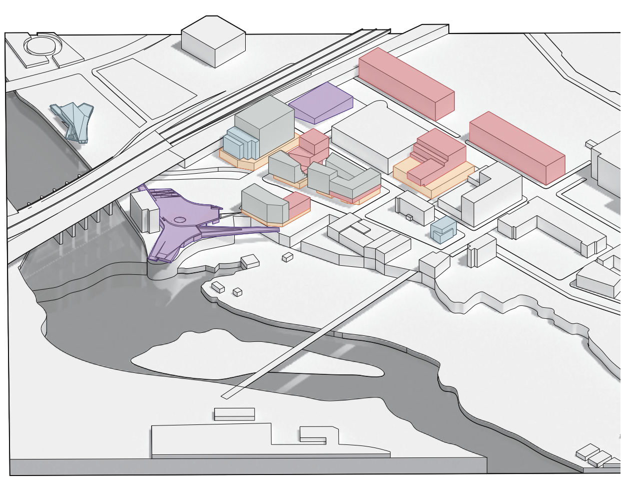
Development Scope

Swarm algorithms and other multi-agent dynamic models were utilized in order to creative vehicle and pedestrian flows to overcome existing conditions such as the train track and highway.



Preservation

To preserve the historical characteristics of the site, the plan proposes to take advantege of existing buildings such as the industrial mill, window and clothing factories, and repurpose them to fit the new urban guidelines. Demolished buildigns constitute mainly parking spaces and underused office buildings.



Use Distribution

In order to activate the area, the mixed-use development composed of residential (green), cultural (blue), retail (yellow), hotel and office spaces (red), was designed to take advantage of the unique High Falls views and flat landscape, by incentivizing multi-modal transportation, wide sidewalks and unobstructed facades.

Hotel Rooftop View

The rooftop is designed to create a relaxing environment through its warm materials and growing vegetation.

Terrace View

Multi-level gardens and terraces compose the West facade, mixing between private and public use

Hotel Aereal View
The wooden columns allow vegetation to grow on its structure

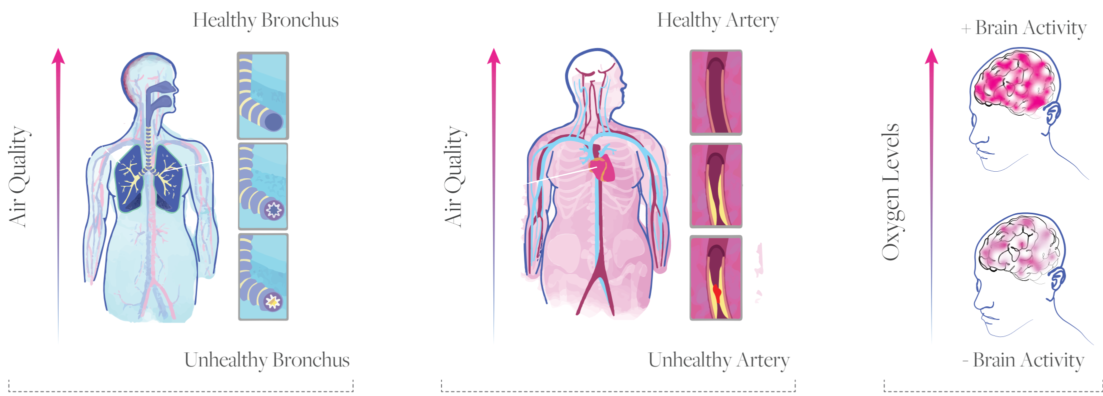
College of Climaticism

Understanding the users physiological needs was the main driver for this project. The College of Climaticism was designed to decrease air pollution levels, increasing air renewal and controlling brain function capabilities through air pressure. Atmospheric pressure drives air flow, that dictates air quality inside and outside spaces, increasing or reducing the concentration of pollutants and bacteria in the air. By controlling passively the placement and geometrical properties of a building, the architecture itself can function as a duct, redirecting air flow to specific spaces that need more air renewal, and reducing air speed when in need of an area of contemplation and relaxation.

