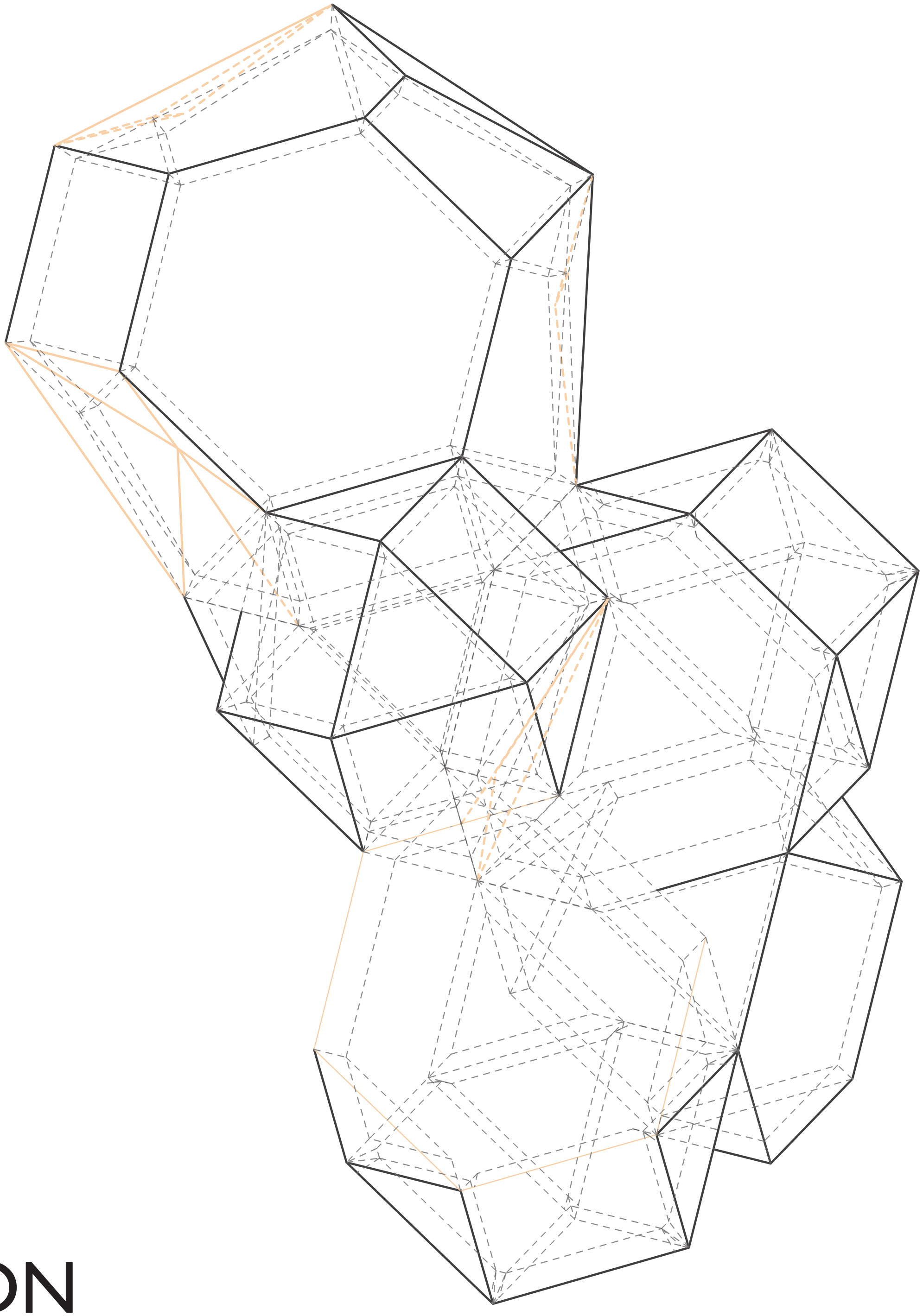
BIO/

DIGITAL/

FABRICATION



THESIS PROJECT TITLE: BIO/DIGITAL/FABRICATION

STUDENT: NEHA BASAVARAJ

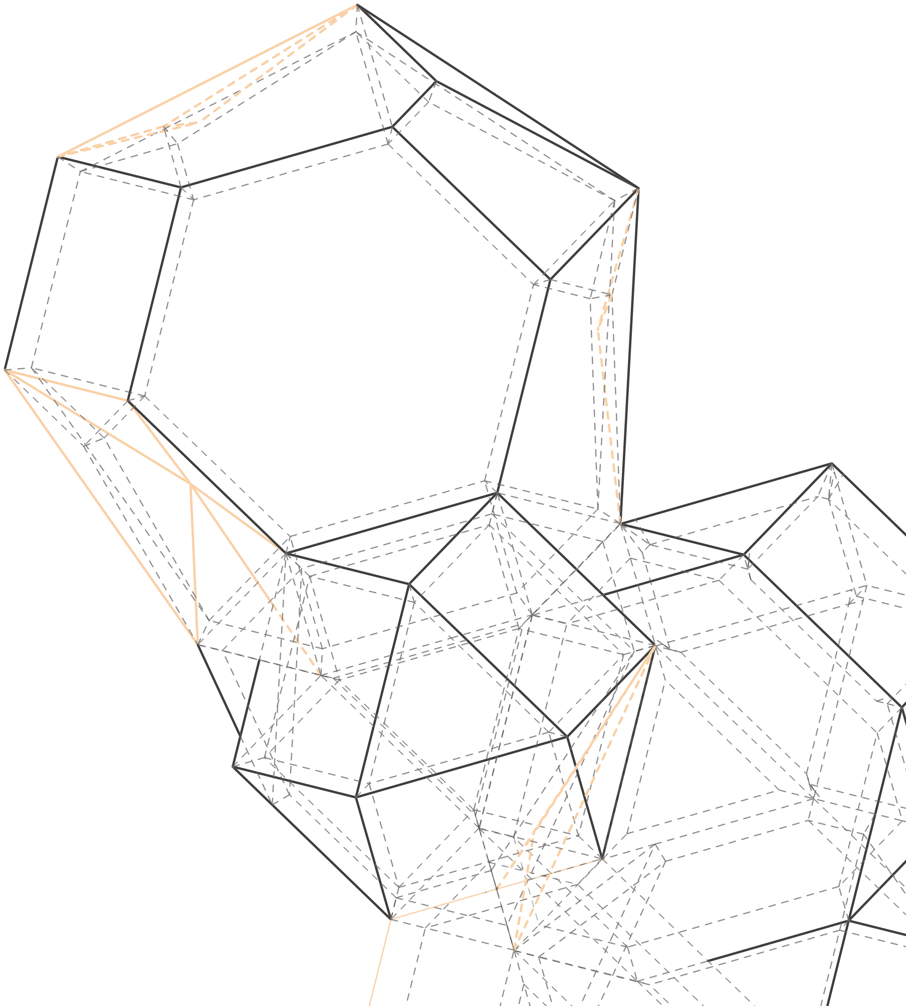
ADVISOR: NICOLE KOLTICK

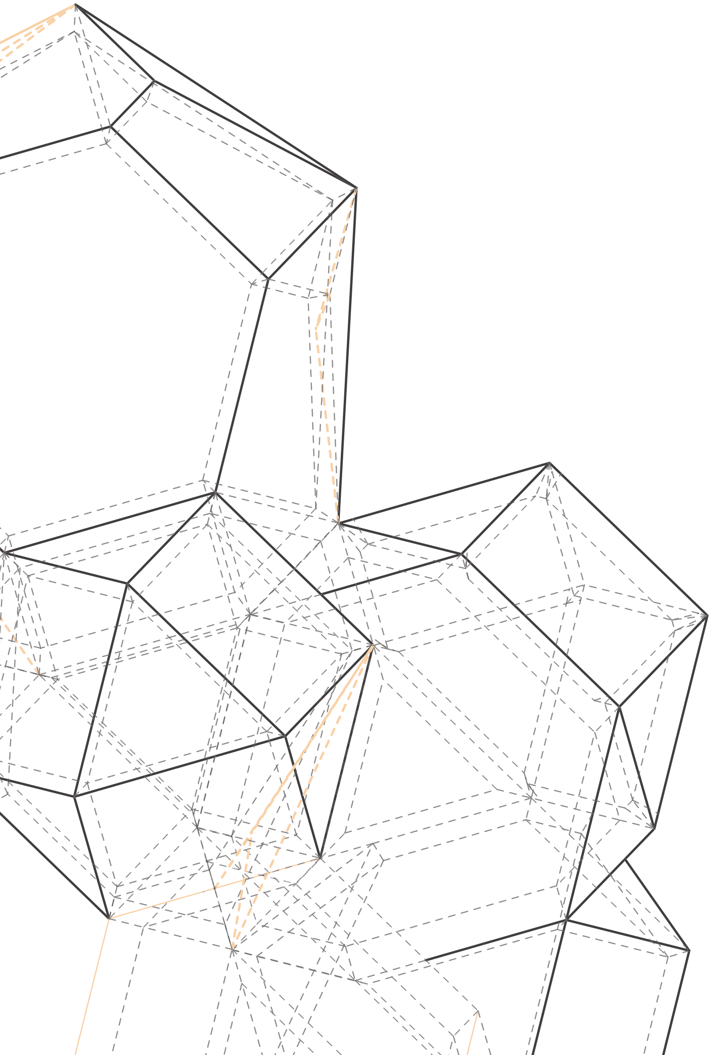
ASSOCIATE PROGRAM DIRECTOR: WILLIAM MANGOLD

YEAR: 2017-18

COLLEGE: WESTPHAL COLLEGE OF MEDIA ARTS AND DESIGN

UNIVERSITY: DREXEL UNIVERSITY





"We don't look at nature as something that is especially efficient, because all natural systems have what biologists call a phylogenetic baggage – they come with their own set of constraints on how they can operate and respond to environmental influences – but natural systems are always very effective and very adaptive, with a high level of specific differentiation. In nature everything is varied and calibrated in response to heterogeneous influences."

- Achim Menges

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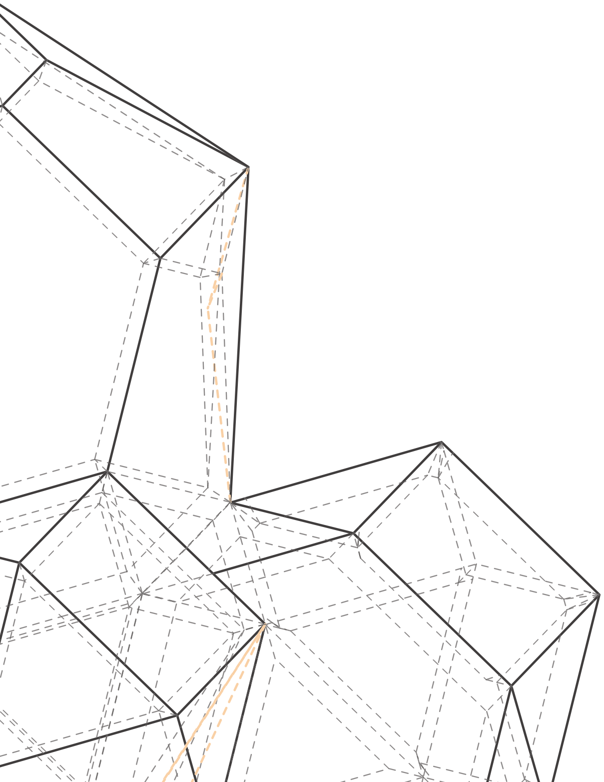

0.0 FOCUS

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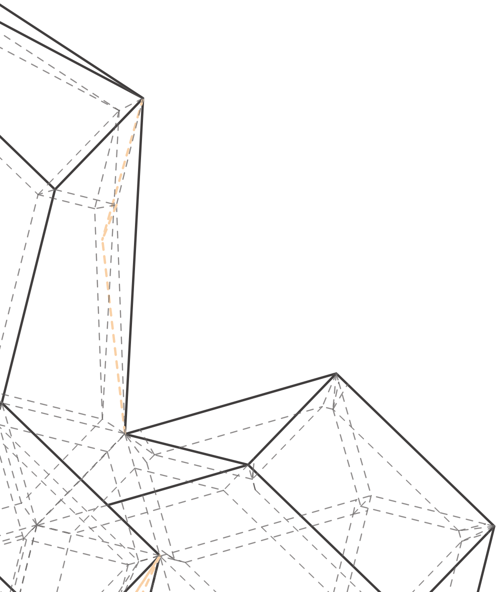
0.0 FOCUS



The thesis focuses on the intersection between digital design computation and biological material explorations. Embracing making as part of the design process.

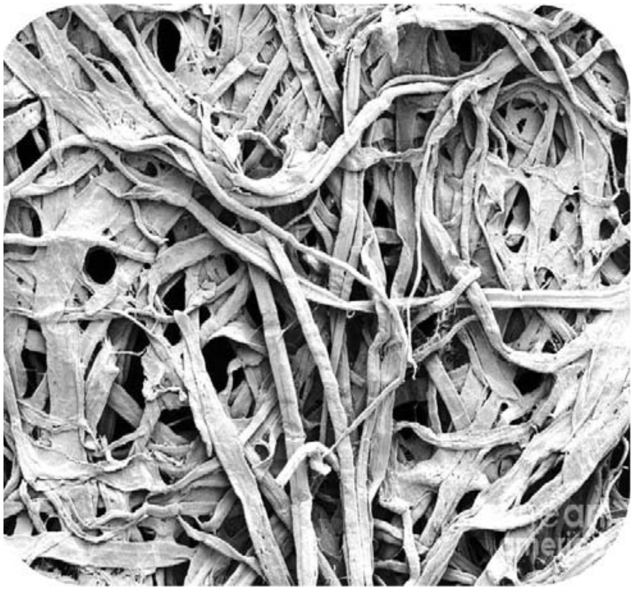
1.0 INTRODUCTION

A key aspect to be noted from the research is that in biology, material is the system.

Where it performs multiple functions like provides form, structure and is part of the operations conducted by the organism. The material is the mechanism.

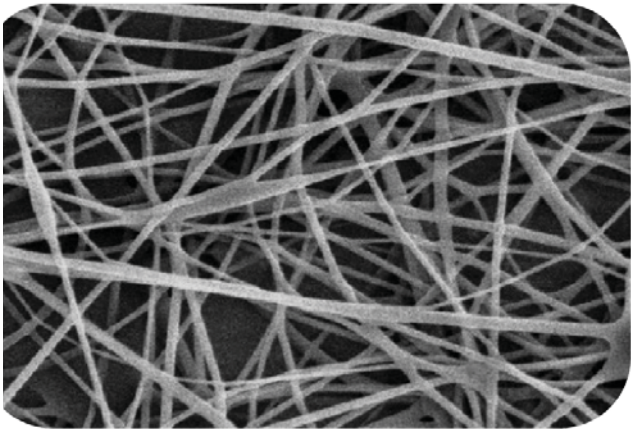
What is interesting is that most biological structures are fibrous composites, but it uses only few materials as its main material for construction.

Cellulose in plants, collagen in animals, chitin in insects and crustaceans and silk in spiders.

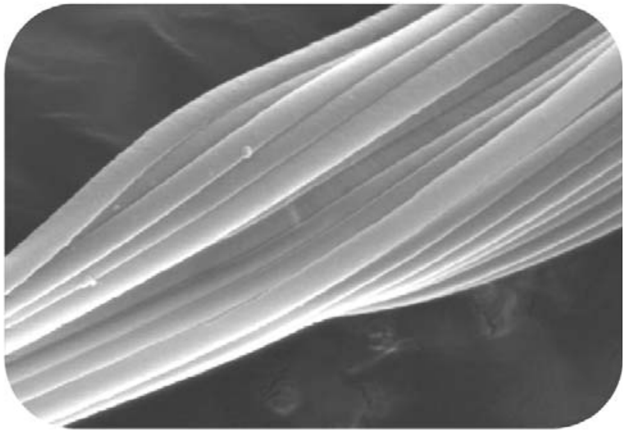


CELLULOSE IN PLANTS

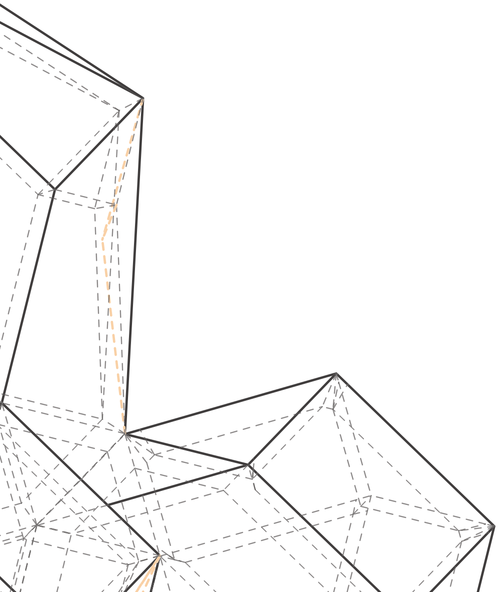
COLLAGEN IN ANIMALS



CHITIN IN INSECTS & CRUSTACEANS



SILK IN SPIDERS



2.0 PRECEDENTS

FORM AND FABRICATION

2.1 RESEARCH PAVILION, 2011

ACHIM MENGES, ICD, STUTTGART

Research pavilion 2011 explores the transfer of biological principles of a certain sea urchins shell structure into architecture, with the help of computer aided generation and fabrication.

The shell is made up of modular systems of polygonal plates, linked together at the edges by finger like calcite protrusions.




The final structure has two levels of 6.5 mm thin plywood sheets joined together by finger joints. Three such plate modules always join together at one point, thus making it a simple joinery mechanism that is easy to assemble and disassemble.

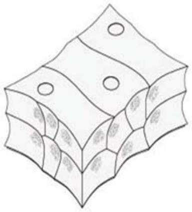
2.2 HYGROSKIN - METEOROSENSITIVE SKIN, 2013

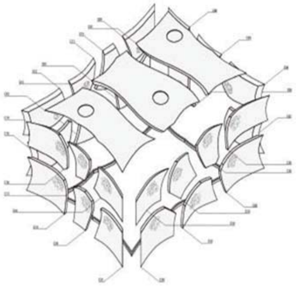
ACHIM MENGES, OLIVER DAVID KRIEG, STEFFEN REICHERT

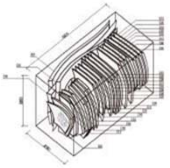
Hygroscope was further developed into a meteorosensitive pavilion, both follow the same hygroscopic principles of the spruce cone. In which it is closed when damp and opens up when the moisture is lost.

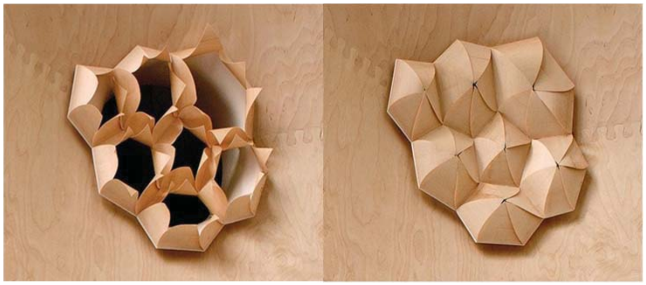
The pavilions modular skin is designed and produced using planar plywood sheets to form conical surfaces based on the materials elastic properties.

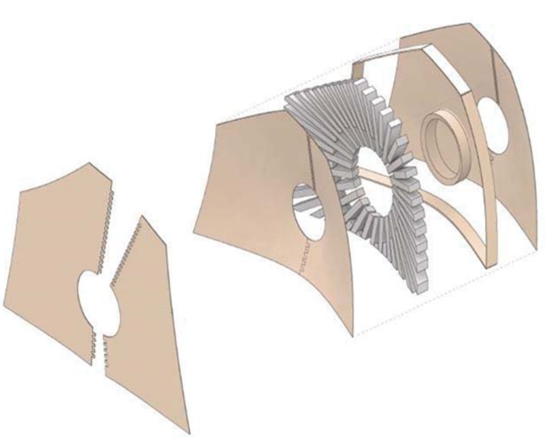
Within each of these modules a weather responsive aperture is placed.











The material is programed to respond to certain levels of humidity present in the environment. The structure is in constant feedback and interaction with its surrounding environment.

The subtle yet constant modulation of the relationship between the pavilions exterior and interior provides for a unique convergence of environmental and spatial experiences.

2.3 RESEARCH PAVILION 2013-14

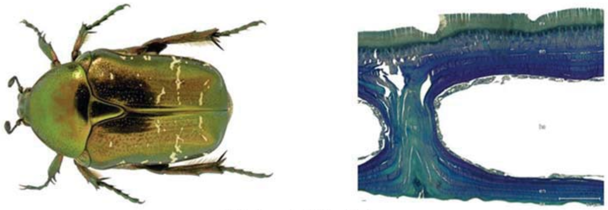
ACHIM MENGES, ICD, STUTTGART

Using composite fiber material as used in the previous project, here they aimed to develop a winding technique of fabrication for a modular double layered structure.

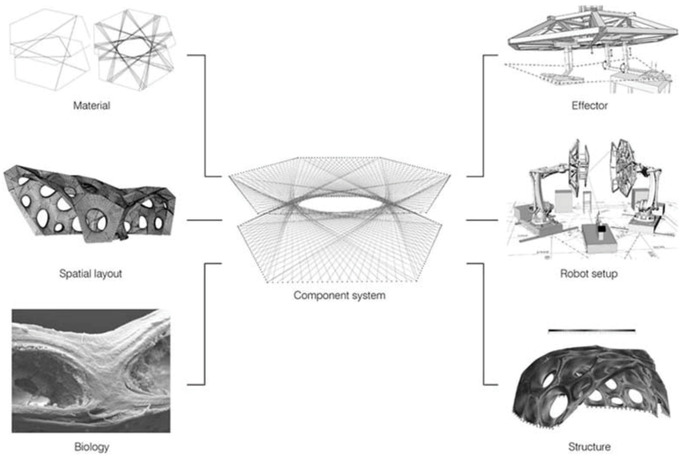
The research team Investigates functional principles of natural lightweight structures of elytron, a protective shell for beetles wings and abdomen.

The elytra morphology is based on a double layered structure which is connected by column-like doubly curved support elements called trabeculae.

Trigonopterus nasutus | Ground Beetle



Cetonia aurata | Flying Beetle



Bases on this morphology and the individual fiber arrangements, a double layered modular system was generated for implementation in an architectural prototype.

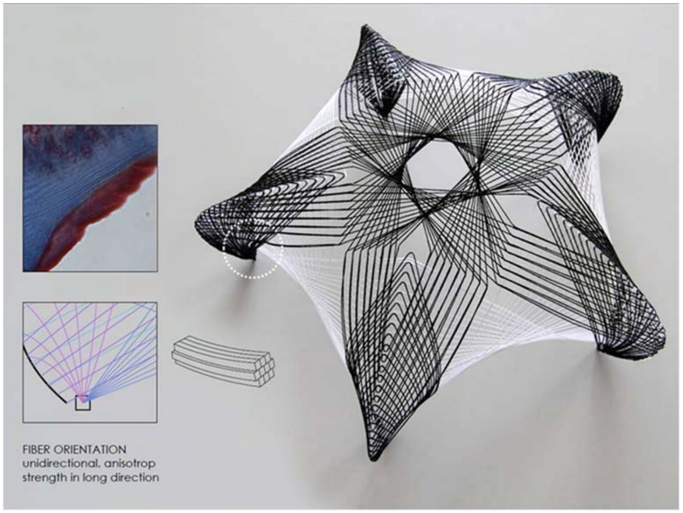
This kind of research approach not only leads to performative and material efficient light weight construction, it also explores novel spatial qualities and expands the tectonic possibilities of architecture and design.

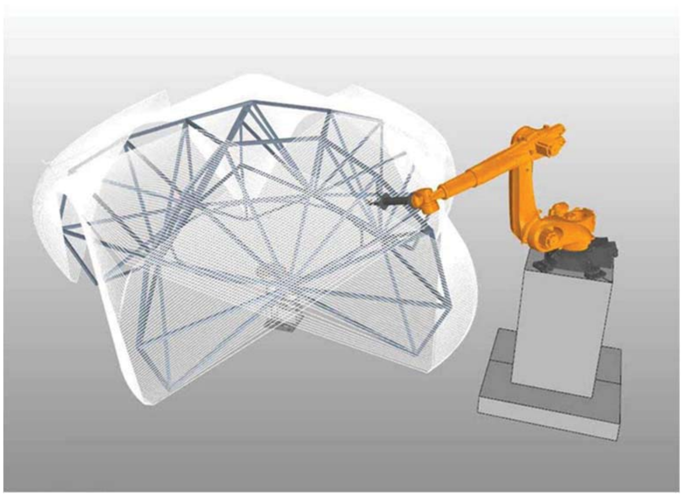
2.4 RESEARCH PAVILION, 2012

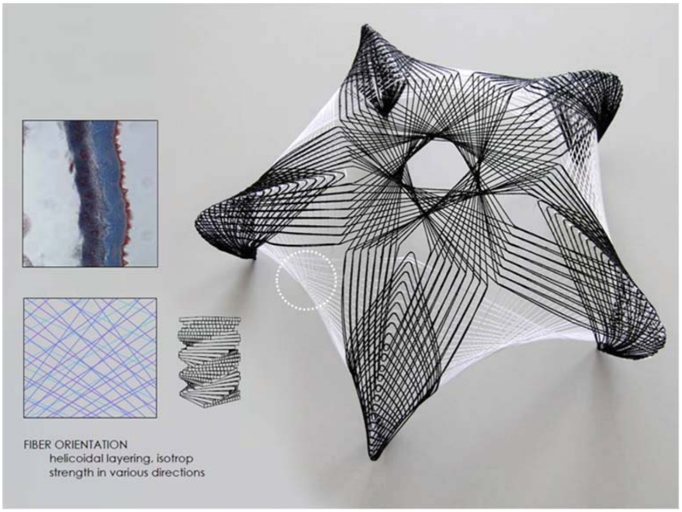
ACHIM MENGES, ICD, STUTTGART

This pavilion was fabricated entirely with robots using carbon and glass fiber.

The project investigates the possible interrelations between biomimetic design principles of the exoskeleton of a lobster and novel processes of robotic production.







The exoskeleton exhibits local material differentiation. That has two variabilities, an endocuticle consisting of a soft part and an exocuticle consists of a relatively hard layer.

This principle of the exoskeleton was applied to the design of a robotically fabricated shell structure based on a fiber composite system.

Resulting in a novel synthesis of form, material, structure and performance.

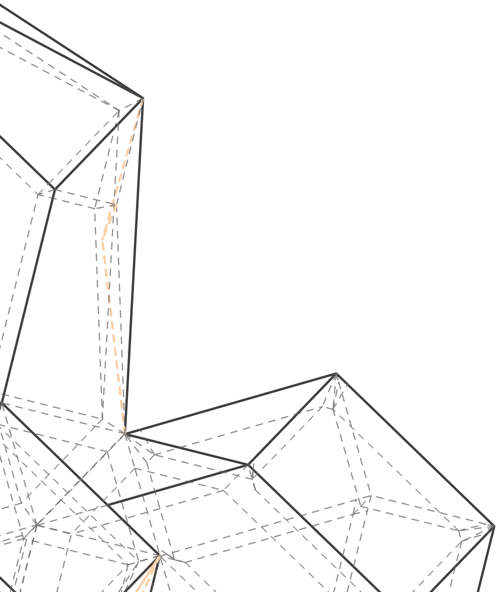
2.5 RESEARCH PAVILION 2013-14

ACHIM MENGES, ICD, STUTTGART

This is another research project that is generated from the previous one.

Here the cellular canopy grows from an onsite fabrication nucleus, and it does so in response to patterns of inhibition of the garden over time, driven by real time sensing data.

It has the capacity to grow in number or reduce making it highly responsive to its need. This project looks at future of inner city garden areas with a speculative lens.



3.0 PRECEDENTS

MATERIAL STUDY

3.1 BIO-RESPONSIVE BLOOM

BIOTA LAB, UCL

Porous Surface Prototype is another example of the work that is done by the lab.

It is a surface made of concrete mixture that results from material testing with various ratios of aggregate, cement and water.

It aims at creating a scaffold that is able to host various bio-receptive materials in its pores, ultimately leading to growth. The resulting components are not only lightweight but also permeable enough to allow the growth of mosses and other microorganisms to proliferate.

This surface was inspired by the ash tree that performs similar functions over time.

3.2 PERVIOUS BRANCH

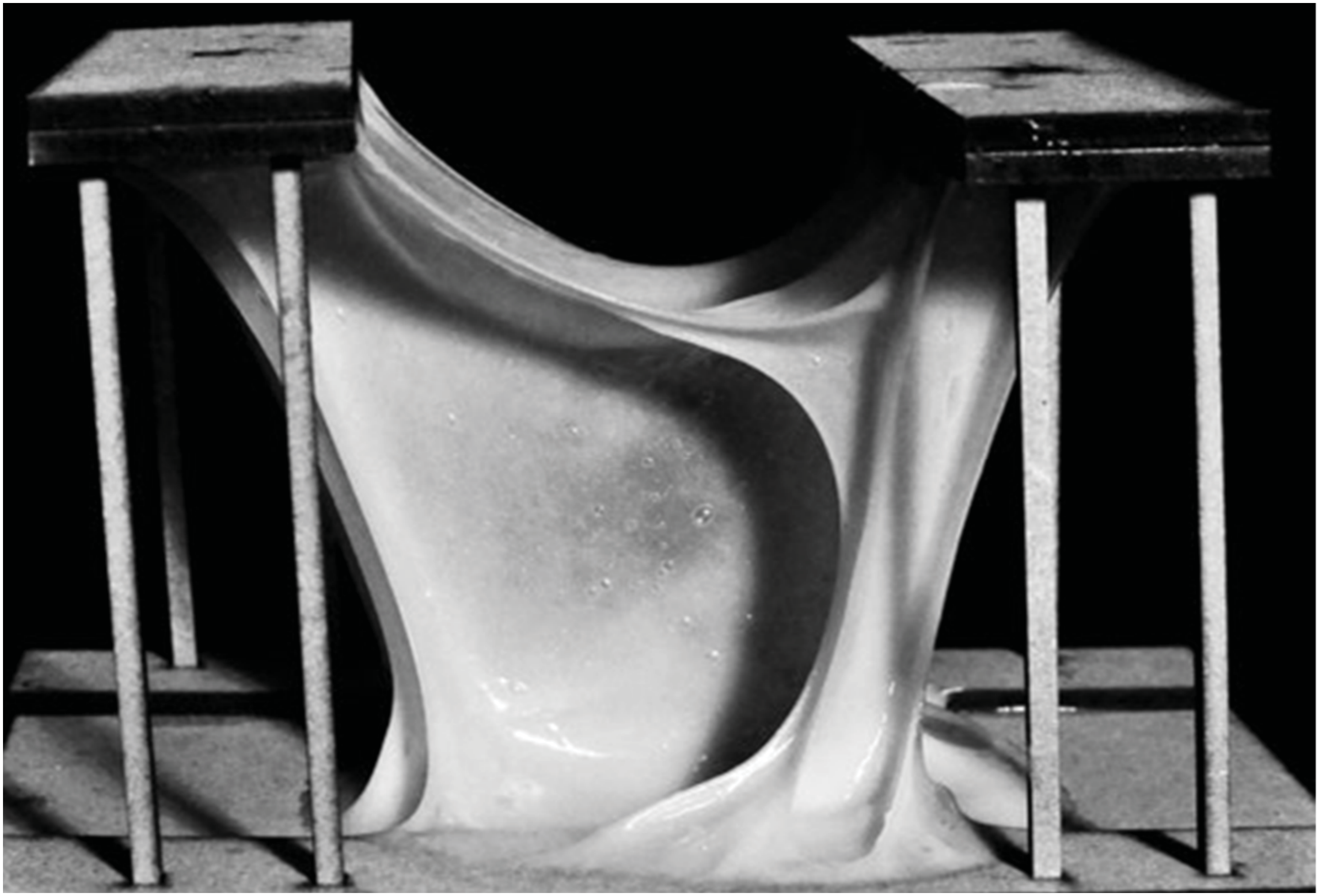
BIOTA LAB, UCL

BiotA lab is a research platform for innovative design research that merges architecture, biology and engineering, at University College London. The lab explores the fields of synthetic biology, biotechnology, molecular engineering and material sciences.

Pervious Branch is a type of facade panel focusing on branching geometries that are generated from inside out. This system evolves from the host structure into a unique porous branching structure that maintains and captures moisture for moss to grow.

3.3 BIO-PLASTIC MORPHOLOGIES, 2013

MARIA VALENTE, UNIVERSITY OF WESTMINSTER



Bioplastics have an inherent viscous material property. Due to which they can be forced to take up any form.

Maria uses this property in an interesting way. Where she elongates the viscous material between two surfaces. This forms dendrite like structures that forms a multidirectional support system.

The base material used for the experiments are potato and tapioca starch, mixed with water, vinegar and glycerin.

3.4 MYCELIUM - GROWING ARCHITECTURE, 2013

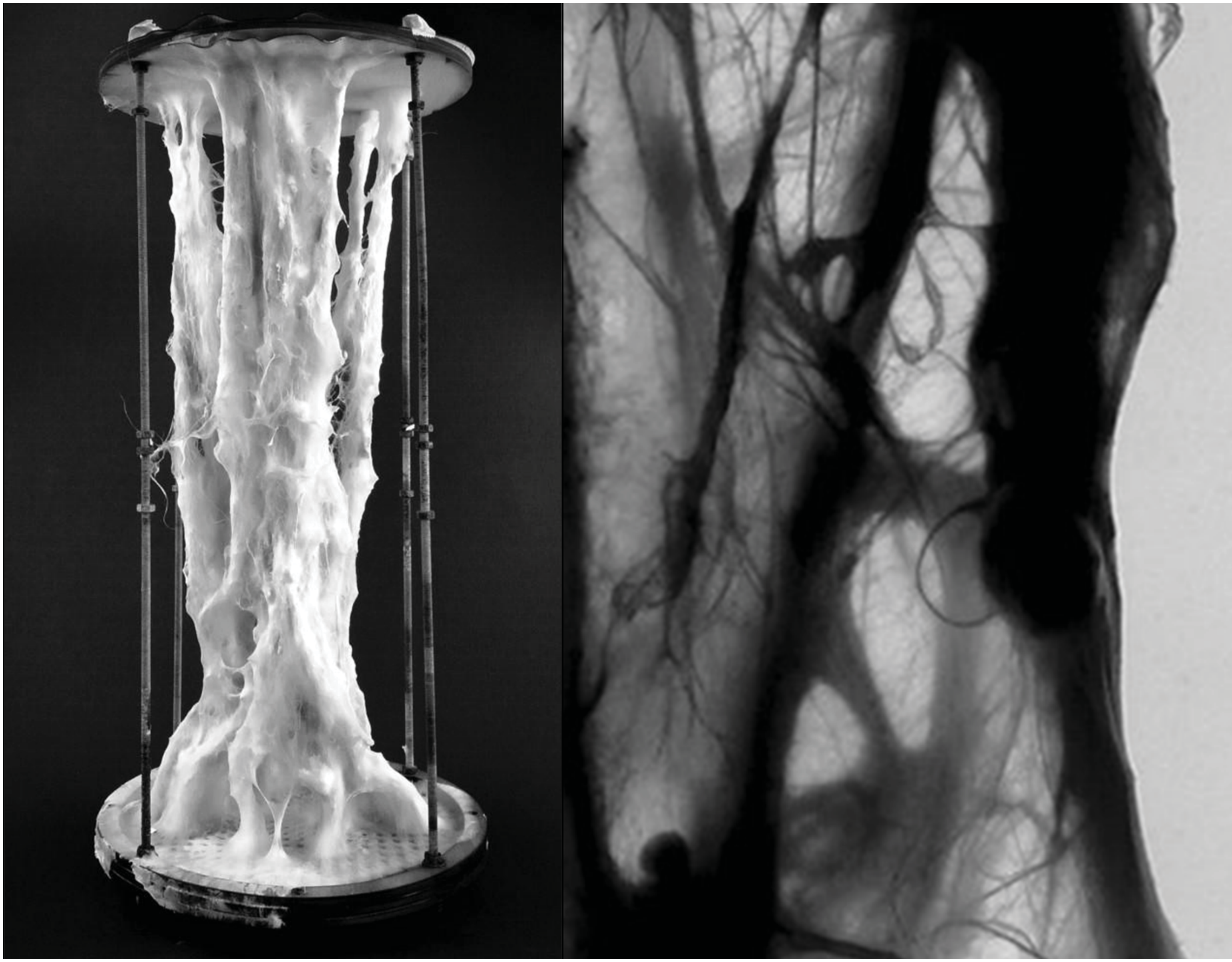
INSTITUTE FOR ADVANCED ARCHITECTURE OF CATALONIA

The team studied the ability of mycelium to adapt to cardboard and plywood structures, in order for it to grow on pre designed specific forms.

Mycelium was able to stick to cardboard and wood firmly.

3.5 MYCELIUM TECTONICS, 2015

GIANLUCA TABELLINI, UNIVERSITY OF BOLOGNA

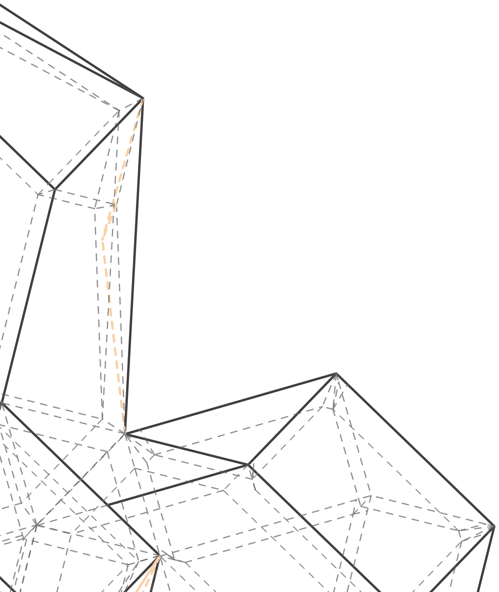


This multidisciplinary research work blends architecture with technology and biology.

Tabellini conducted various experiments using mycelium morphologies and investigating the strategies used for growth by mycelium.

The research focused on growing mycelium on filamentous hemp structures. This base structure was generated digitally in order to build physical models that allowed the fungi to grow on.

4.0 THESIS PROJECT AIM

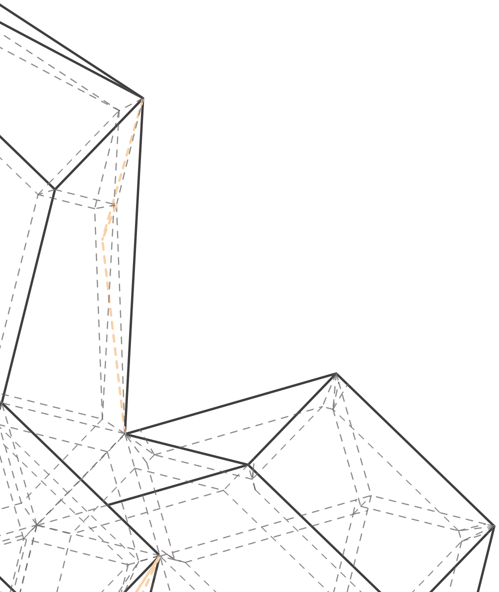


Design of a Kiosk/Pavilion is generated at the intersection of 3 separate areas of work: 1) Biology, 2) Design and 3) Fabrication.

The project explores use of Mycelium, Bacterial Cellulose with aluminum as the frame in a temporary structure.

Mycelium and aluminum are used for their light weight property and also an added advantage of being able to decompose and reuse respectively. Bacterial cellulose due to its translucency when dry adds an aesthetic light and shadow quality to the design.

The structure is proposed to be able to flat pack and shipped to various locations to be used as a kiosk/pavilion that can help reach a wider audience. The developed system opens up many possible design potentials for the future.



5.0 CLIENT

5.1 ECOVATIVE

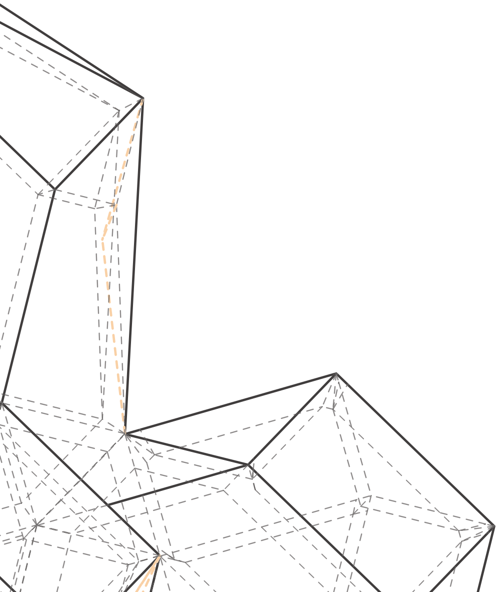
GREEN ISLAND, NEW YORK

Ecovative's core mission is to envision, develop, produce, and market Earth friendly materials, which, unlike conventional synthetics, can have a positive impact on our planet's ecosystem.

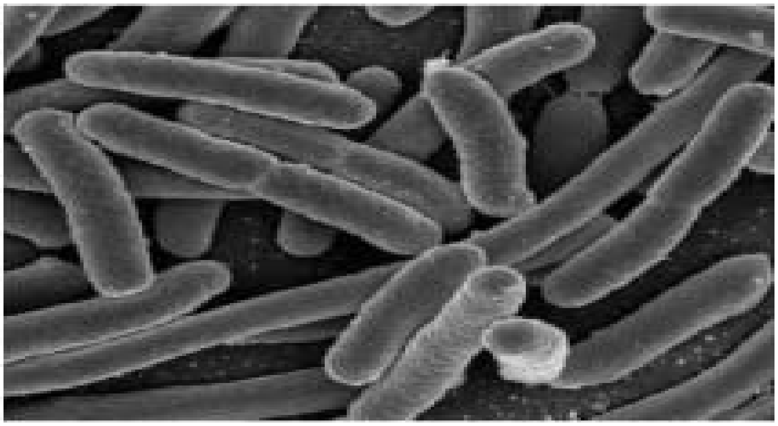
They are committed to working with industry and consumers to rid the world of toxic, unsustainable materials. They believe in creating products that enable companies and individuals to achieve their sustainability goals, without having to sacrifice on cost or performance.