Collecting data from user oxygen levels per activity, it is possible to identify spacial qualities and disadvantages for a specific program, and tackle these problems punctually. The geometry of a classroom for example, can be optimized in order to reduce the level of pollutant molecules in the air, by changing the ceiling curvature, the size of air intake and outtake. Starting with a simple cube, the classroom is then sectioned into pieces to analyze air flow patterns. It is then optimized parametrically using generative design, achieving a balance between constructibility, interior volume and air quality.

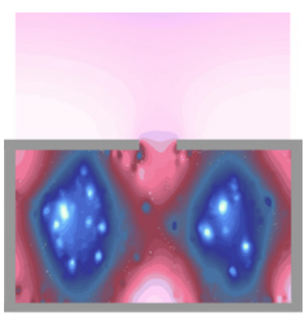
After redesigning the classroom, other principles of air flow can be applied to the building design. By understanding a single air flow direction, it is possible to predict air pressure patterns and dictate what activity should be placed on a specific region. For high pressure zones, activities that require high brain activity are placed, and for low pressure zones, activities with less brain function are placed.

The geometry of the building enclosure also plays an important role on redirecting air flow to the desired spaces for optimum air quality.

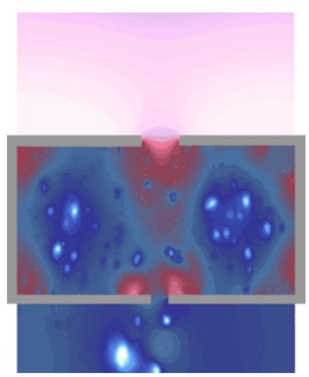


Lungs *Heart* *Brain*

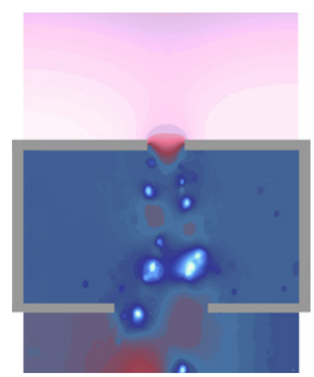
Pollutant physiological effects
Pollution can cause seriou health problems and decrease brain activity