5.2 PRODUCTS

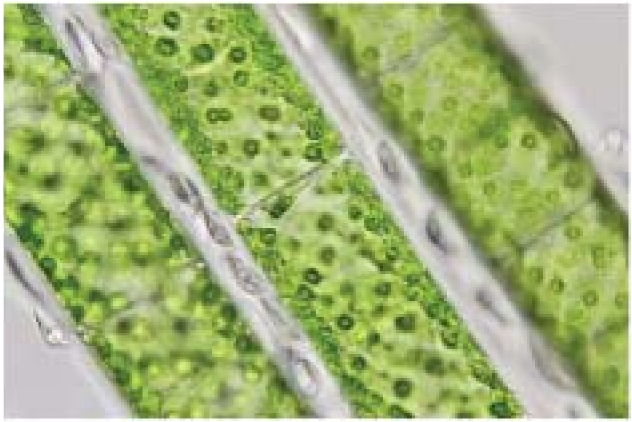
RAW MATERIALS



MYCELIUM



BACTERIA



ALGAE

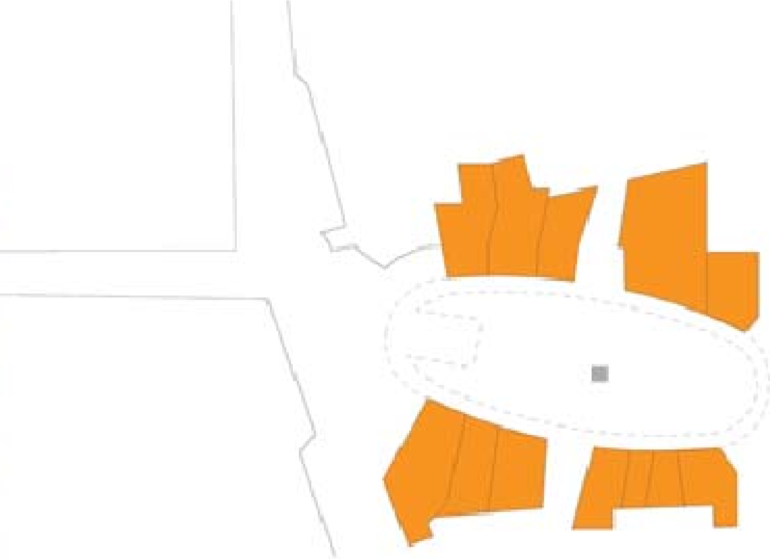
YEAST

5.3 SITE

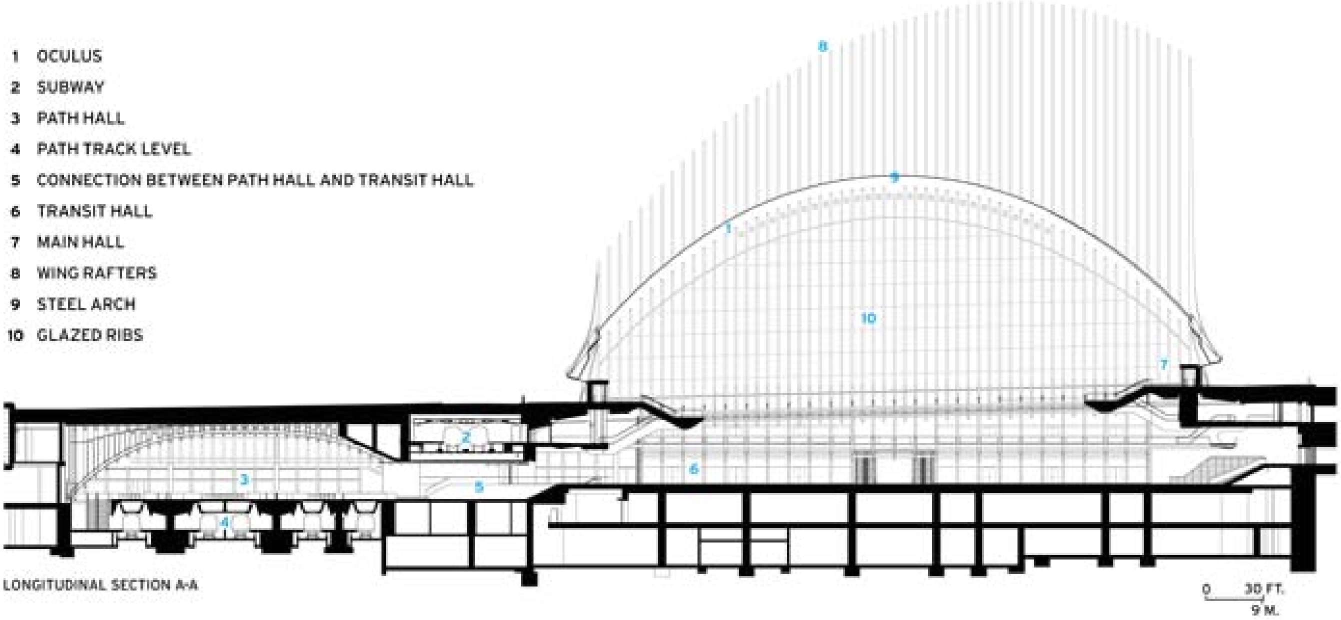
WORLD TRADE CENTER TRANSPORTATION HUB

ARCHITECT: SANTIAGO CALATRAVA
800,000 SQ FT AREA IN TOTAL AND 400,000 SQ FT OF RETAIL SPACE

350 FEET LONG, 115 FEET WIDE AND 96 FEET HIGH
USED EVERY DAY BY 250,000 COMMUTERS



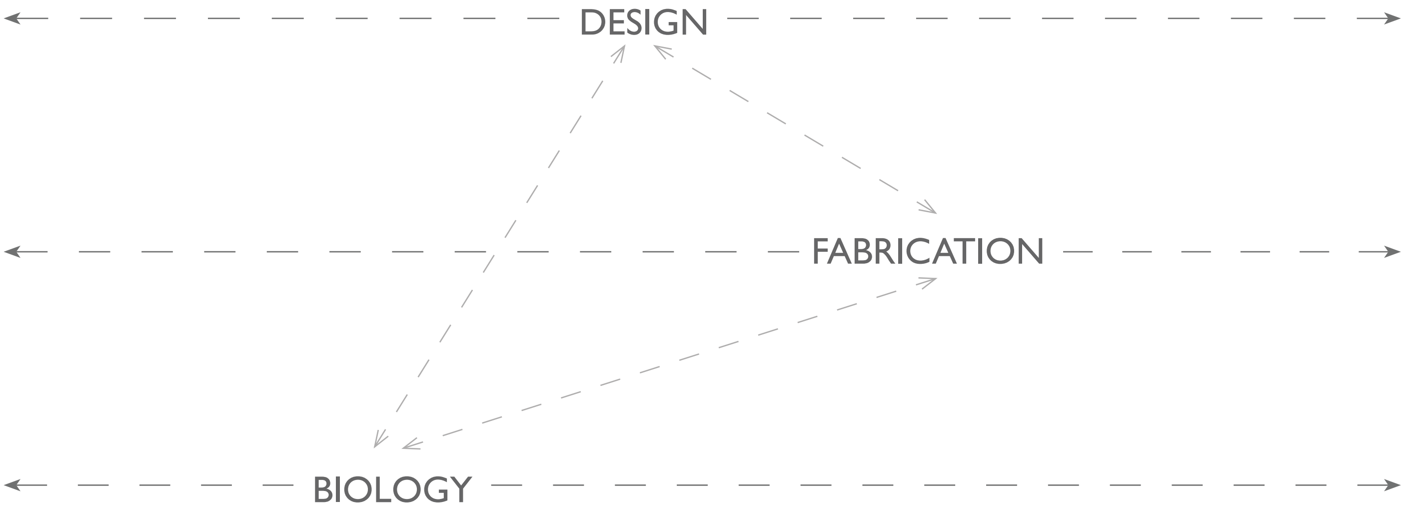
1. OCULUS
2. SUBWAY
3. PATH HALL
4. PATH TRACK LEVEL
5. CONNECTION BETWEEN PATH HALL AND TRANSIT HALL
6. TRANSIT HALL
7. MAIN HALL
8. WING RAFTERS
9. STEEL ARCH
10. GLAZED RIBS



LONGITUDINAL SECTION A-A

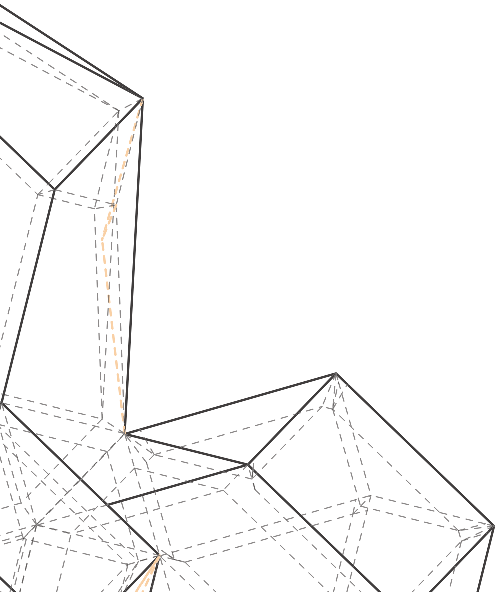
5.4 PROGRAM

AREAS OF WORK/PROCESS



DESIGN INTENT

- LIGHT WEIGHT
- EASY TO TRANSPORT
- EASY TO ASSEMBLE
- EASY TO DISASSEMBLE
- COMPOSTABLE
- LOCALLY SOURCED MATERIAL

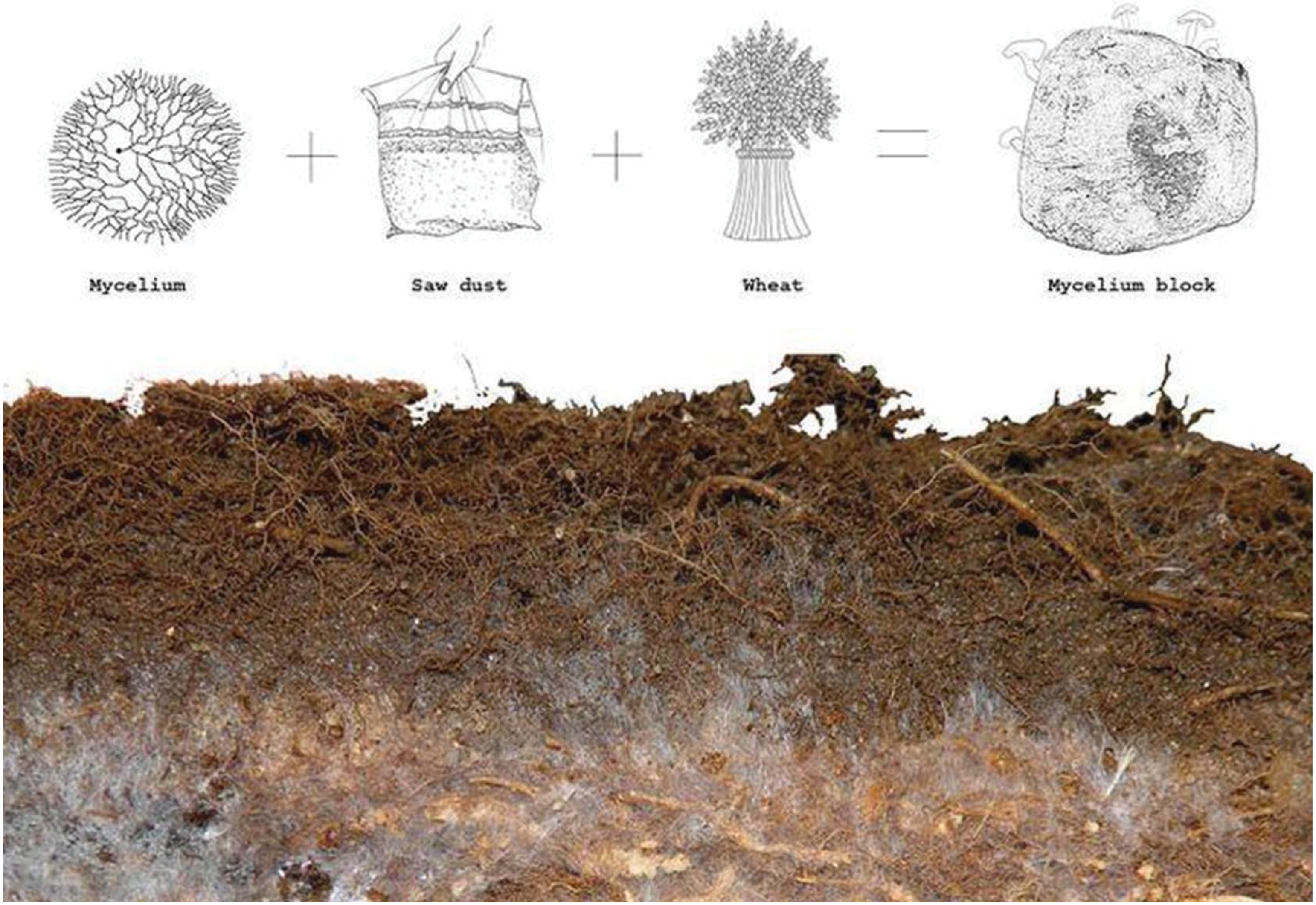


6.0 MATERIAL INVESTIGATION

6.1 Cellulose

An insoluble substrate that is the main constituent of plant cell walls and of vegetative fibers such as cotton. It is a polysaccharide consisting of chains of glucose monomers.

6.21 Mycelium



Mycelium is the vegetative (root) part of a fungus, consisting of a network of fine white filaments called the hyphae.

Next couple of material studies focus on Mycelium as the main construction material.

Mycelium is the vegetative part of fungus and its primary role in nature is to decompose organic compounds. It is composed of chitin fibers.

The objects grown from mycelium usually use organic products like saw dust, corn waste or hemp. It takes about 2 to 3 weeks to grow in a mold and 3 to 4 days to dry after.

6.22 ADVANTAGES OF MYCELIUM

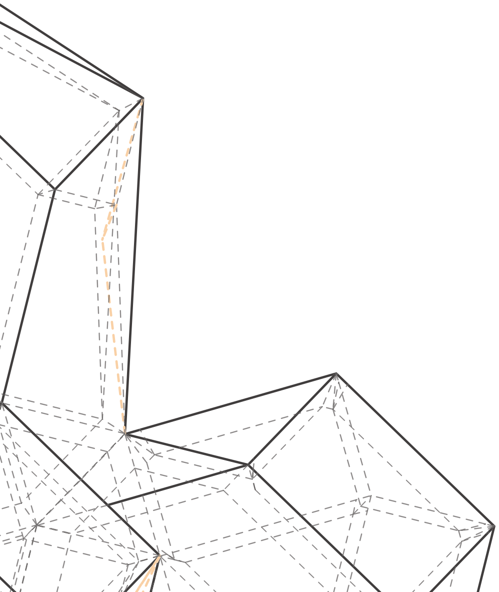
FIRE RETARDANT

WATER RESISTANT

SELF HEALING

COMPOSTABLE

POTENTIAL TO REPLACE PLASTIC



7.0 PRECEDENTS

FORM AND MATERIAL

7.1 MBRn

JESSICA GREGORY

Jessica Gregory is an artist that explores natural materials.

MBRn is a solution which uses cellulose based plastic grown from glucose that is derived from food waste like apples and beetroots. Cellulose has properties such as high purity, strength and moldability, making it suitable for a products like packaging.

The regenerative process of growing bacterial cellulose starts from one mother culture, also known as a symbiotic culture of bacteria and yeast. This culture produces cellulose from fibers, when it is combined with tea, vinegar and glucose. The cellulose is formed as a layer on top of the solution. This layer takes two weeks to grow before it is harvested, molded and left to air dry for four days.

This process involves no harmful toxins, generates no waste, and the process itself is cumulative making mainstream cellulose farming a future possibility.

7.2 HY-FI

DAVID BENJAMIN, MOMA

The structure designed by David Benjamin, is made of 10,000 mycelium bricks that were grown by Ecovative using cut hemp and corn waste.

The structure is made of three cylinders that converge into each other. This structure is completely biodegradable.

7.3 MYCELIUM BENCH

TERREFORM ONE, NY

Designed at the intersection of parametric CAD software and synthetic biology.

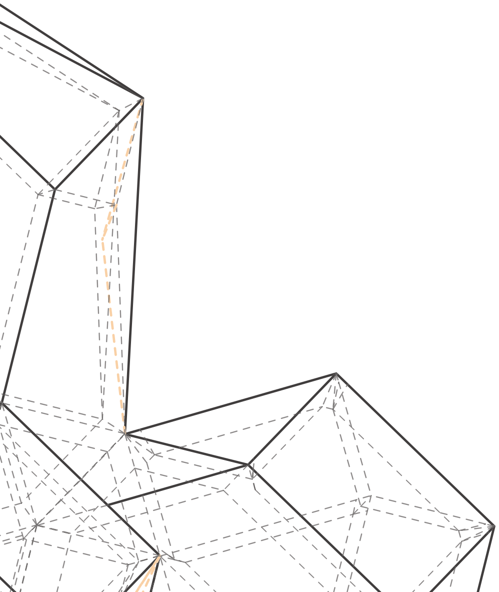
This bench by Terreform One, has a surface system made out of mycelium strips. Its base is made from bamboo and the external skin is made of bacterial cellulose.

7.4 MYCELIUM CHAIR

ERIC KLARENBEEK

The mycelium chair by Eric, here he uses two main steps in its making. The first is 3D printing the base structure using biodegradable filaments and then the next step is filling it with waste agricultural material with mycelium into the openings.

The resulting chair is extremely lightweight having a solid, durable structure.



8.0 FABRICATION

8.1 BIO/FABRICATION

PREPARING AGAR WITH MUSHROOM SAMPLES

STEP 1A

GRAIN INOCULATION

STEP 2A

ADD GRAIN TO SUBSTRATE

STEP 3A

GROW IN FORM (MYCELIUM AND CELLULOSE)