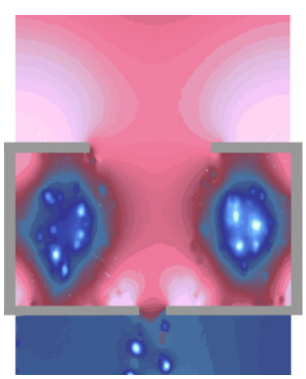
No air outlet



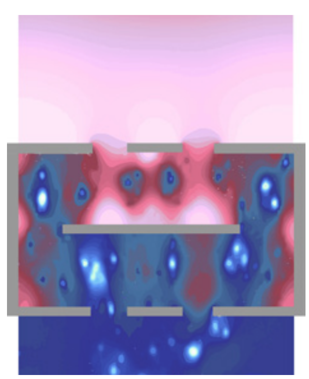
Neutral Pressure



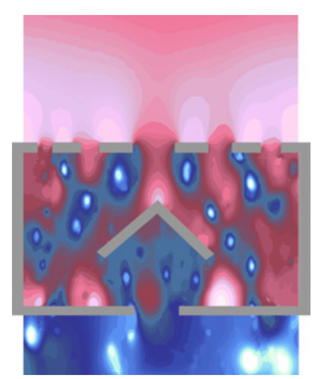
Negative Pressure



Positive Pressure

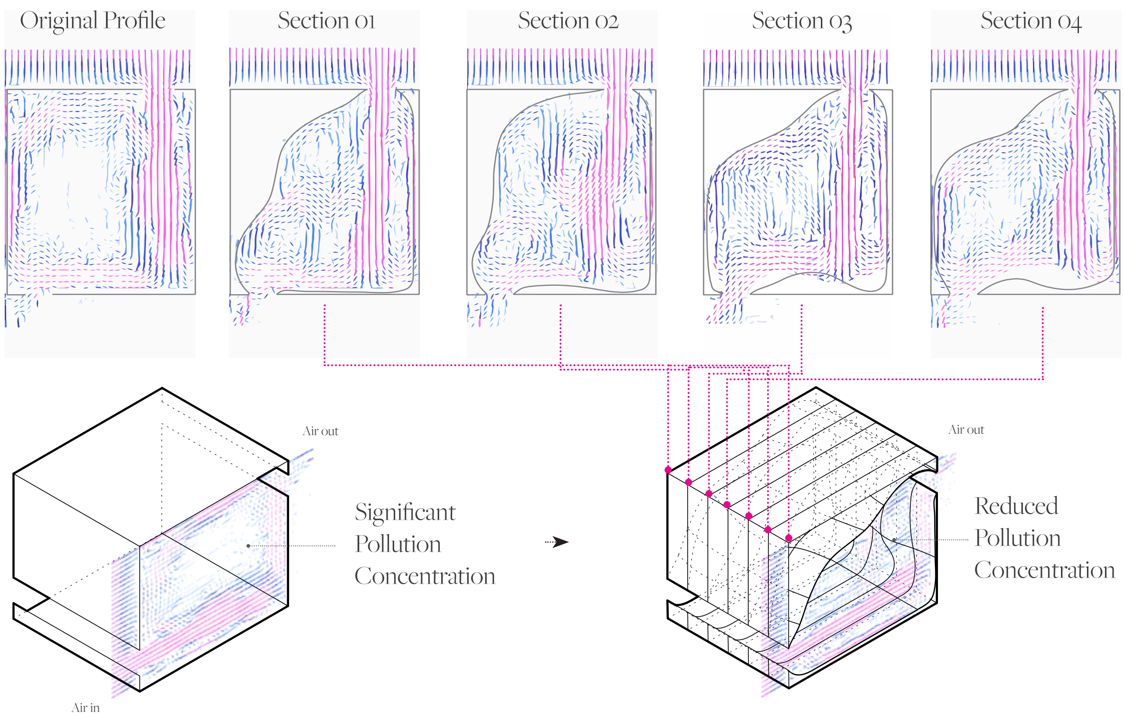


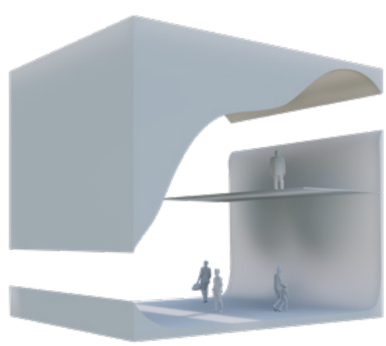
Large inlets, small outlets



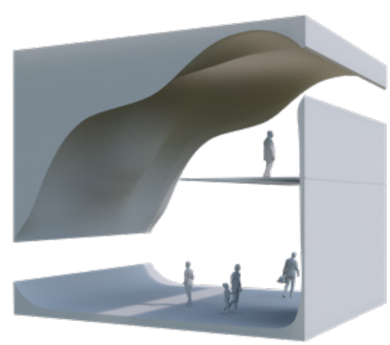
Multiple Inlet with one outlet

Wind flow pattern exploration
CFD analysis provides insight on pollution concentration and air flow patterns.