STEP 4A

DRY AND BAKE

STEP 5A

8.2 DIGITAL/FABRICATION

FORM FINDING

STEP 1B

PHYSICAL MODEL

STEP 2B

CONNECTION DETAIL

STEP 3B

CNC AND VACUUM FORMING

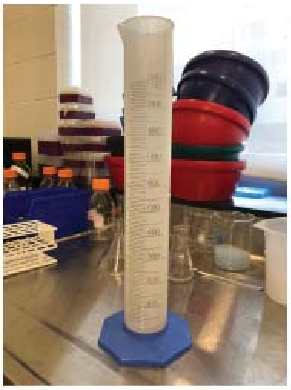
STEP 4B

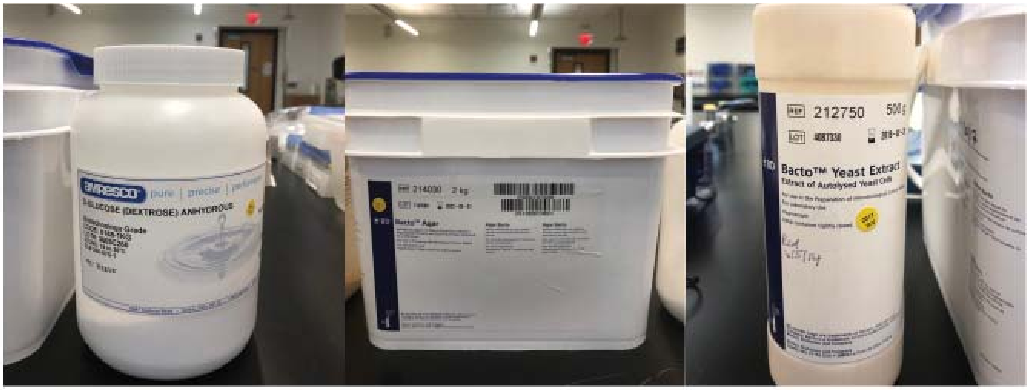
FINAL 3D MODELING

STEP 5B

8.11 PREPARING AGAR WITH MUSHROOM SAMPLES

STEP 1A





WATER

+

AGAR

+

MALT EXTRACT

+

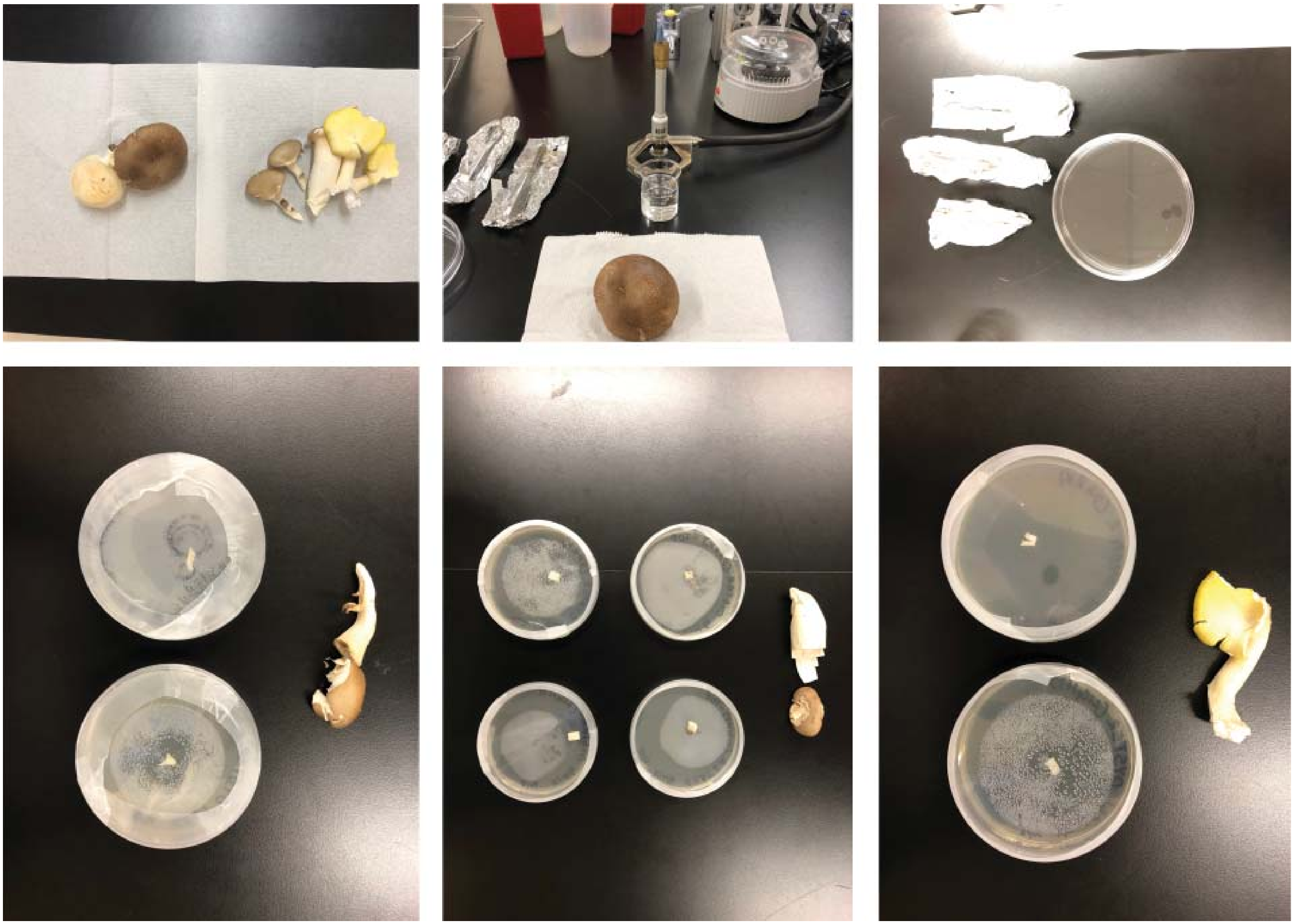
YEAST

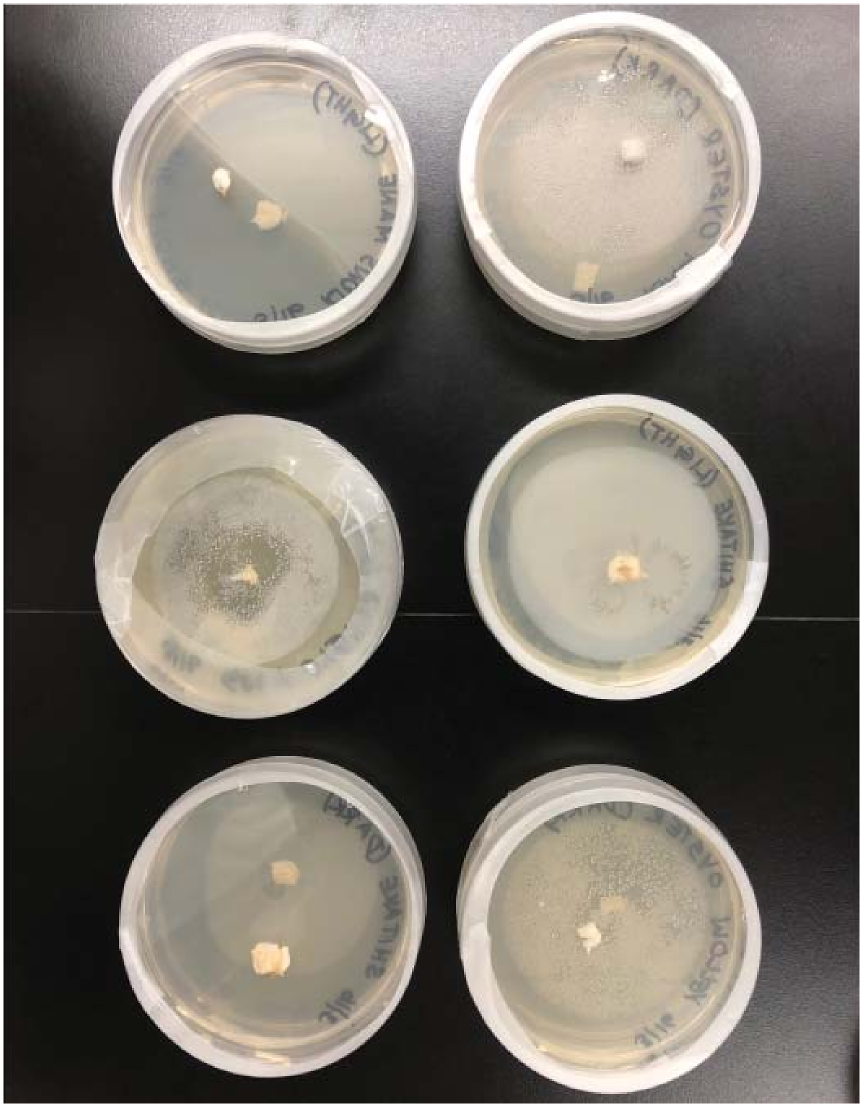
+

STIR

8.12 PREPARING AGAR WITH MUSHROOM SAMPLES

STEP 1A





MUSHROOM SAMPLES

+

BUNSEN BURNER

+

SURGICAL BLADE

+

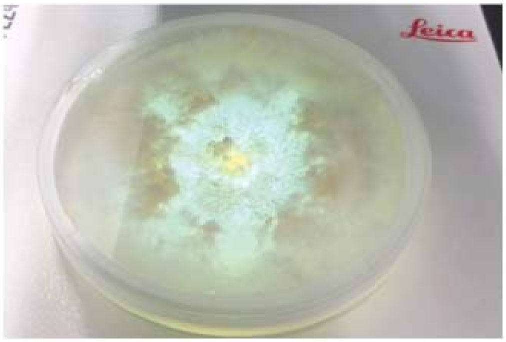
PREPARED AGAR PLATES

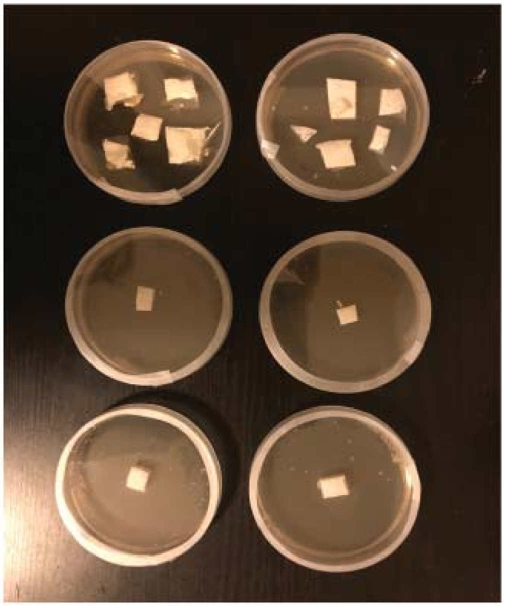
+

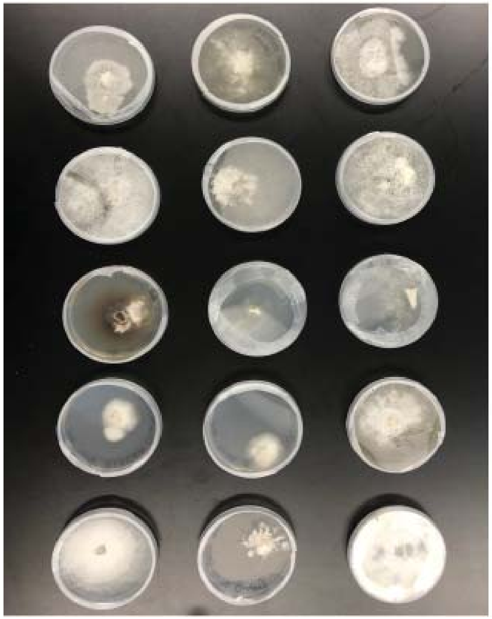
TAPE

8.13 PREPARING AGAR WITH MUSHROOM SAMPLES

STEP 1A







8.14 ADD GRAIN TO SUBSTRATE

STEP 3A

GROWN MUSHROOM PLATES

\+

GRAIN

\+

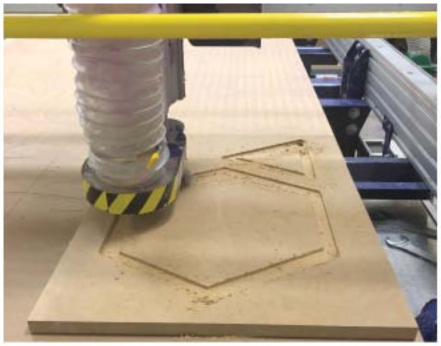
PLASTIC BAGS WITH AERATION PATCH

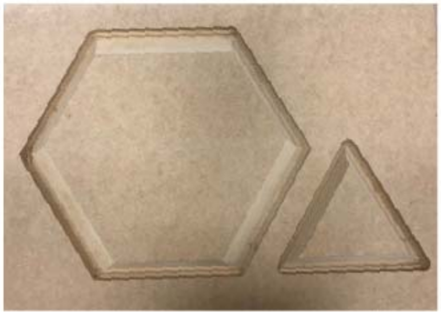
\+

MASON JARS

8.21 CNC AND VACUUM FORMING

STEP 4B





MAKE FORM

+

ADD PREPARED
MYCELIUM

8.15 GROW IN FORM (MYCELIUM)

STEP 4A

REMOVE FROM FORM

+

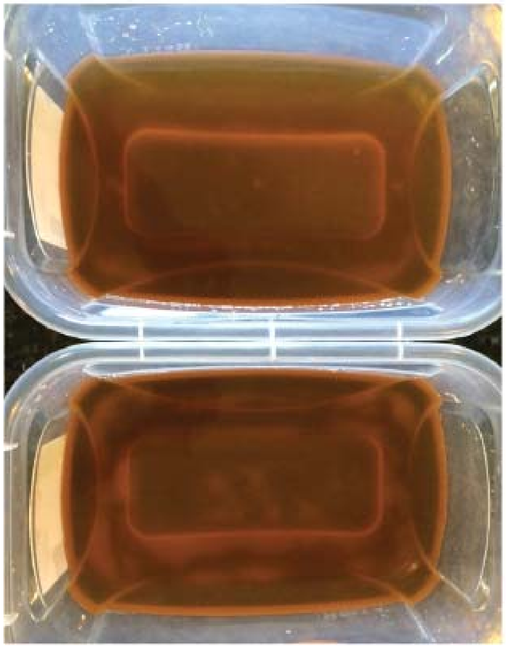
DRY AND BAKE

8.16 DRY AND BAKE

STEP 5A

8.17 GROW IN FORM (CELLULOSE)

STEP 4A



PLASTIC/GLASS CONTAINER

+

WATER

+

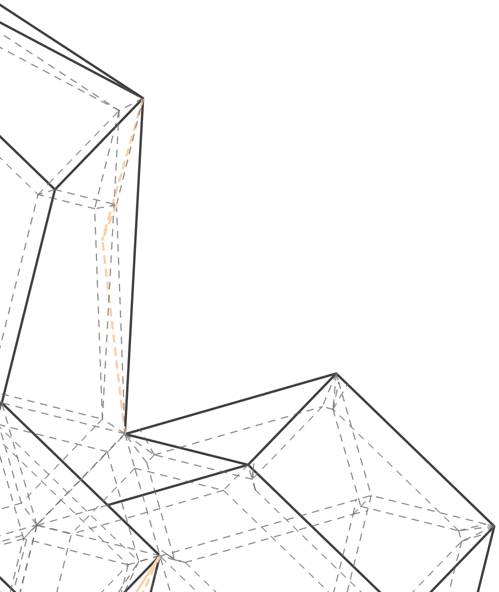
ORGANIC BLACK TEA

+

SUGAR

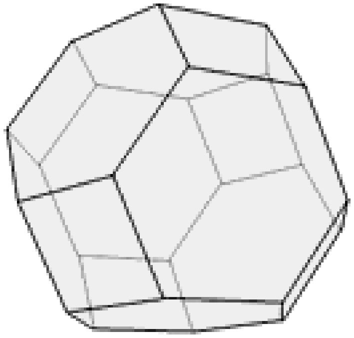
+

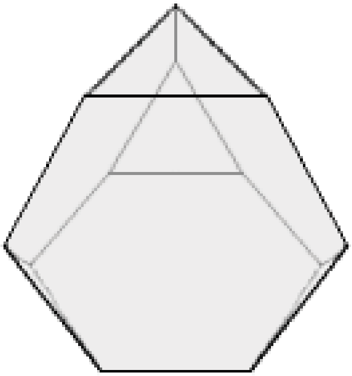
SCOBY

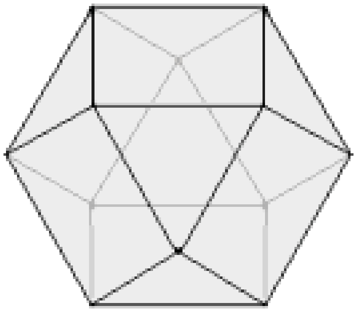


9.0 DESIGN

9.1 COMPONENTS USED







The hexogonal face of the truncated octahedron matches the hexogonal face of the truncated tetrahedron.

The triangular face of the truncated tetrahedron matches the triangular face of the cubeoctahedron.

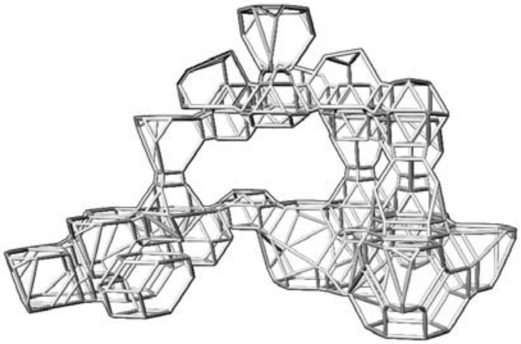
the square face of the cubeoctahedron matches the square face of the truncated octahedron.

TRUNCATED OCTAHEDRON

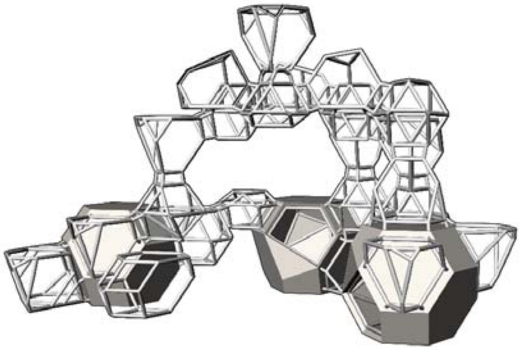
TRUNCATED TETRAHEDRON

CUBEOCTAHEDRON

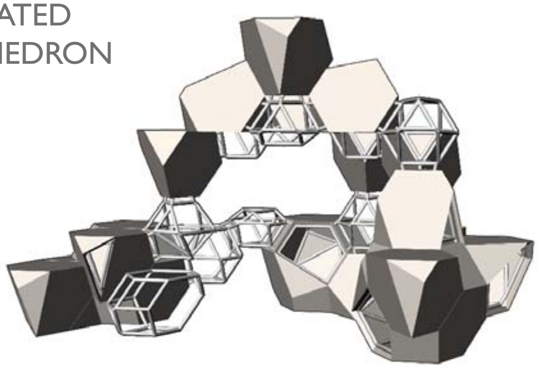
ALUMINUM
FRAME



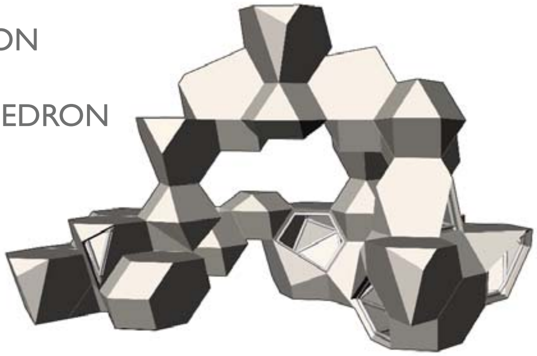
ALUMINUM
FRAME
+
TRUNCATED
OCTAHEDRON



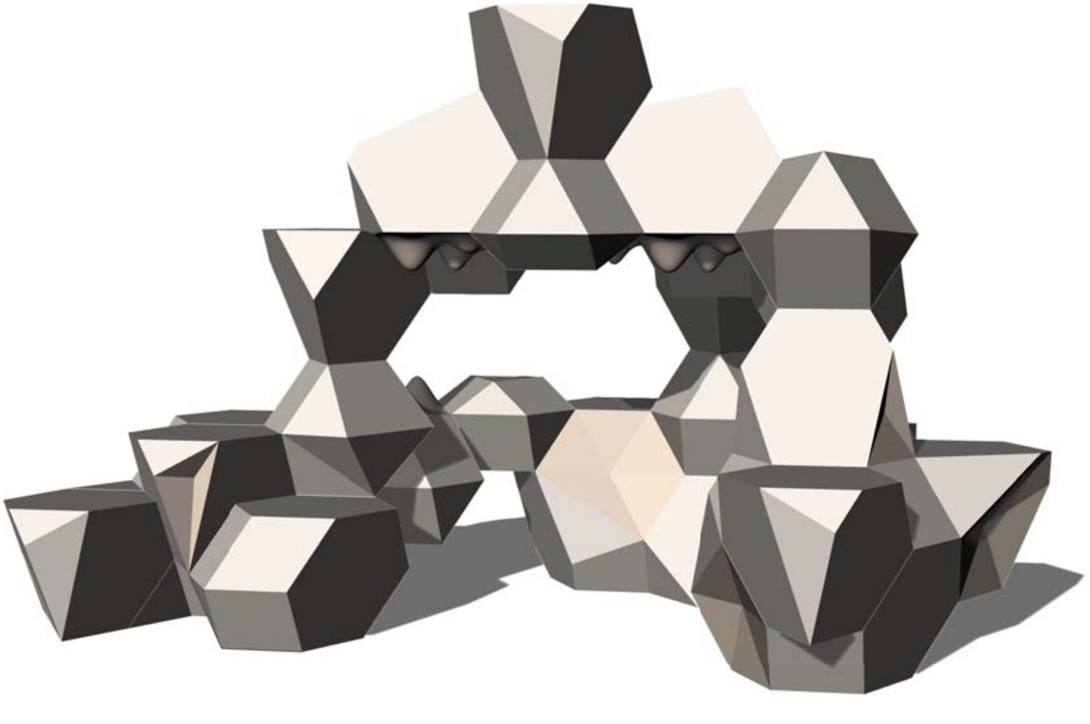
ALUMINUM
FRAME
+
TRUNCATED
OCTAHEDRON
+
TRUNCATED
TETRAHEDRON



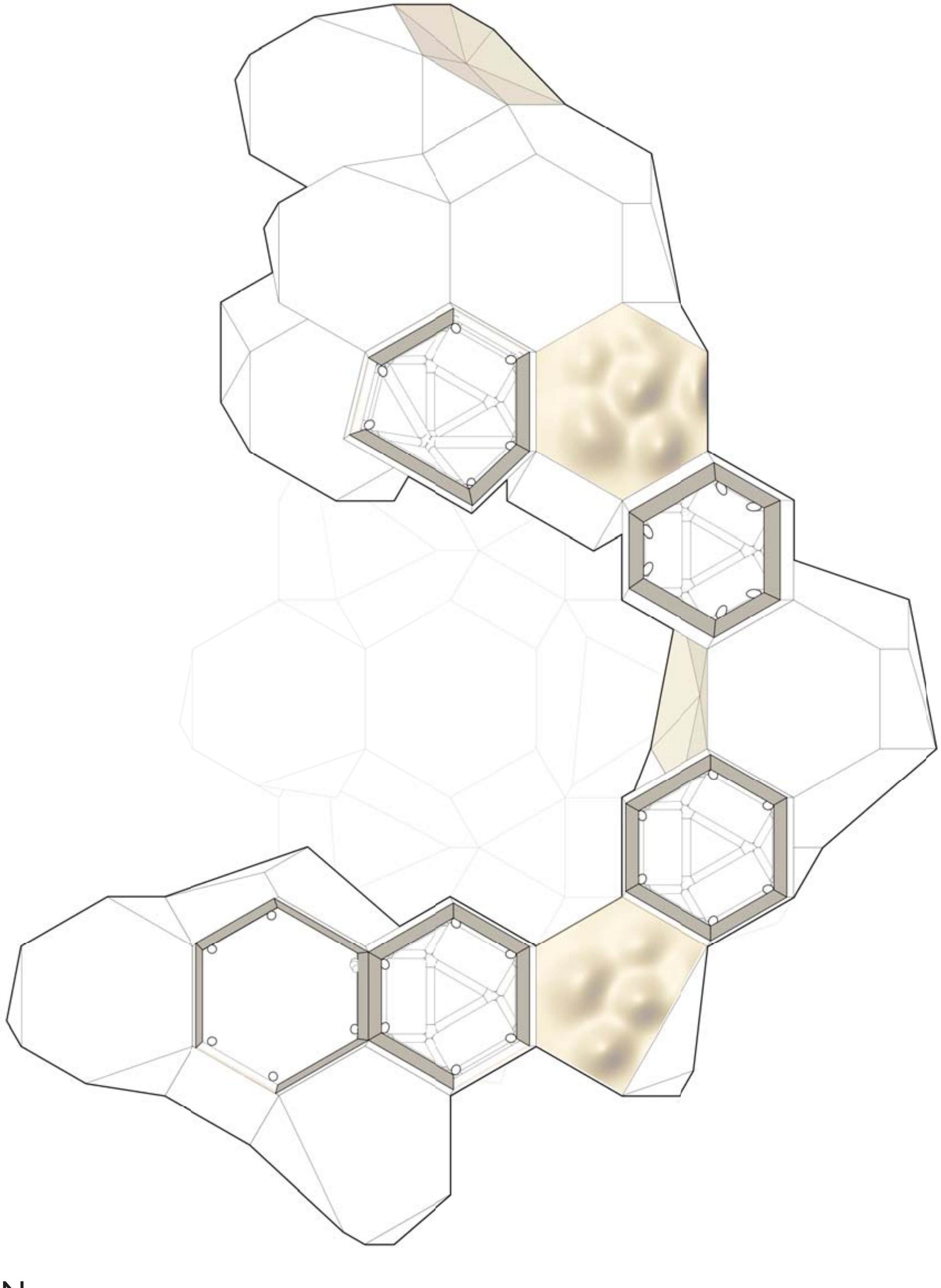
ALUMINUM
FRAME
+
TRUNCATED
OCTAHEDRON
+
TRUNCATED
TETRAHEDRON
+
CUBEOCTAHEDRON



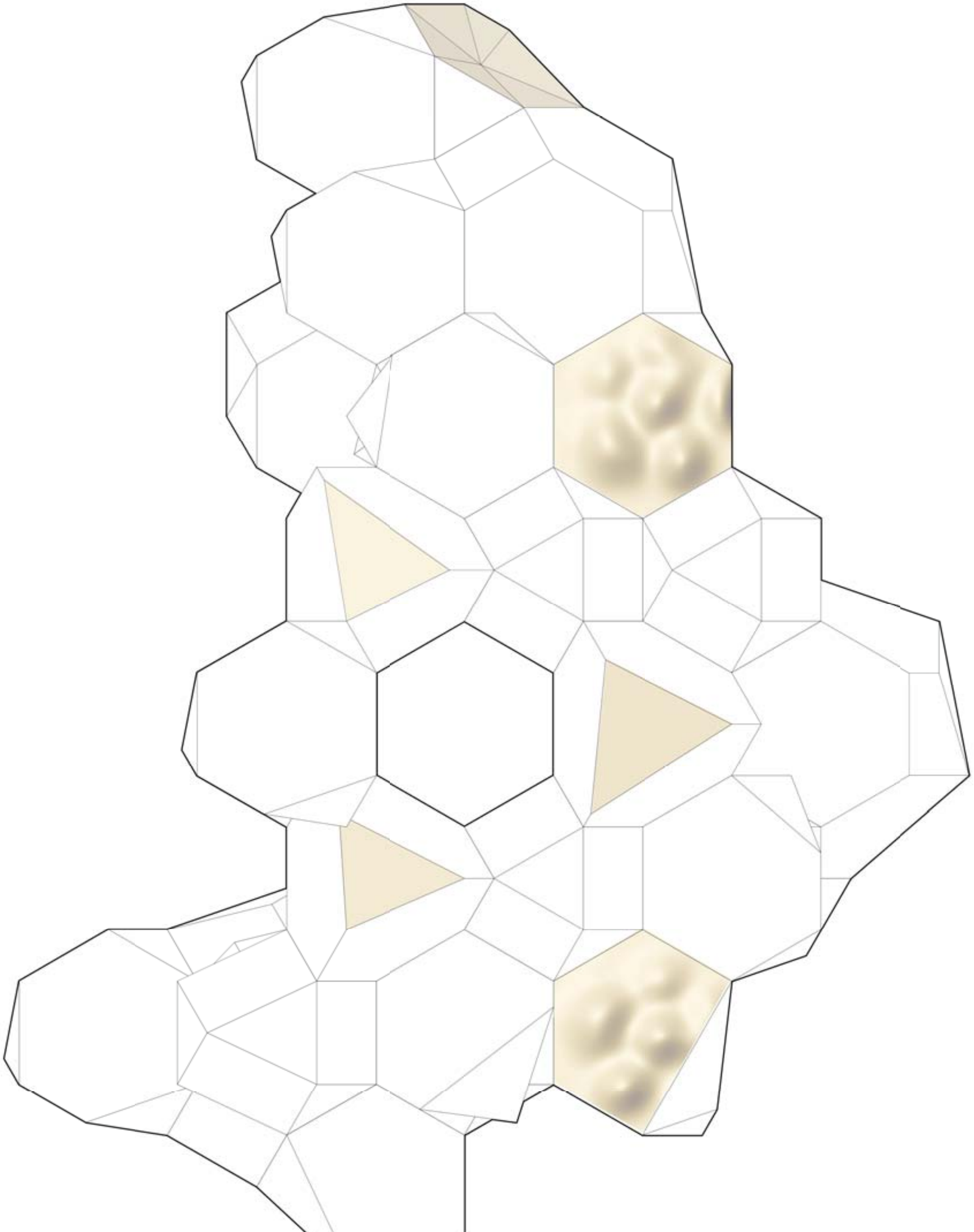
ALUMINUM
FRAME
+
TRUNCATED
OCTAHEDRON
+
TRUNCATED
TETRAHEDRON
+
CUBEOCTAHEDRON
+
MYCELIUM
+
BACTERIAL CELLULOSE



9.2 PLAN

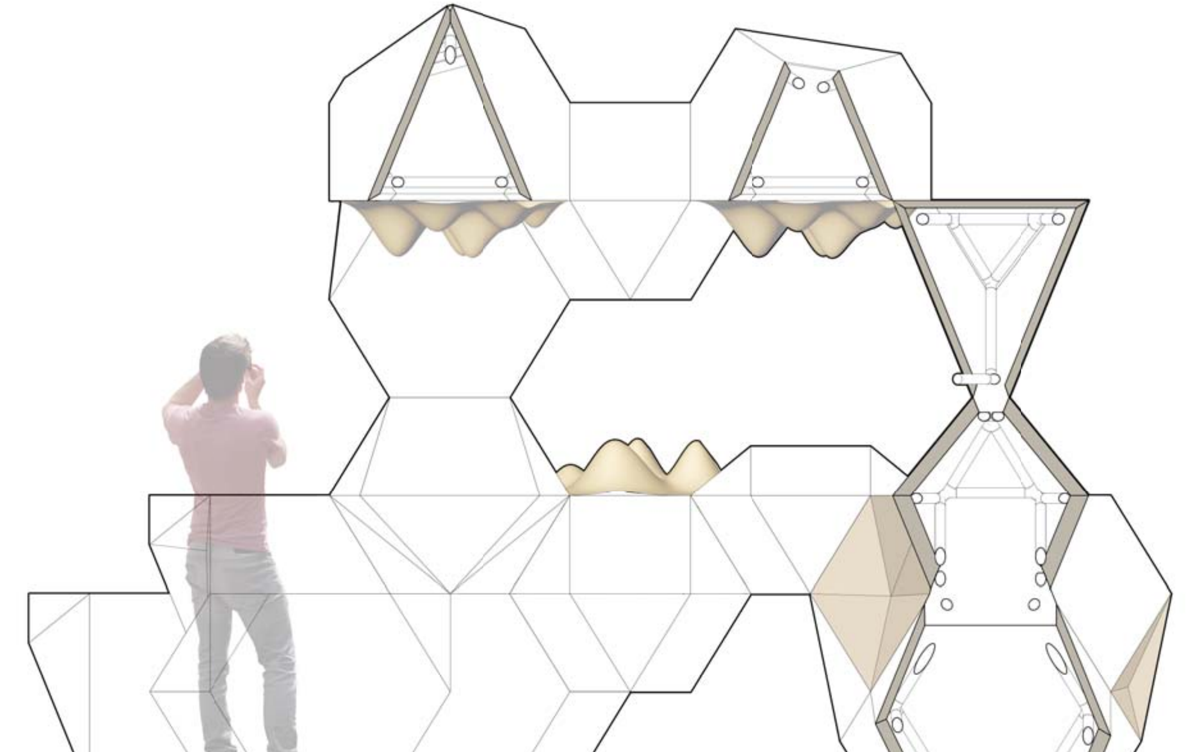


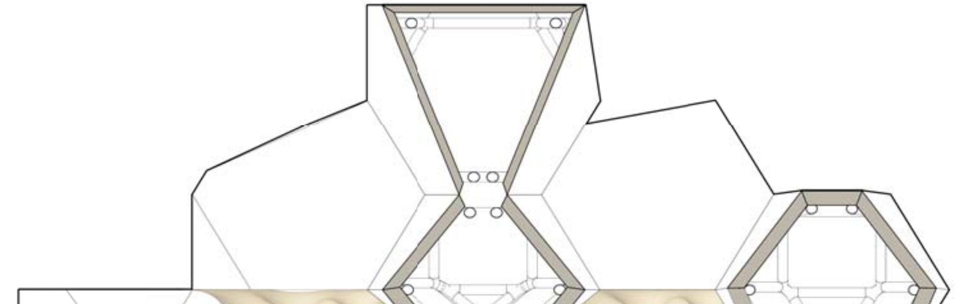
PLAN



TOP VIEW

9.3 SECTIONS





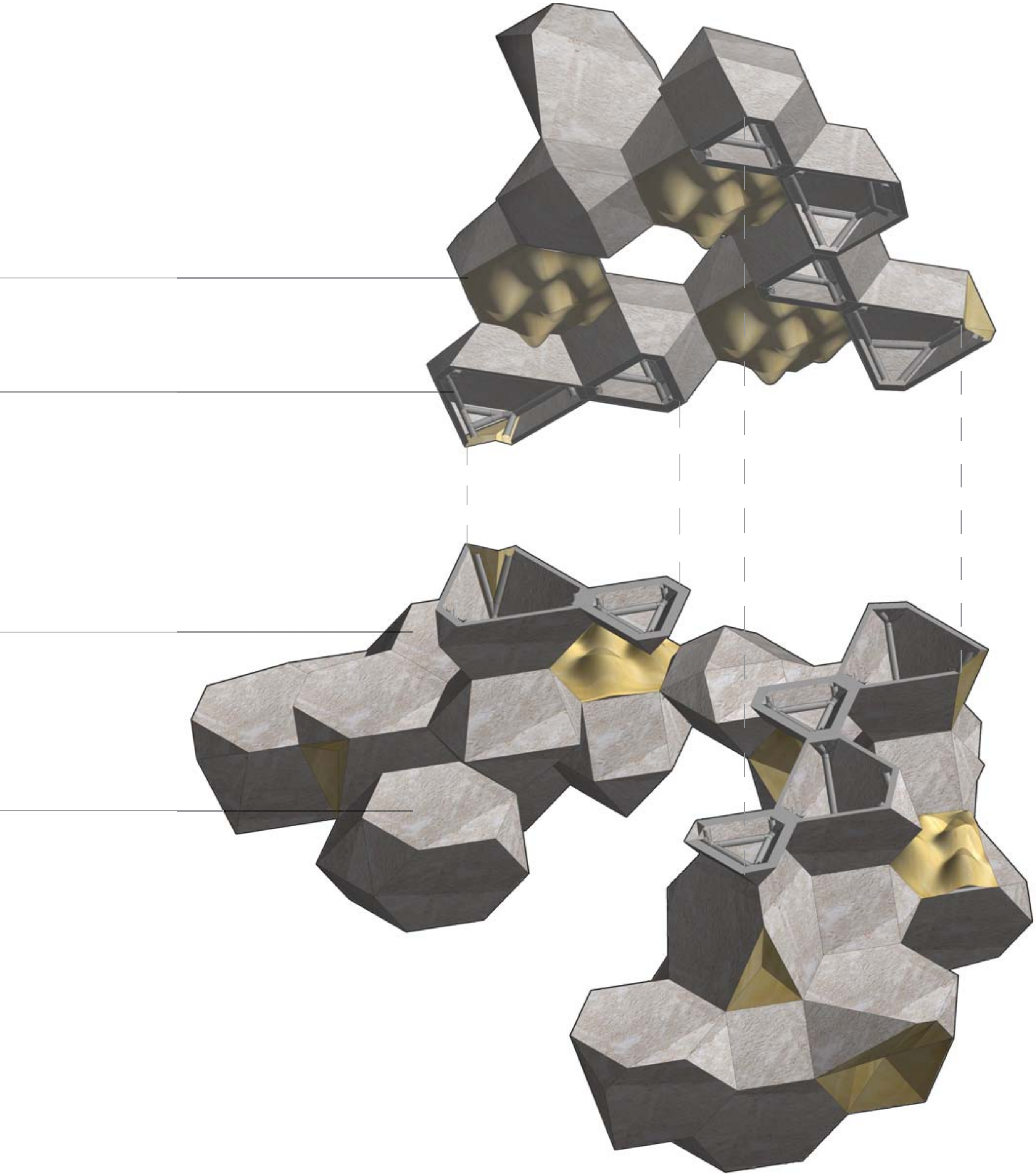
9.4 BLOWN UP AXON

BACTERIAL CELLULOSE
SKYLIGHT

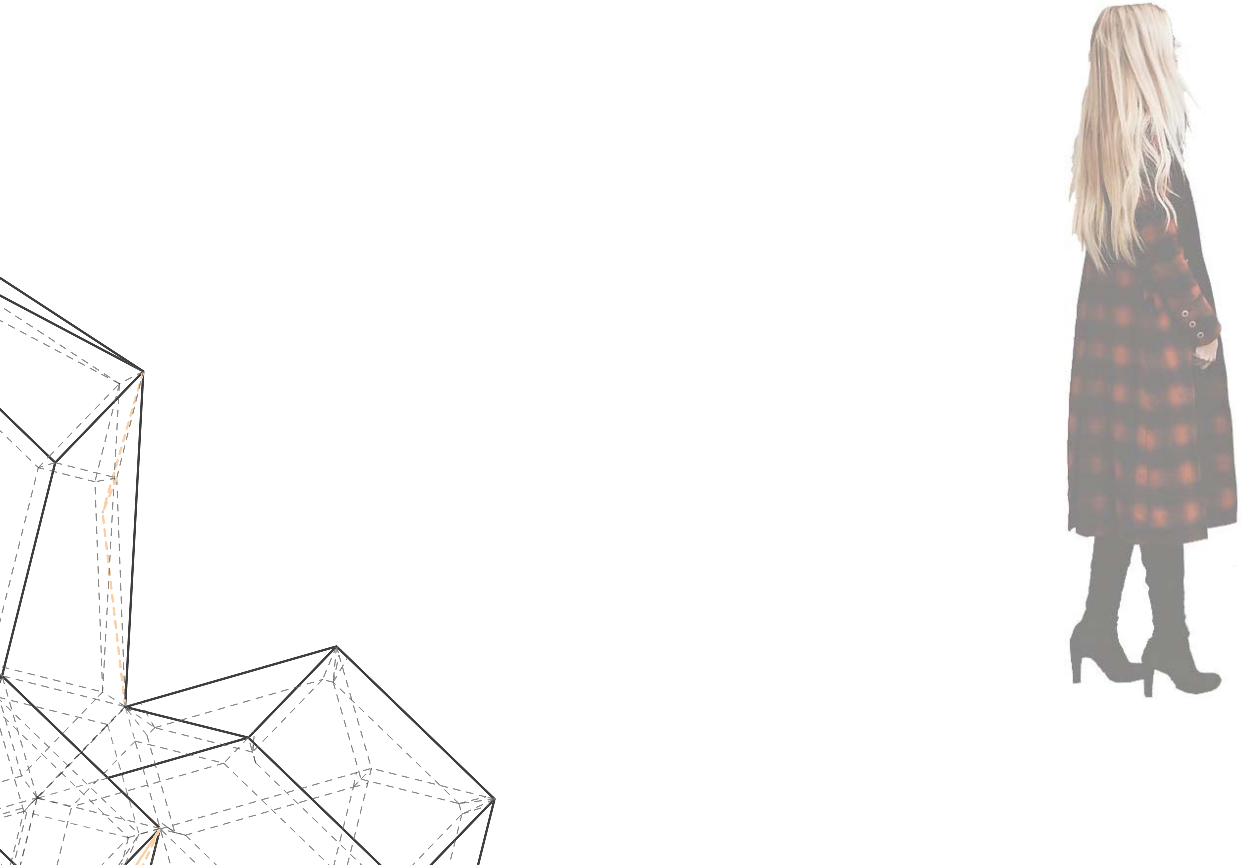
ALUMINUM FRAME
ENCLOSED

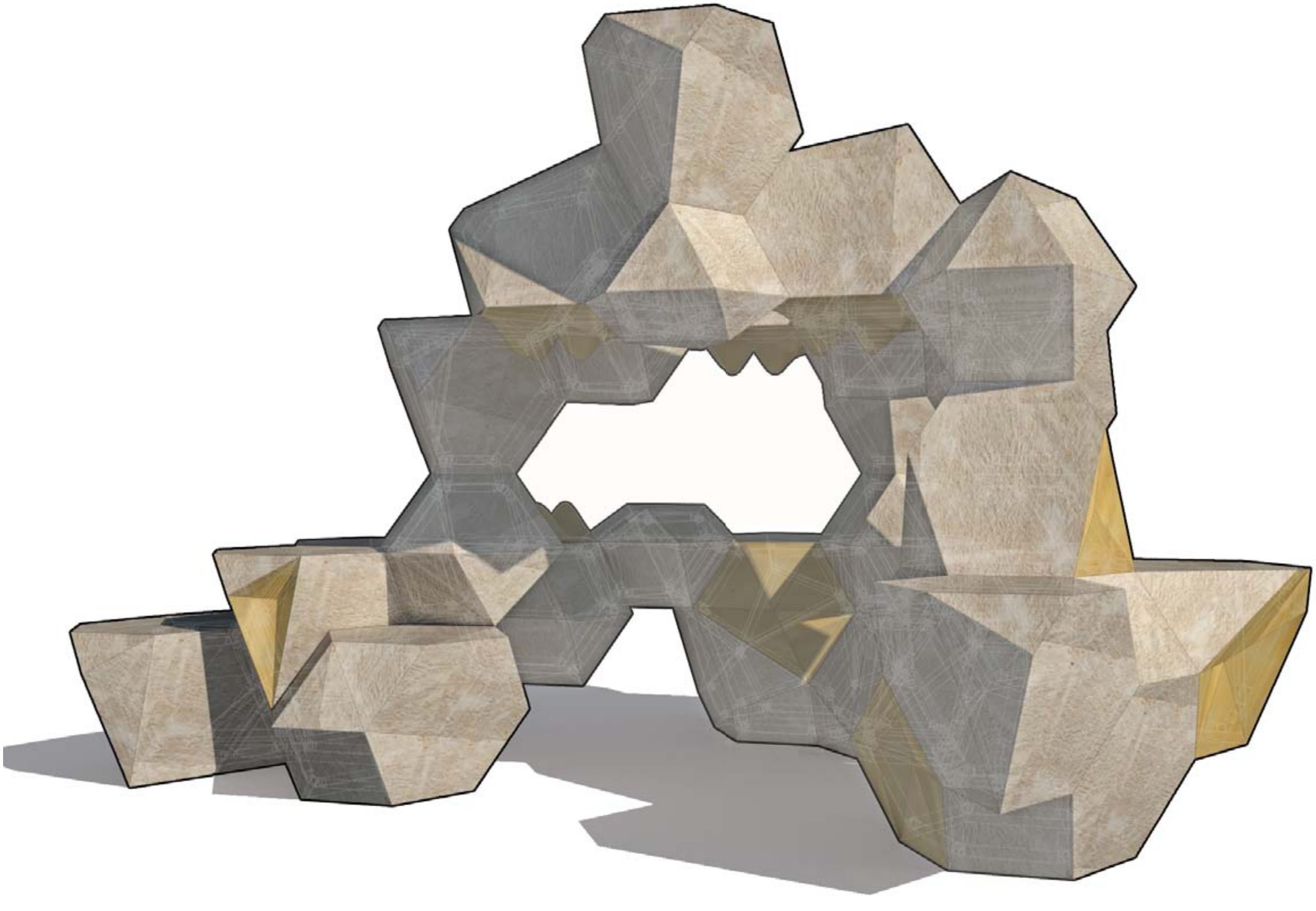
MYCELIUM PANEL AT
BAR HEIGHT (4'-0")

MYCELIUM PANEL AT
COUNTER HEIGHT (3'-0")