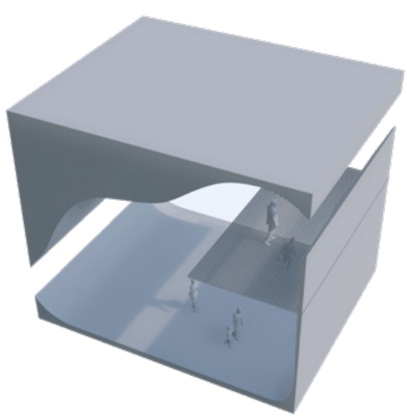




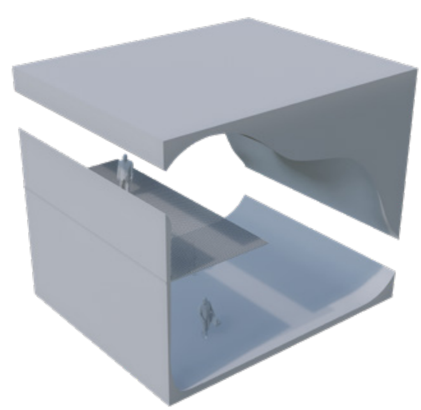
Side View A



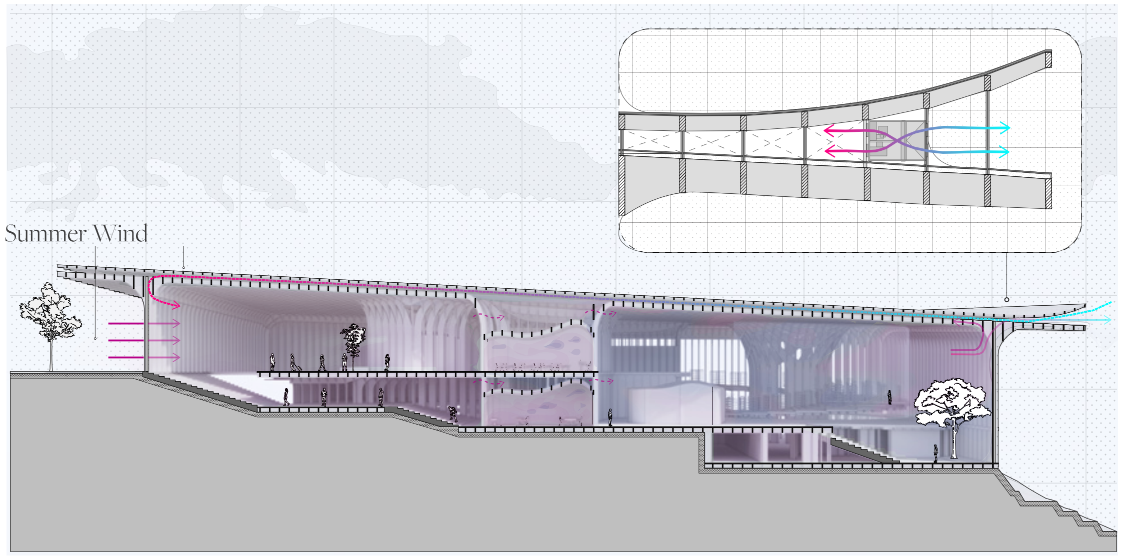
Side View B



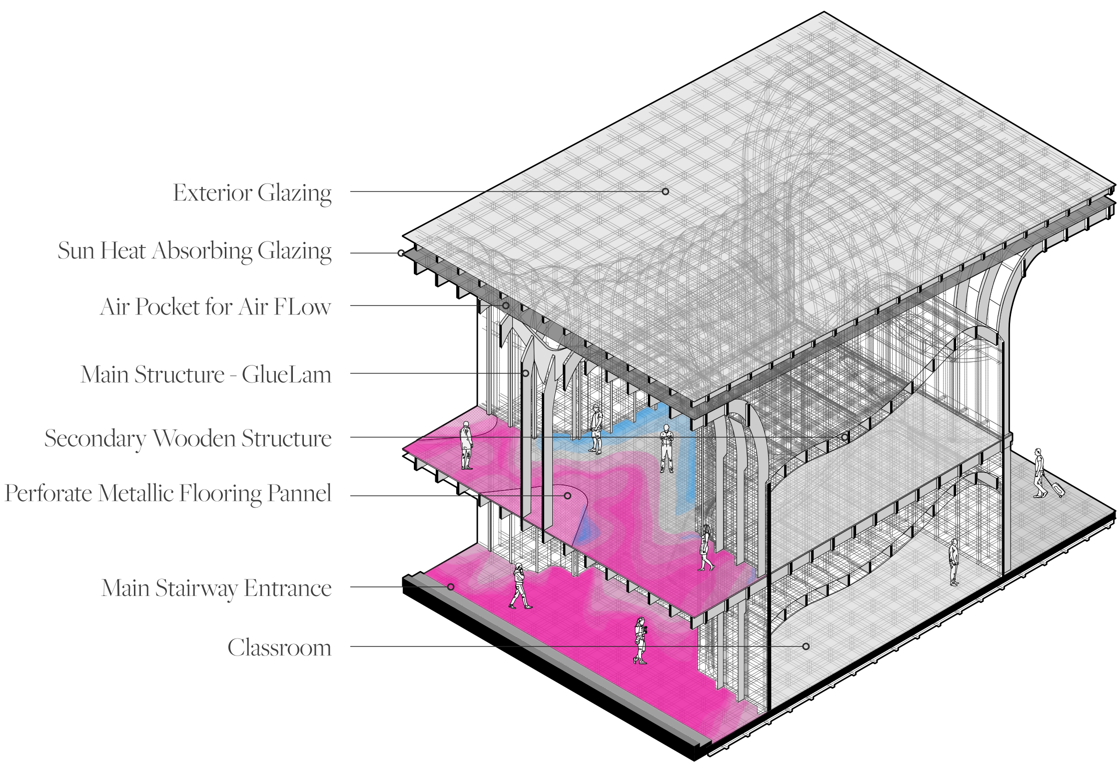
Top View A



Top View B



Longitudinal Section
Air flows in one single direction allowing the control of pressure zones and air flow patterns



Isometric Section
The waffle structure constructed out of glue laminated wood houses the pressure controlled ambients

Outdoor Rendering - North facing facade
The building follows the topography while the roof creates a funneling directing air to the interior

Entrance View
Vertical and horizontal structures are blended into a single component that is sculpted for optimum air flow

Interior Entrance View
Perforated metallic meshes are placed on the floor plane to allow a seamless air flow between levels

Interior Entrance Space
High and low pressure zones defined by the geometrical configuration of the rooms dictate program placement

Classroom Corridor
Circulation is composed of solid walkable areas, porous metallic floors and green patches that together allow for air flow and quality to perform at its highest levels

Study area and Library
The study areas air flow is directed following the natural topography toward the library, that in turn has an elipsoid shape, concentrating pollutants in its center

Conclusion

Architects are known to often make decisions based on intuition, rule sets or general knowledge acquired through time and experience, however current trends and necessities in design, demand decision-making based on the intersection of expertise and data analysis. By using nature, its systems, methods, metrics and processes to inform and guide design, either by using bio-inspired tools to interpret data, or to extract data from Nature itself for architectural application, designers expand the creative scope, and allow for inusitated and efficient outcomes.

The projects described above in this paper demonstrate some of the many possible applications of bio-inspired design, touching on a range of tools and methods, for modeling, analyzing or visualizing, that allows turning analytical insights into actionable ideas and projects.

Data is becoming increasingly complex to manage, therefore there is an opportunity to study and develop tools needed to collect, extract patterns and facts from that data, in order to inform design consciously.

Nature tends to decentralize control and select the optimum alternative, considering accuracy, adaptability and speed. Transportation networks, energy consumption and physical expansion for example can deeply benefit from the understanding and application of Nature's behavior, leveraging the quality of the design, and efficiency of production.

It is important however, that architects understand the different levels and functionalities of bio-inspired concepts, including semantics. Biomimetic, biometric, bionic and biophilic are all different concepts that approach design through a common denominator: Nature. Understanding the correct application of these lexicons and models into design, can lead to the embodiment of several features that are desirable in architecture, including adaptability and computational efficiency.

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