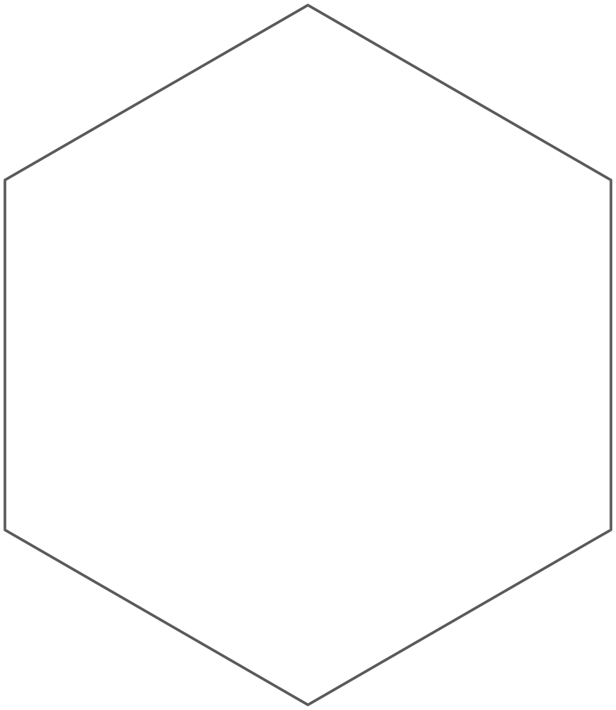
9.5 FRONT VIEW

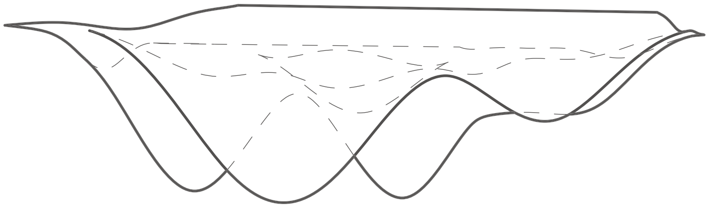


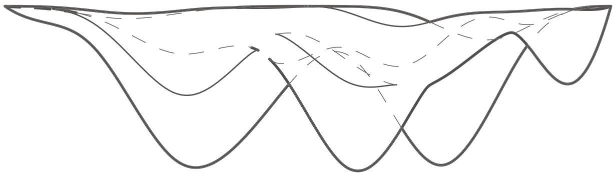


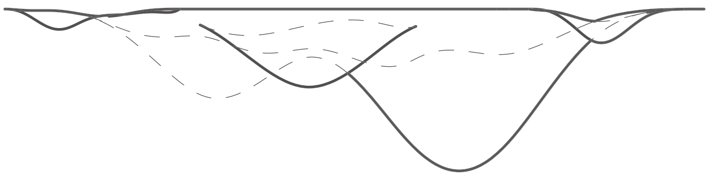
9.61 FORM FOR CELLULOSE

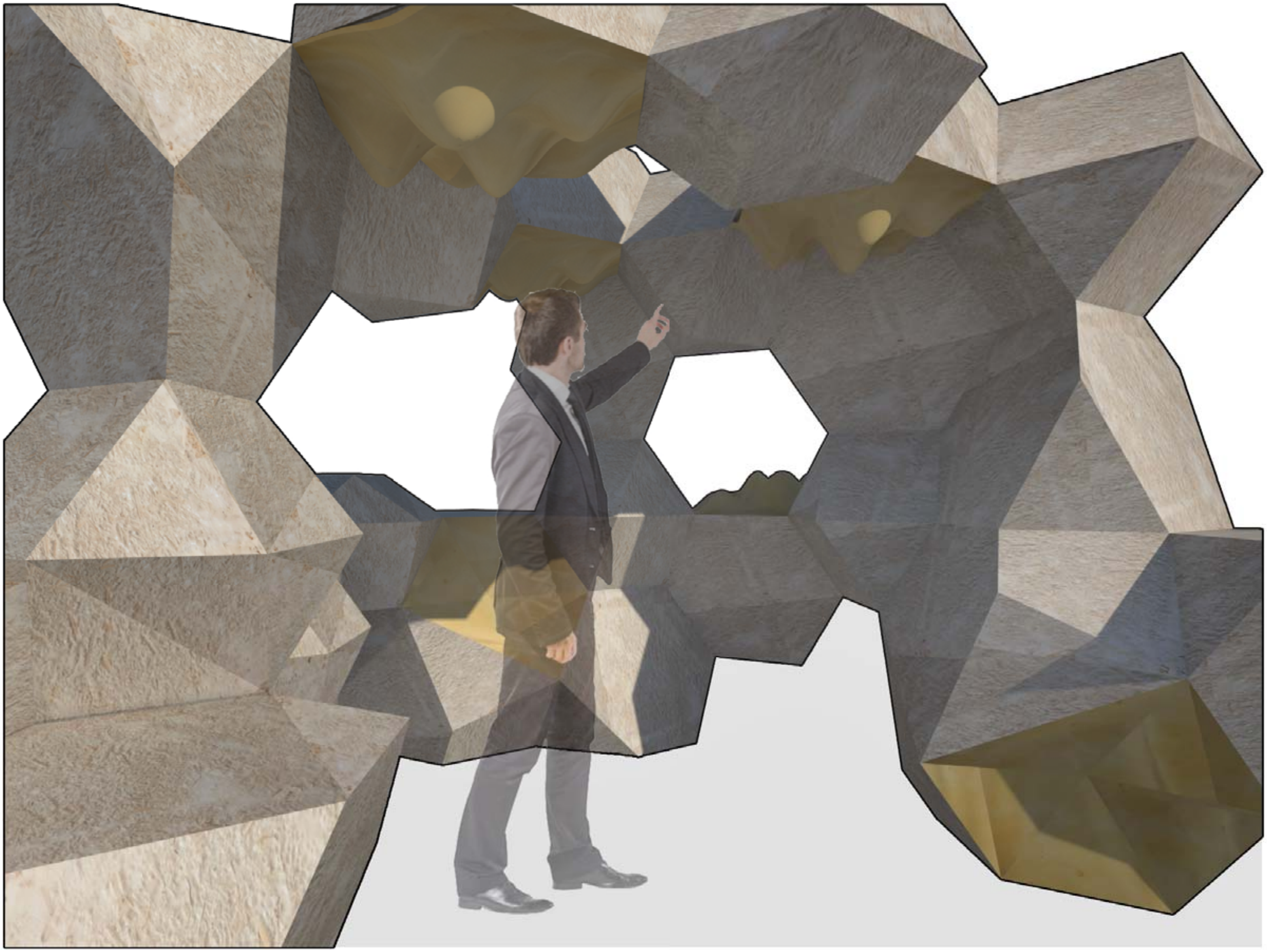
OPTION 1





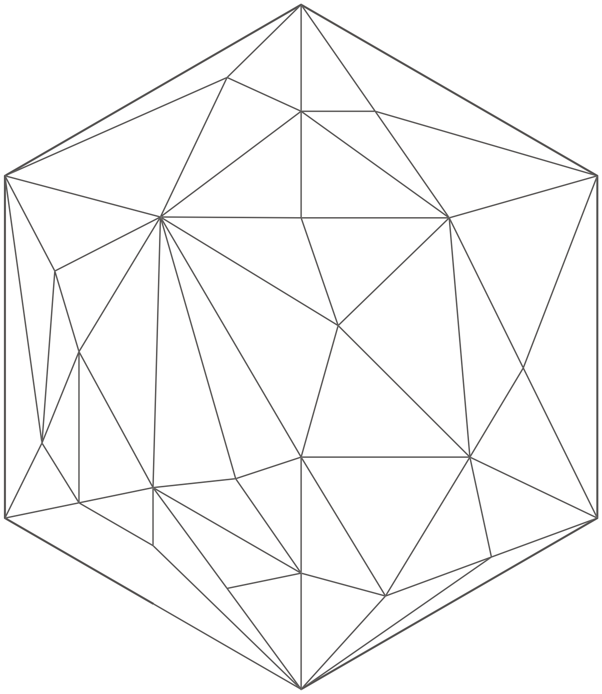


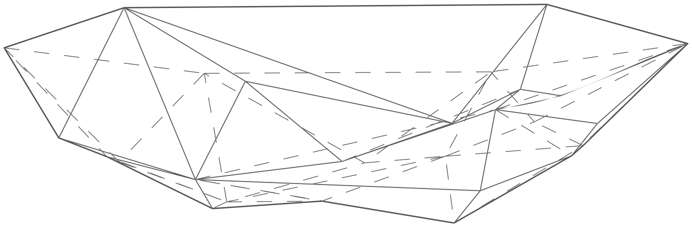


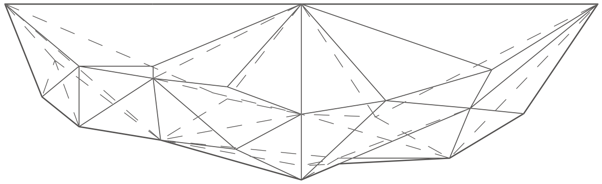


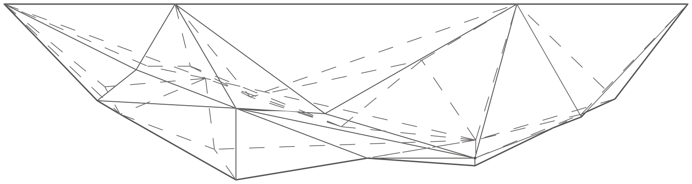
9.62 FORM FOR CELLULOSE

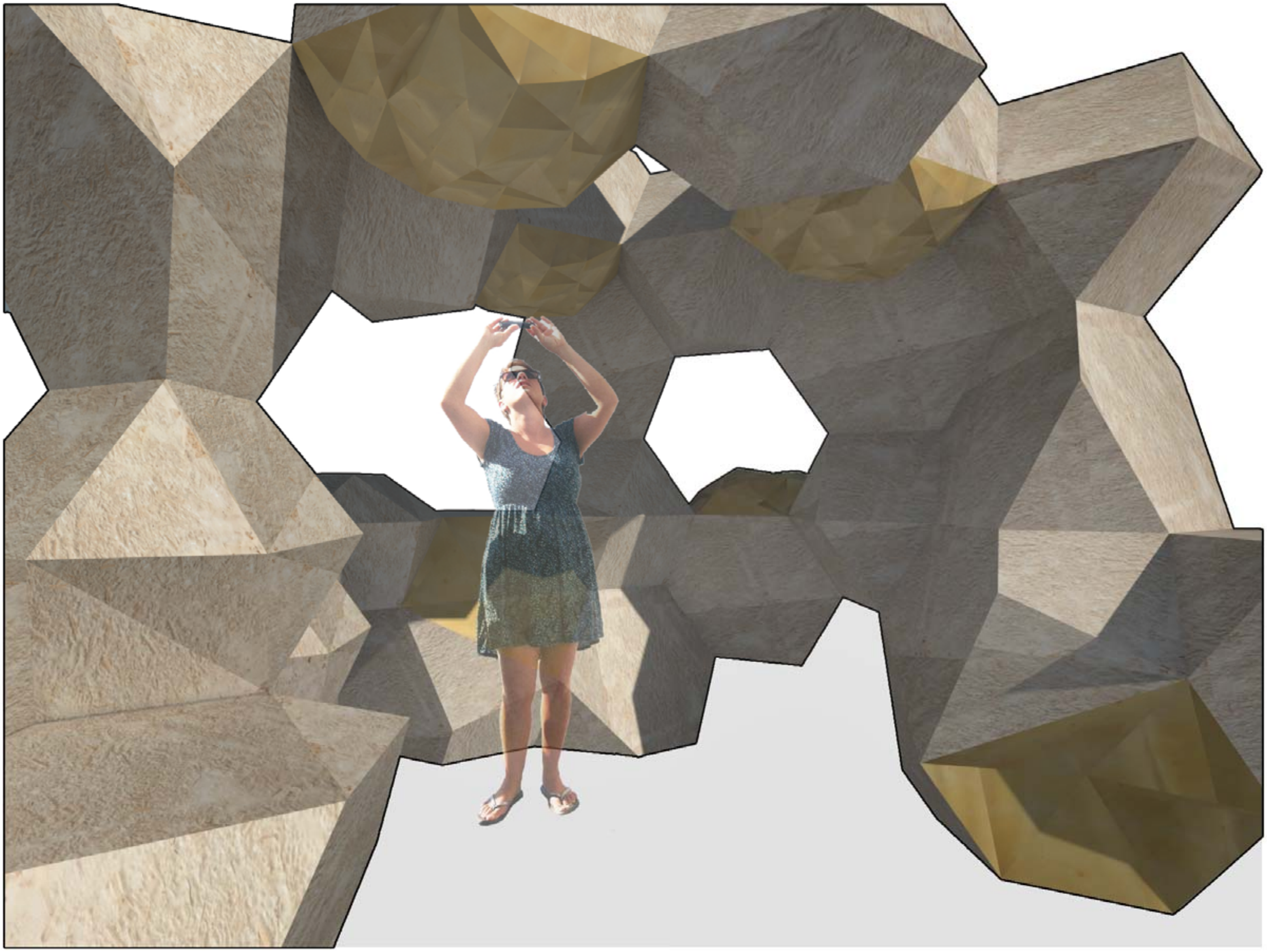
OPTION 2





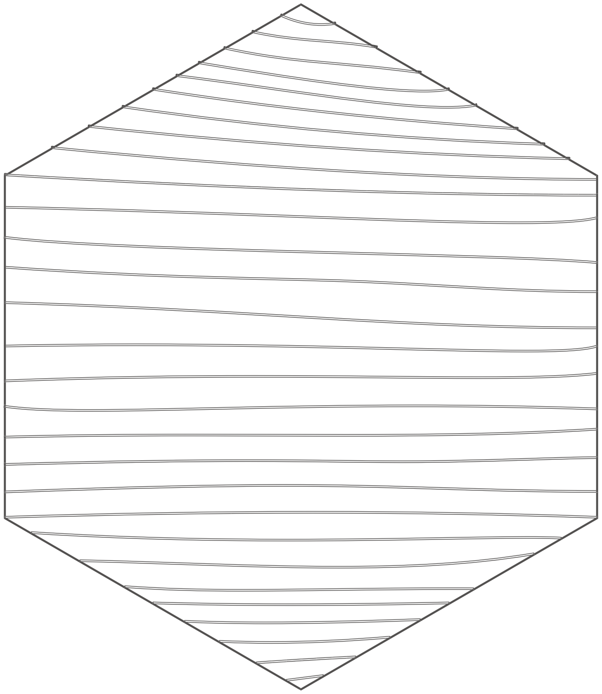


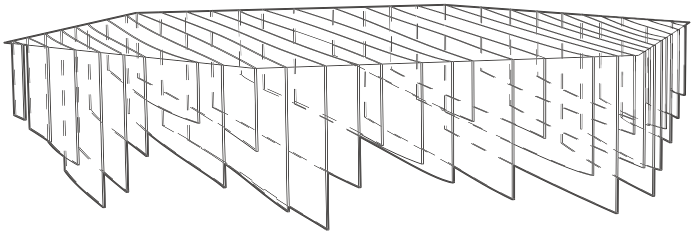


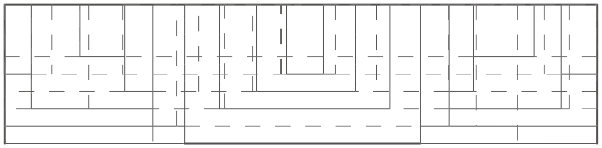


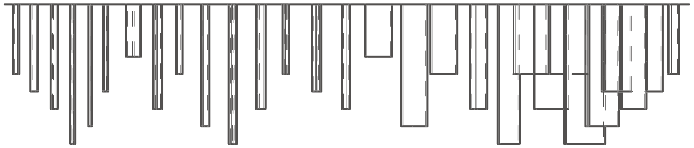
9.63 FORM FOR CELLULOSE

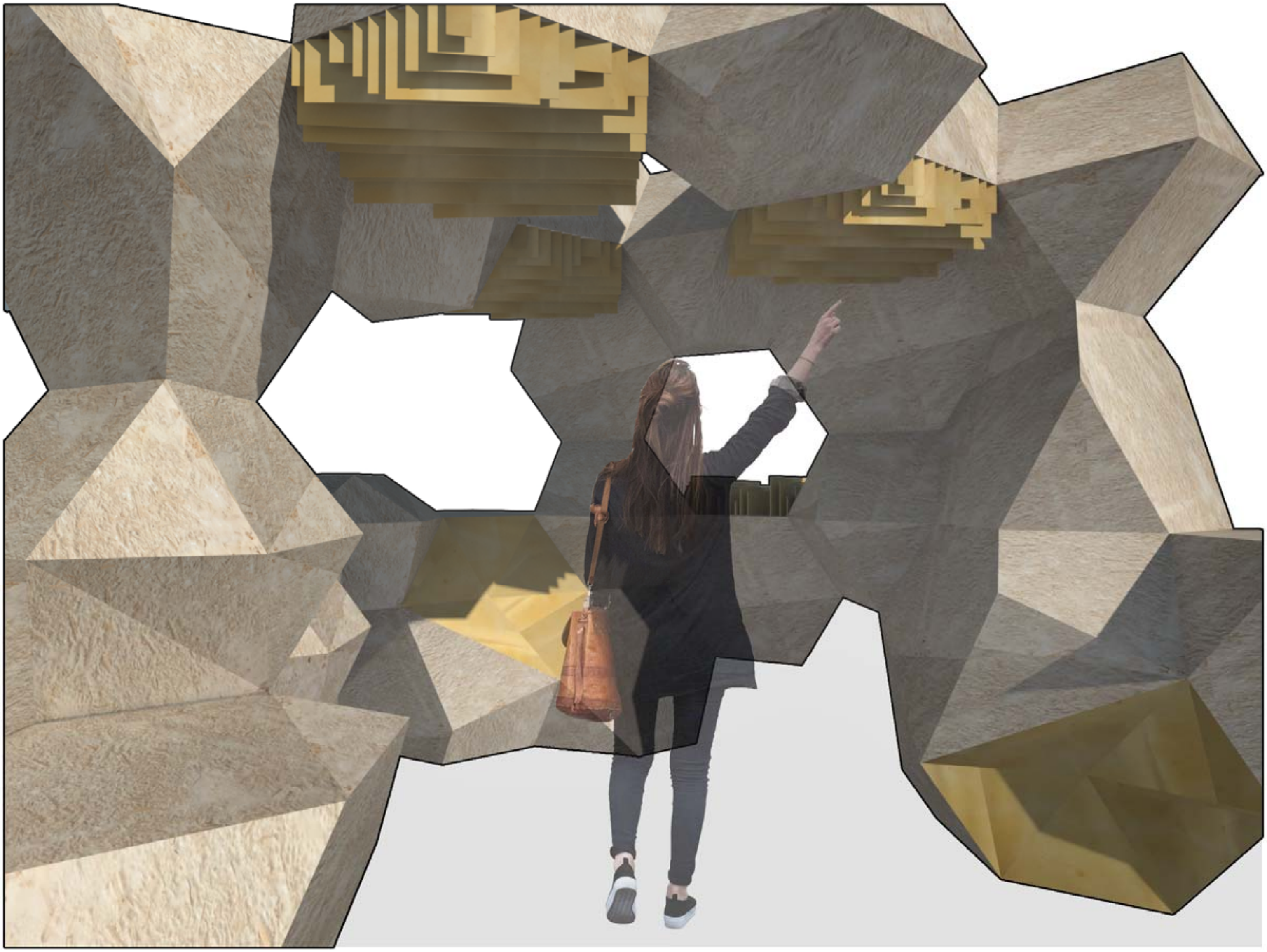
OPTION 3



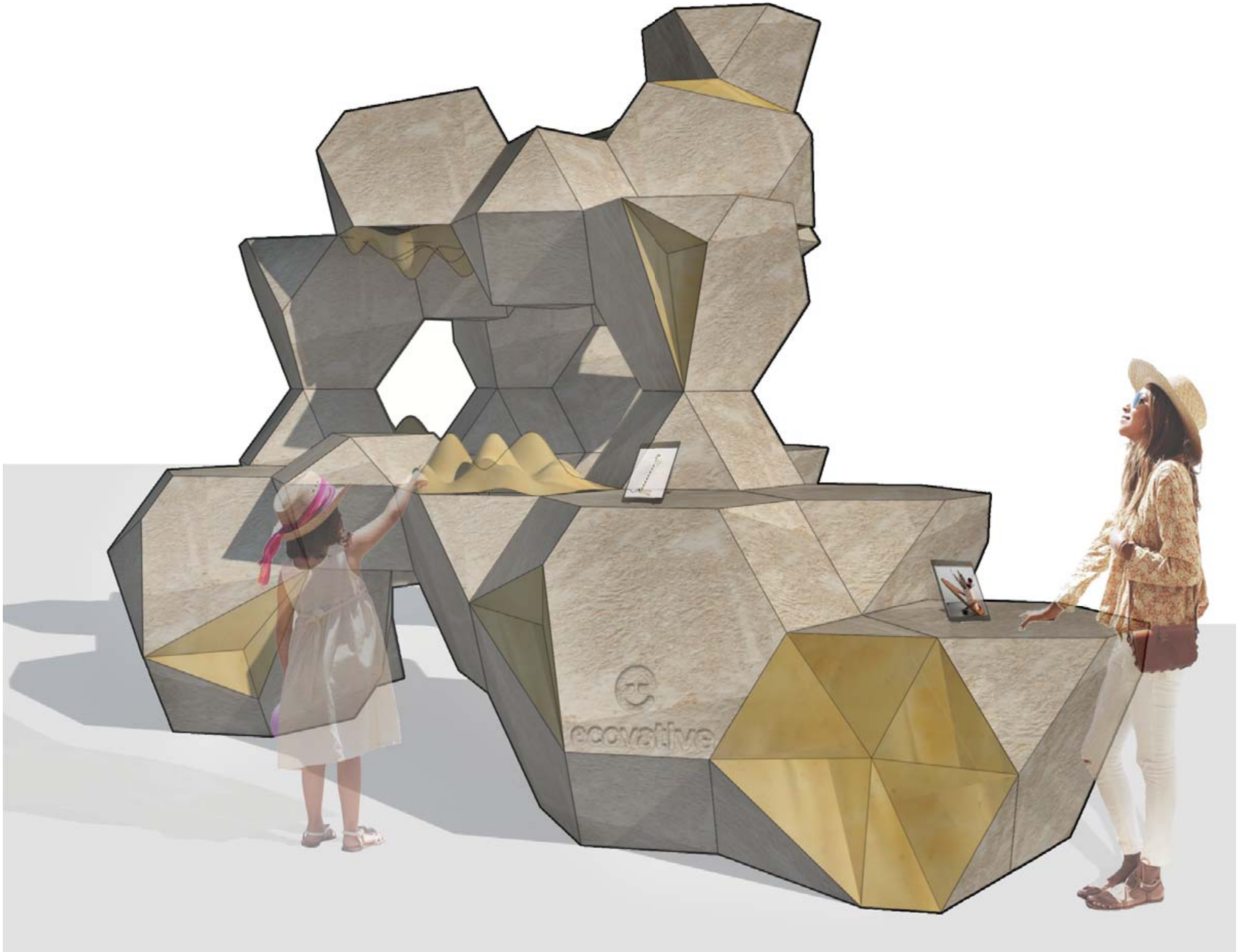




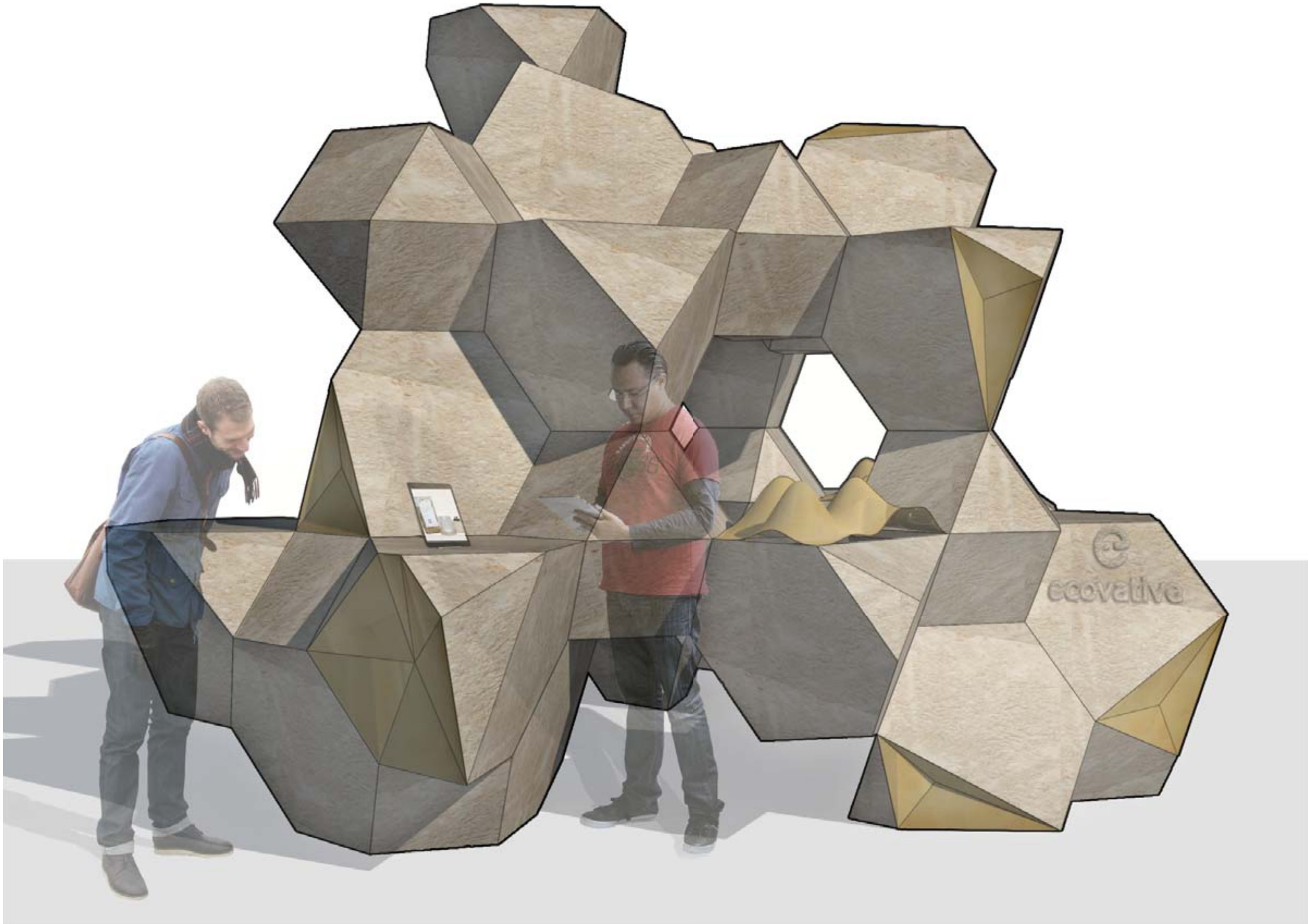




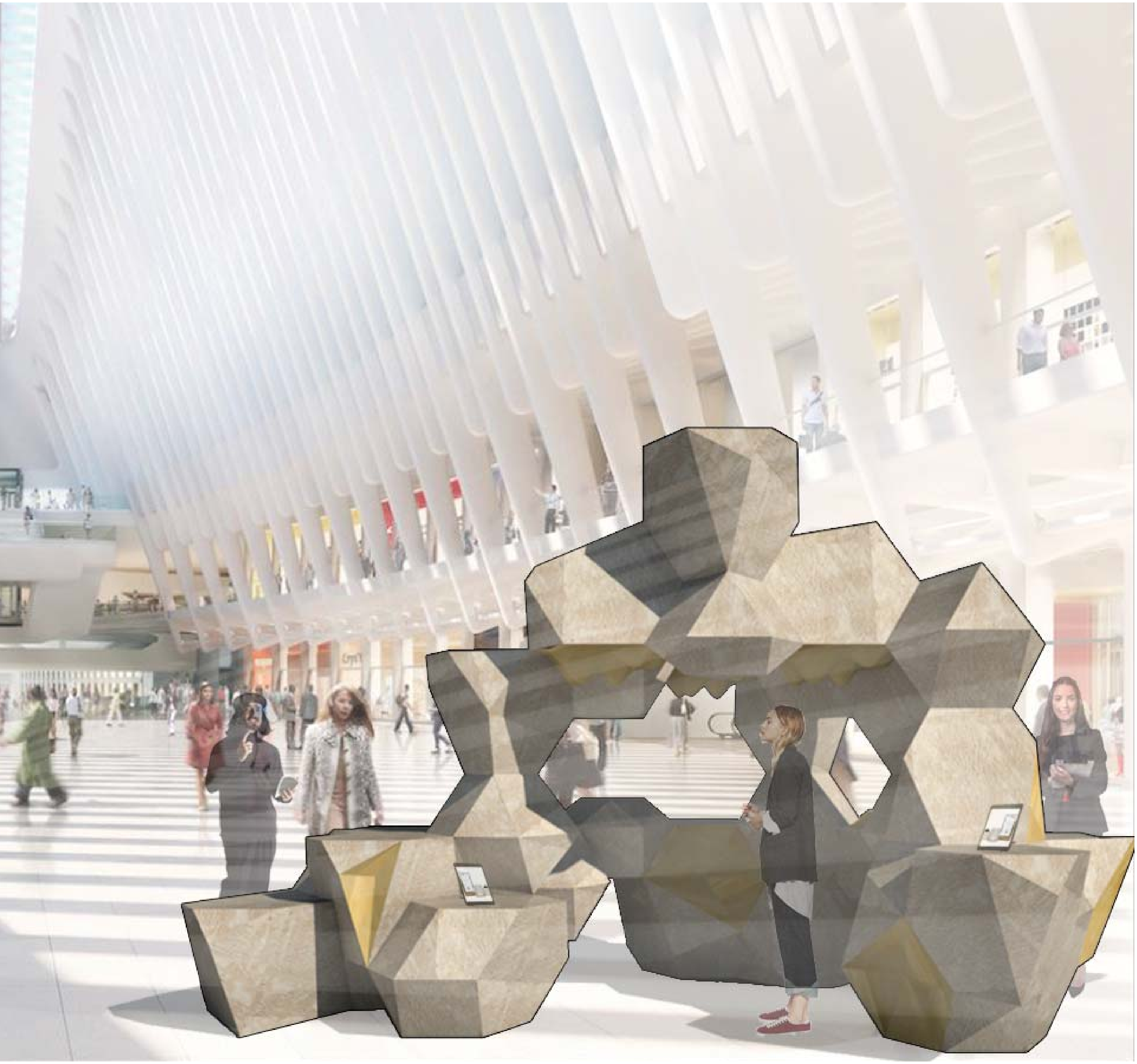
9.71 PERSPECTIVE 1


ecovative

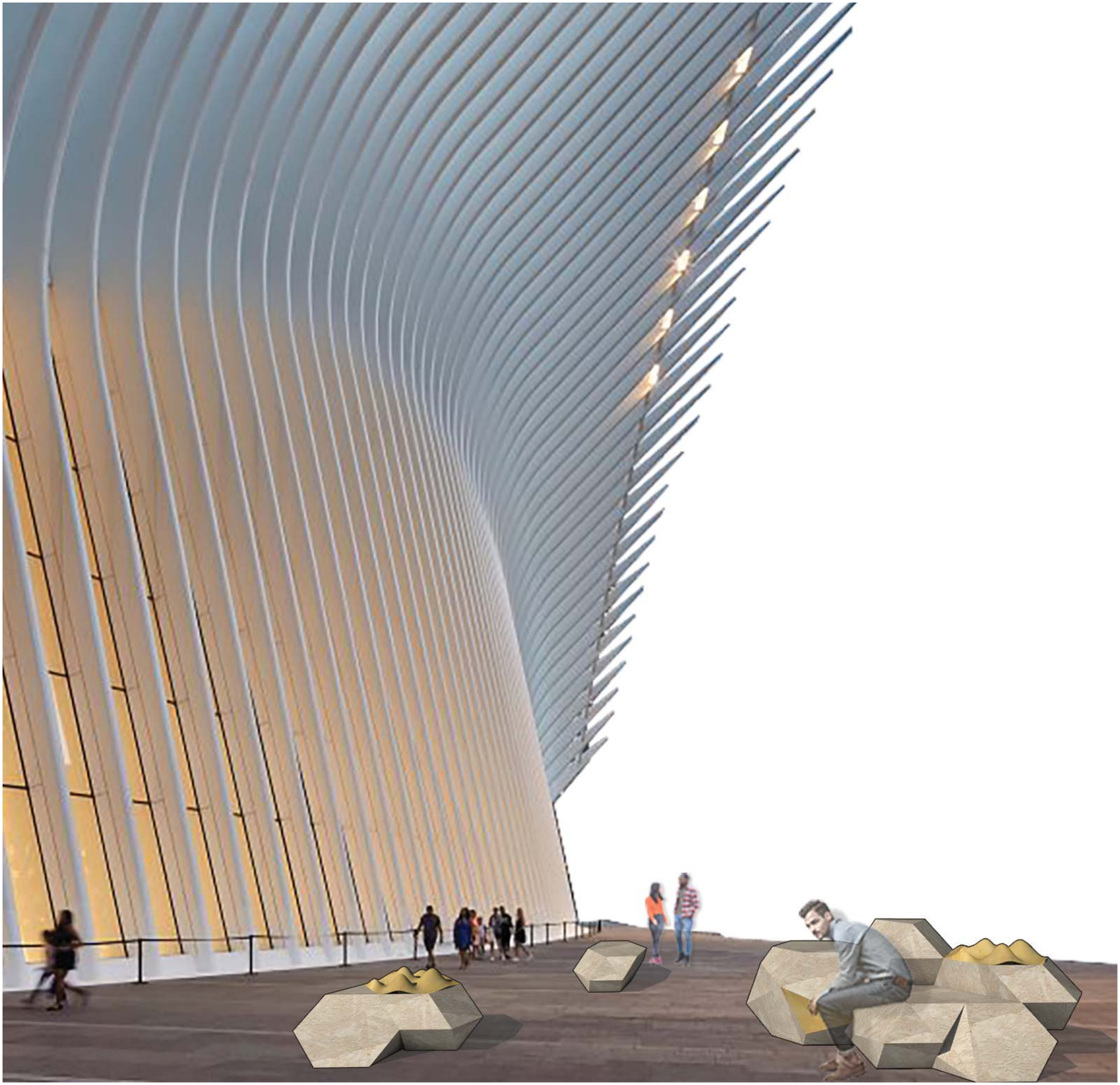
9.72 PERSPECTIVE 2

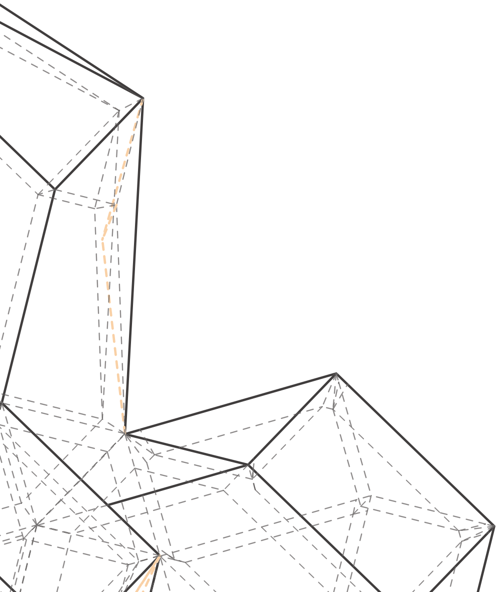

ecovative

9.8 PERSPECTIVE OF THE STRUCTURE PLACED IN SITE INDOOR



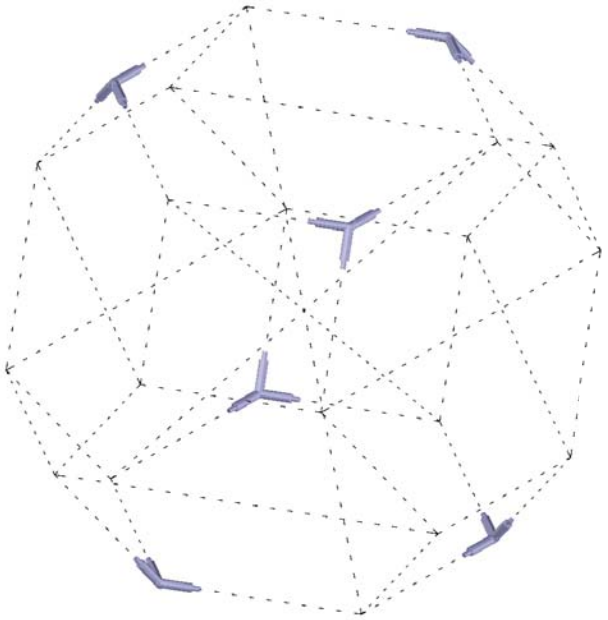
9.9 PERSPECTIVE OF THE STRUCTURE PLACED IN SITE OUTDOORS

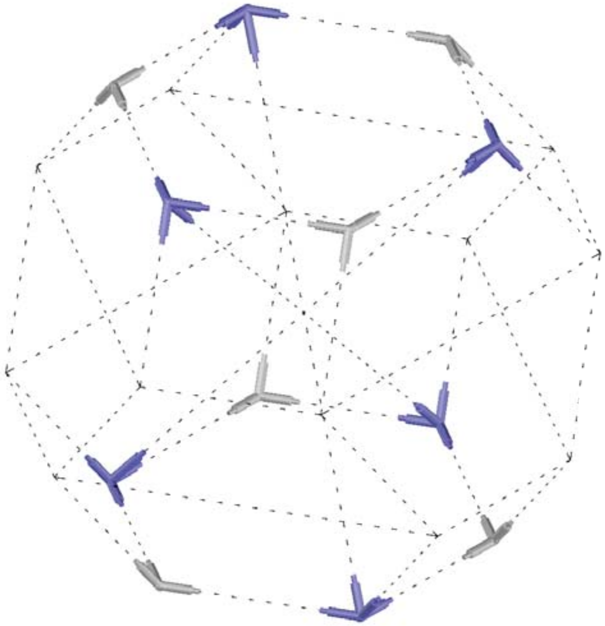




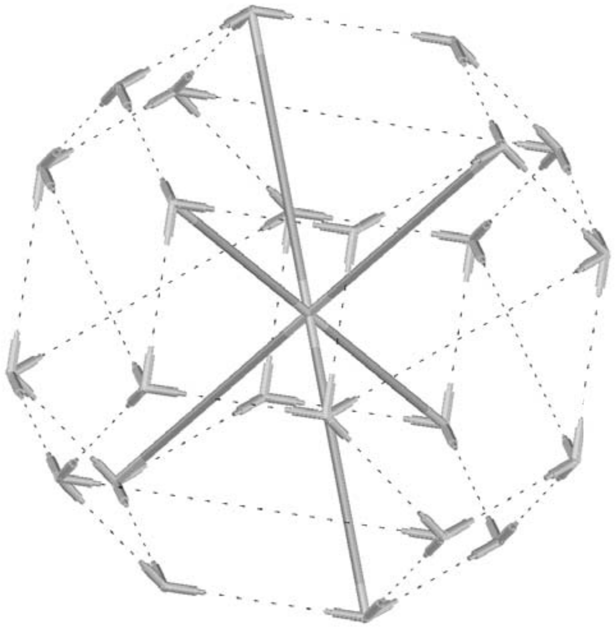
10.0 FLAT PACKING SYSTEM

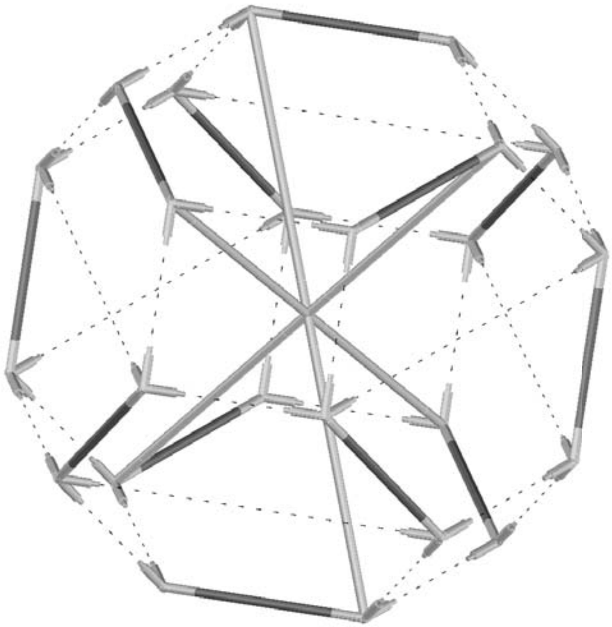
10.1 TRUNCATED OCTAHEDRON



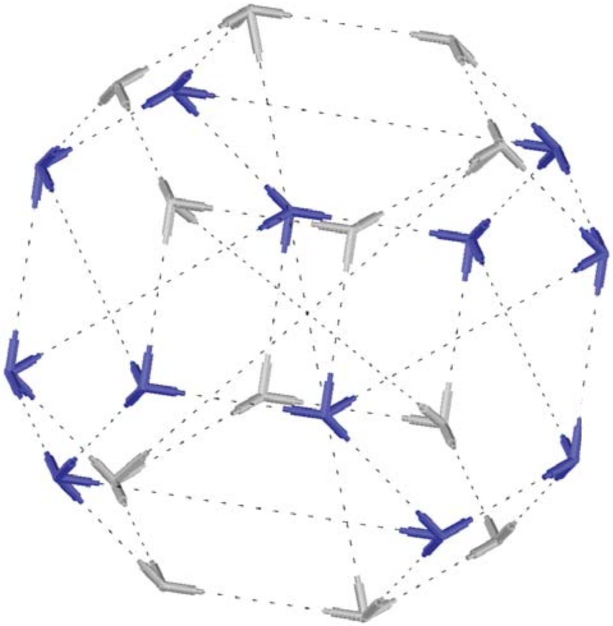


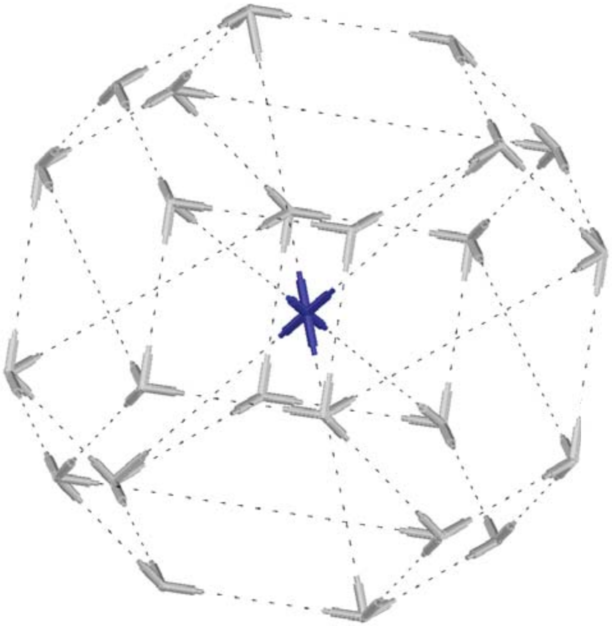
NODES

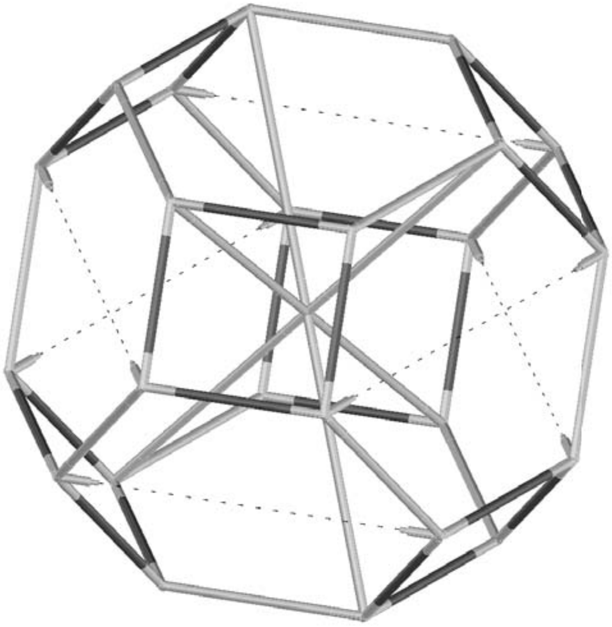


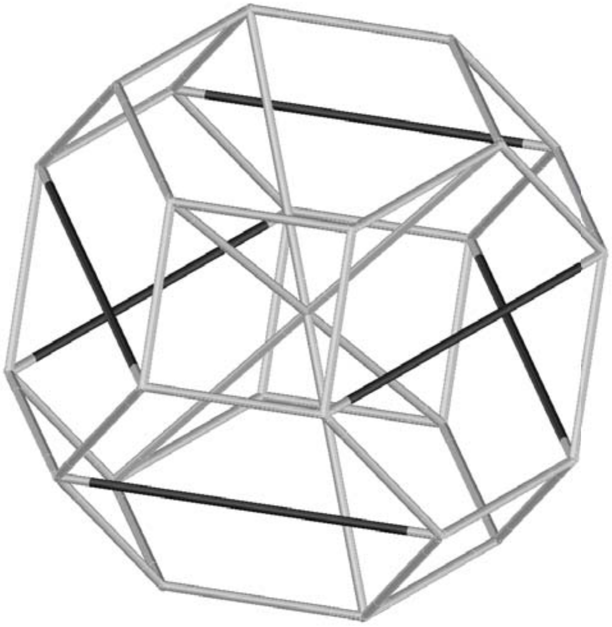


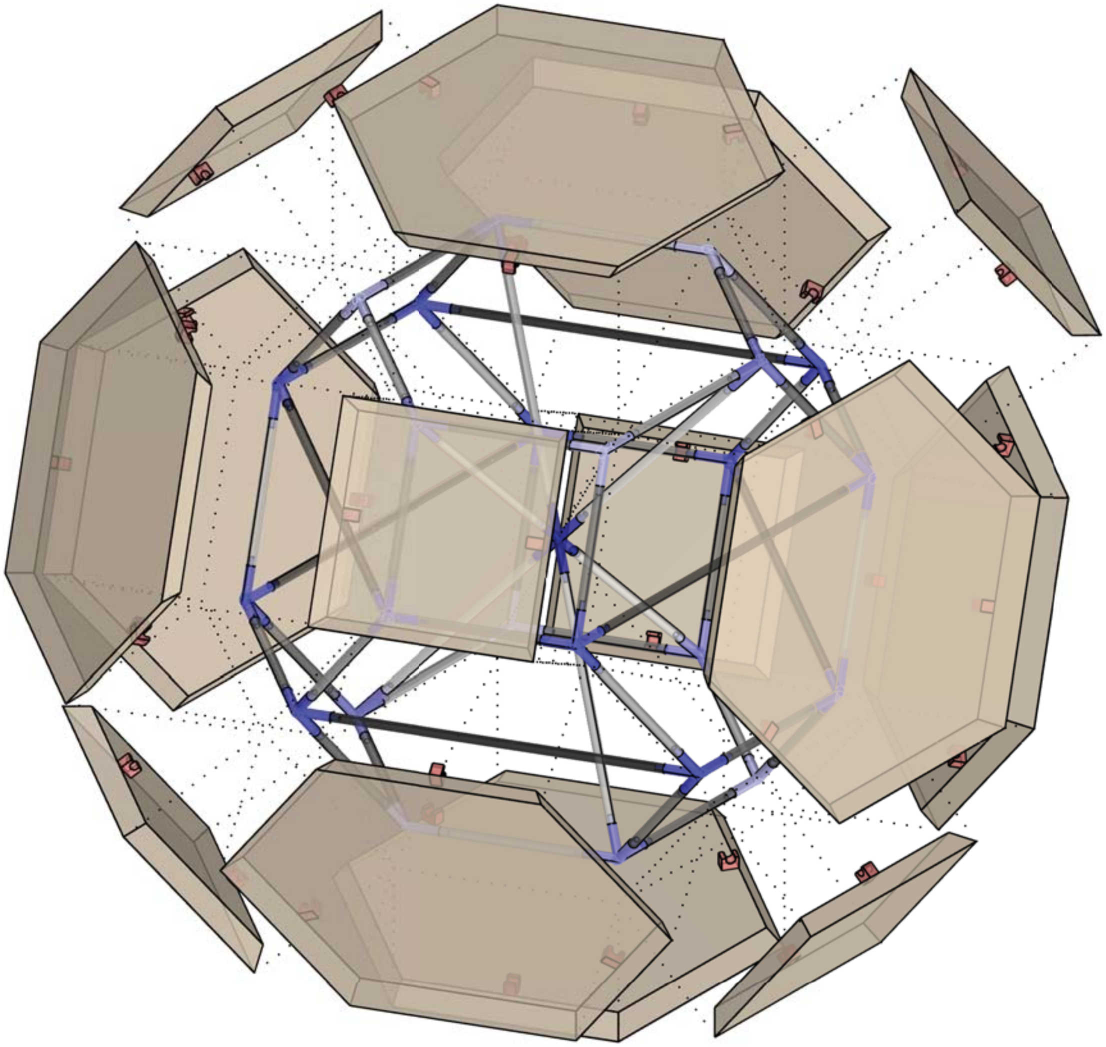
RODS

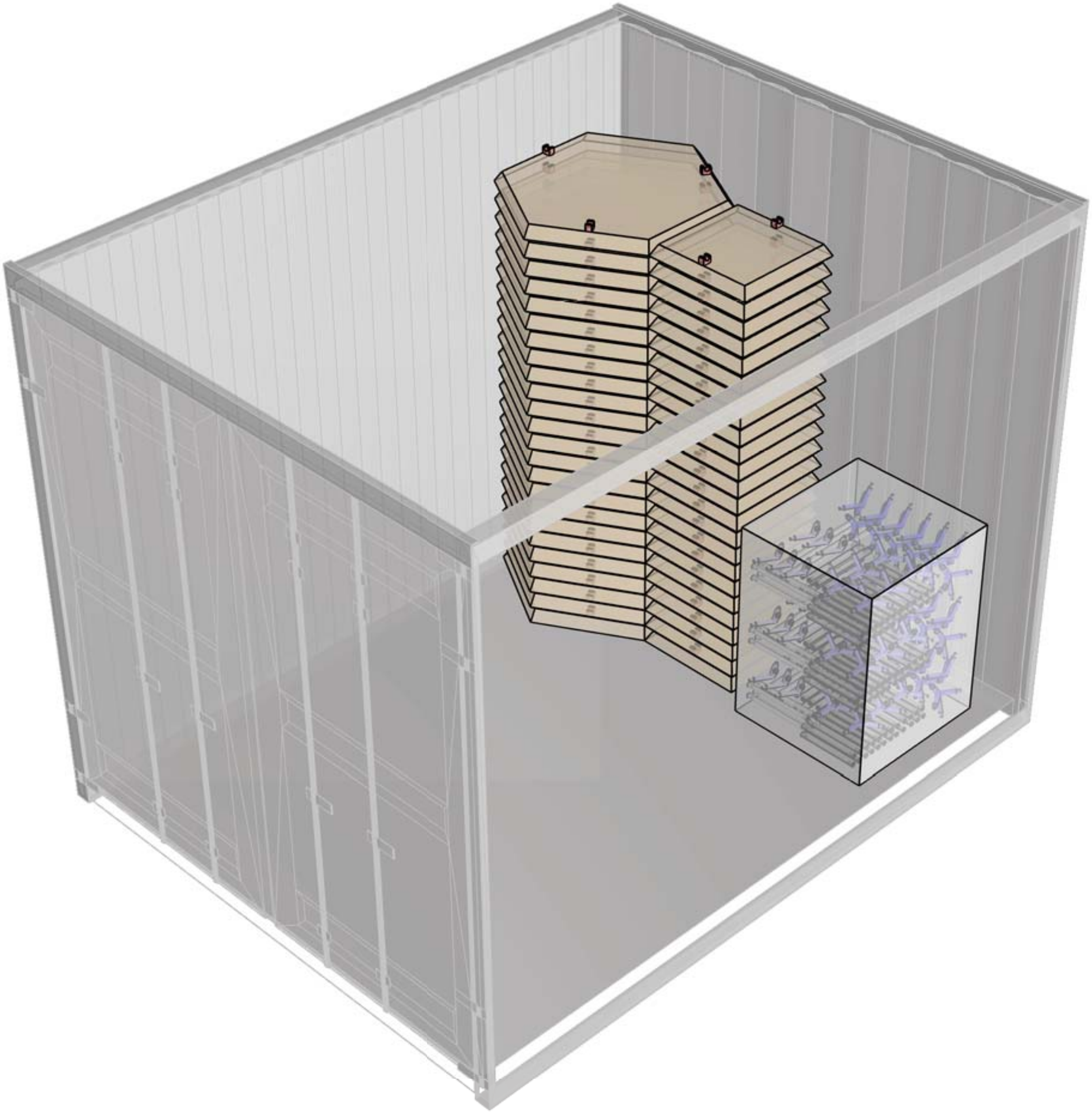




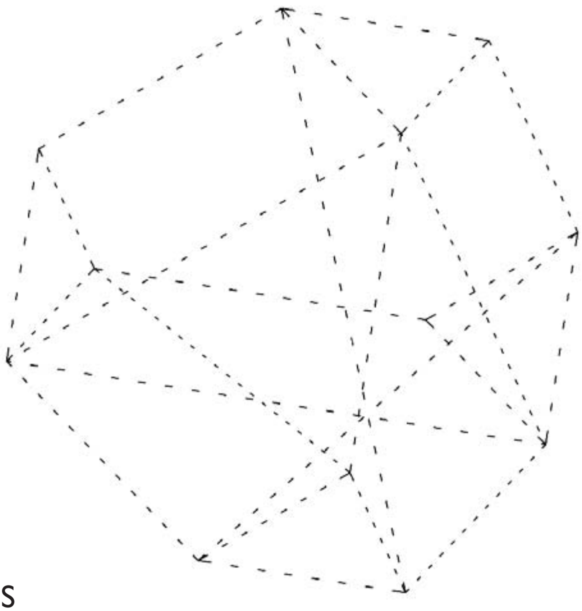


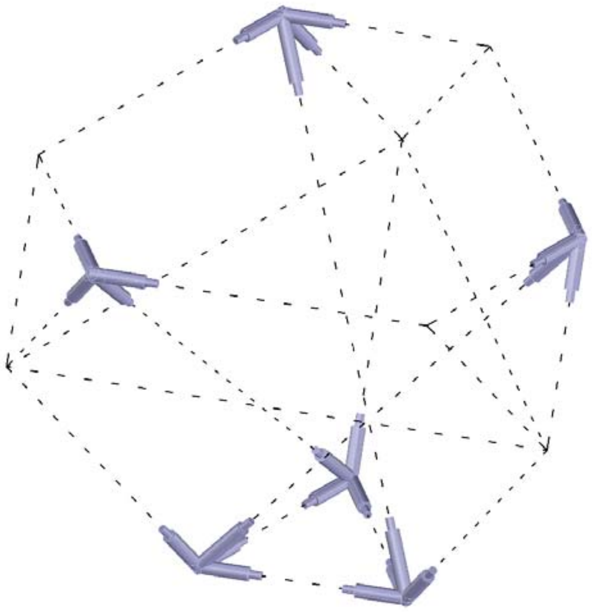






10.2 TRUNCATED TETRAHEDRON





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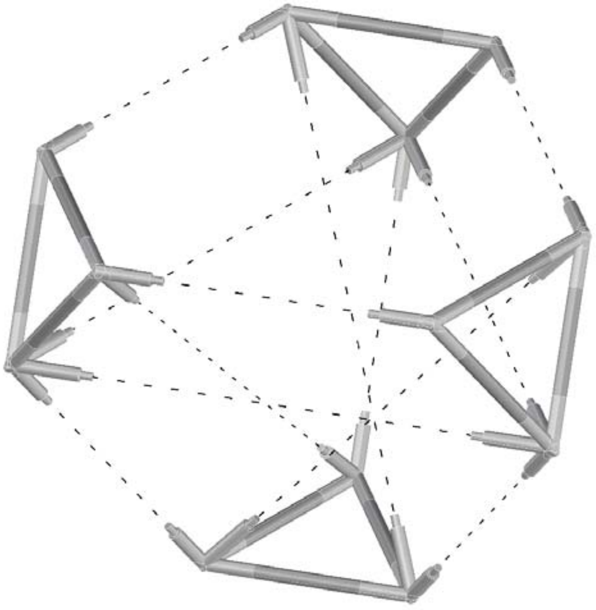
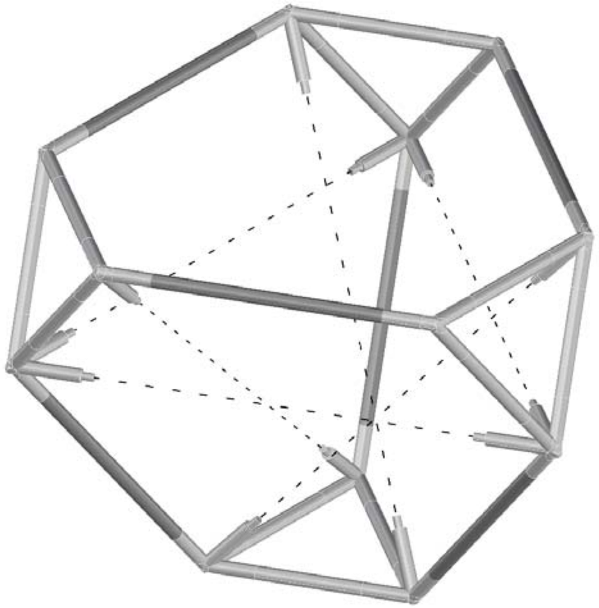
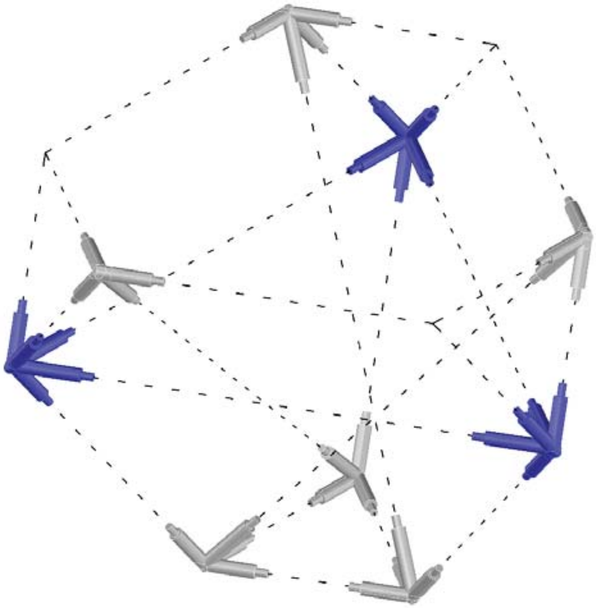
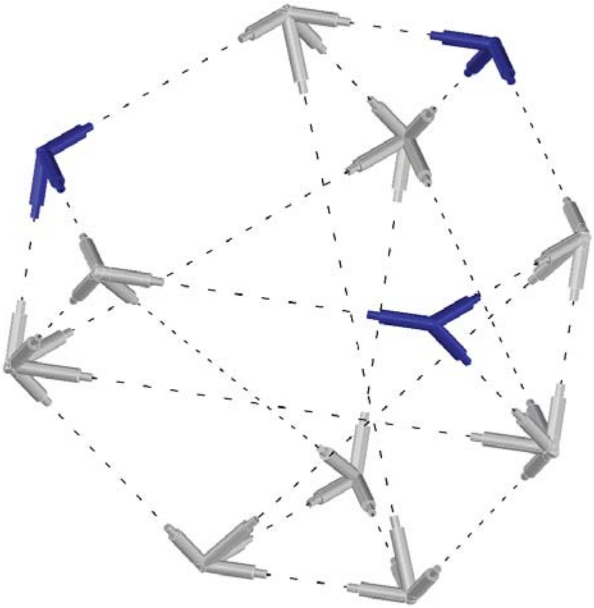
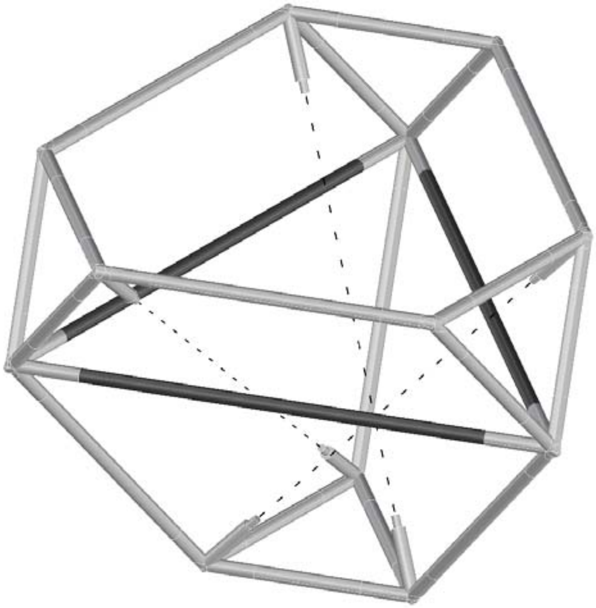


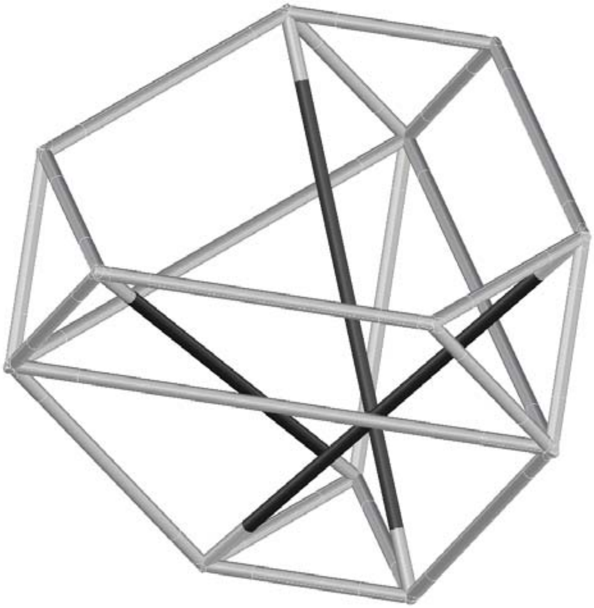


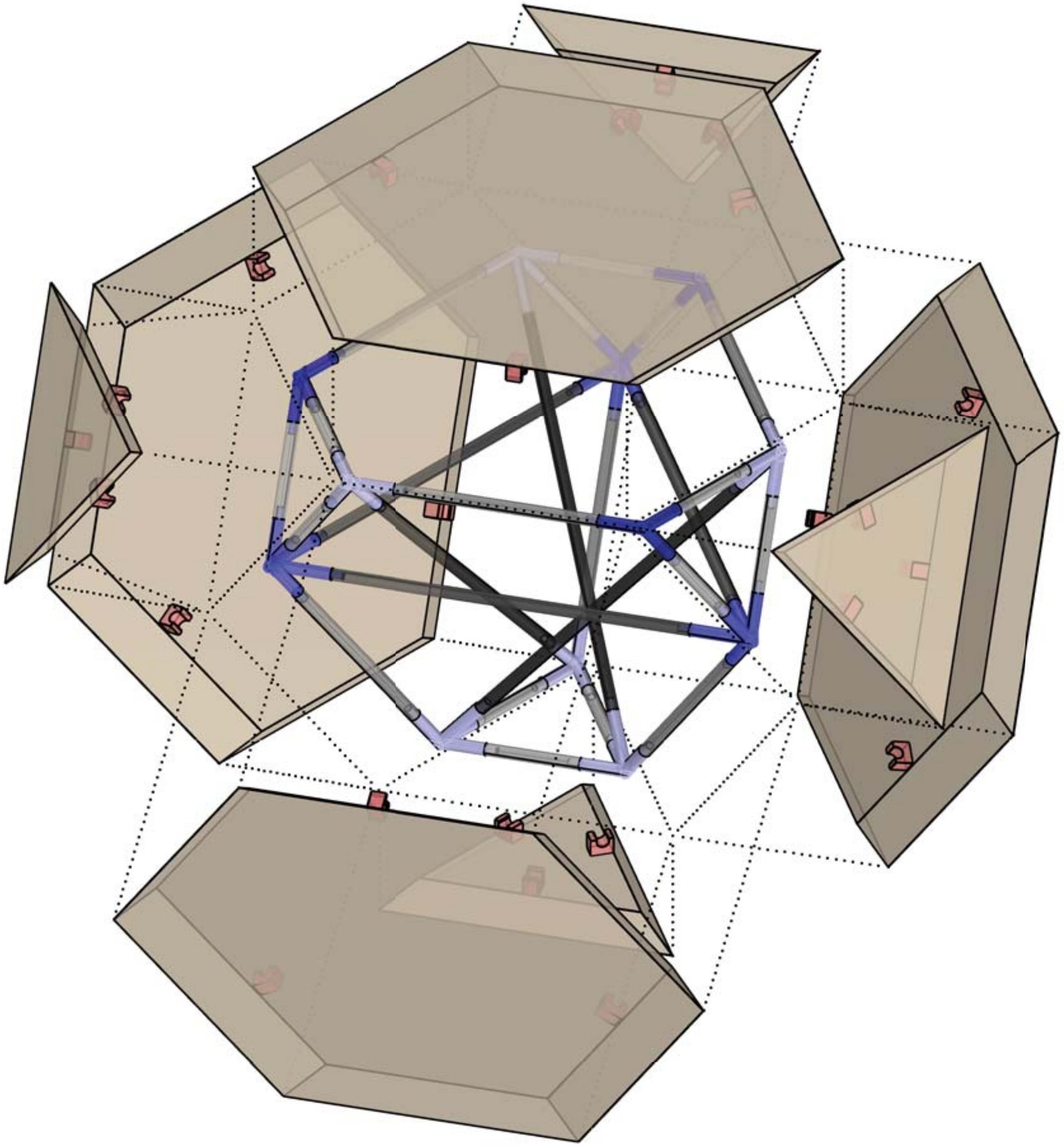
RODS



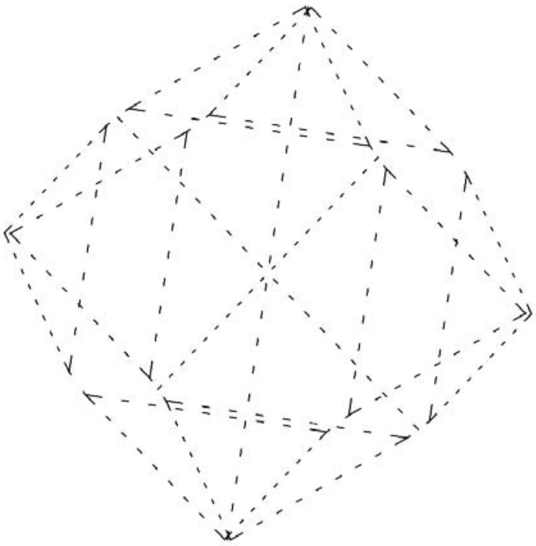


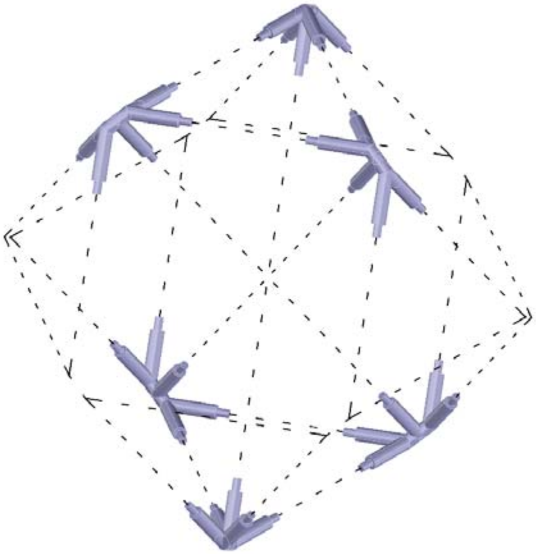






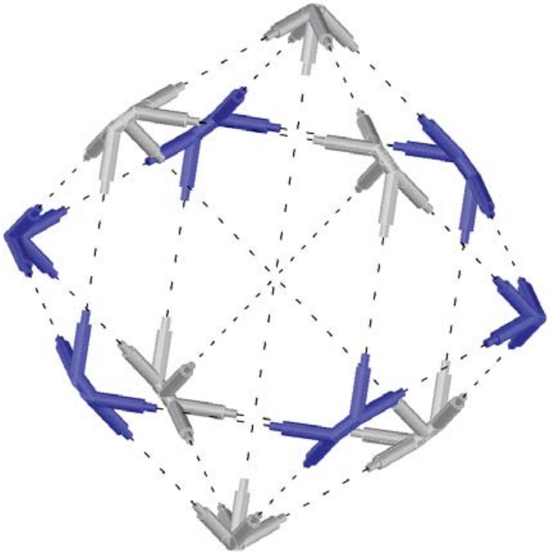
10.3 CUBEOCTAHEDRON

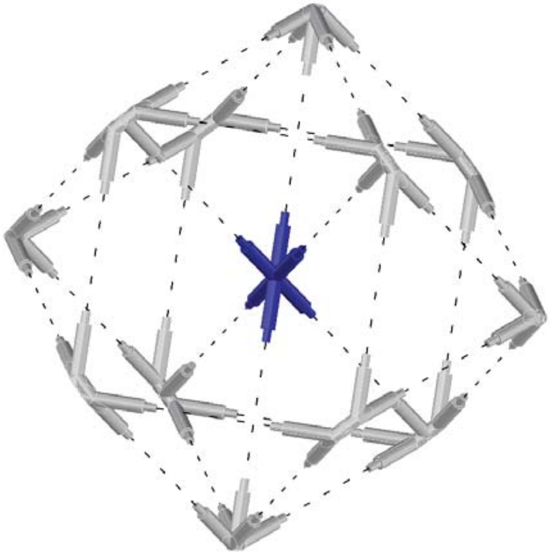


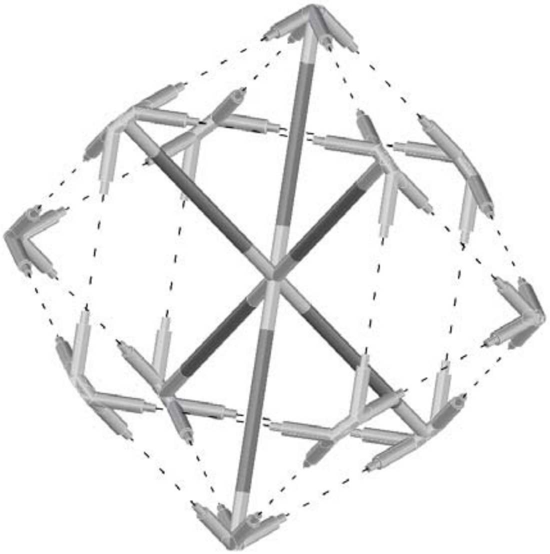


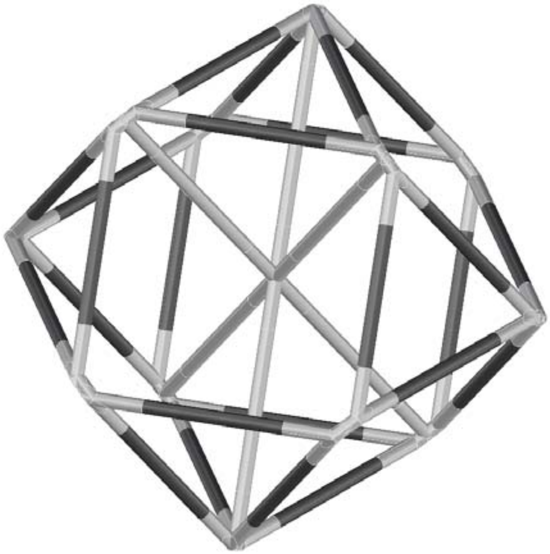
NODES

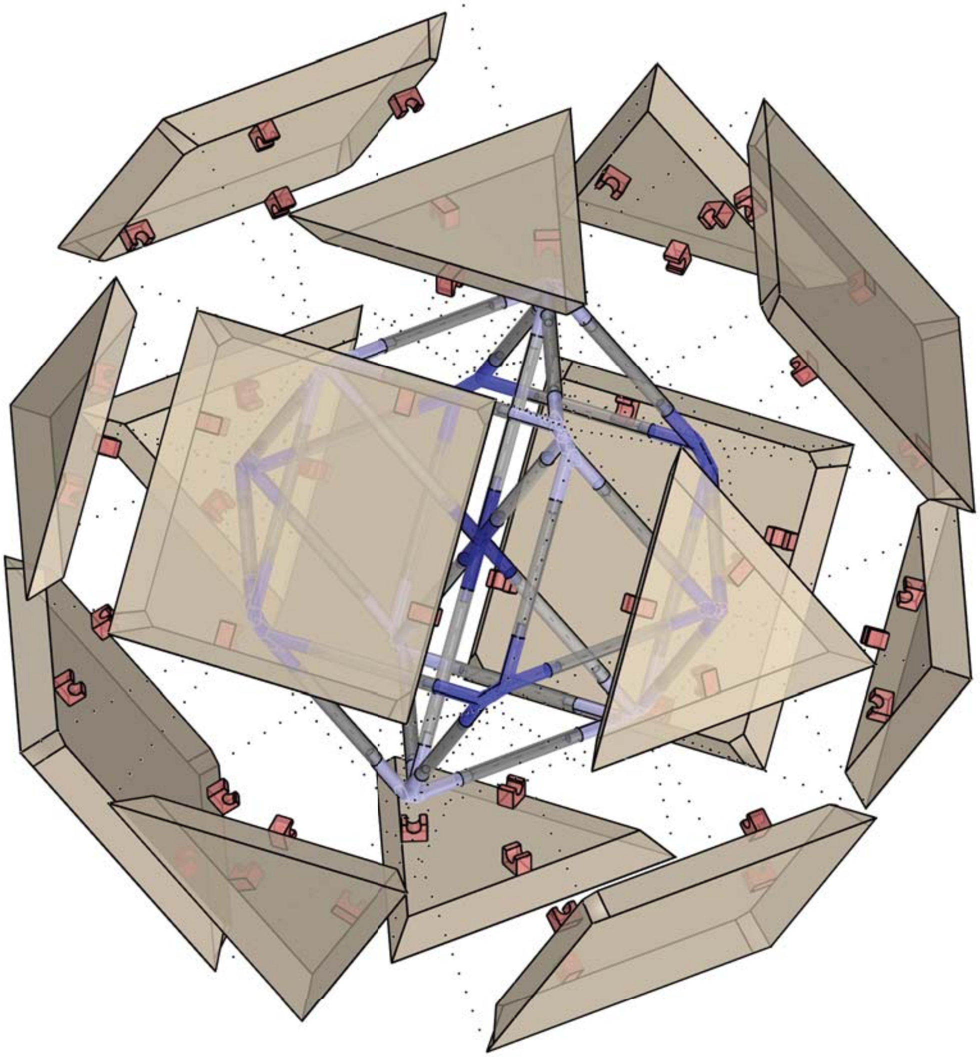
RODS

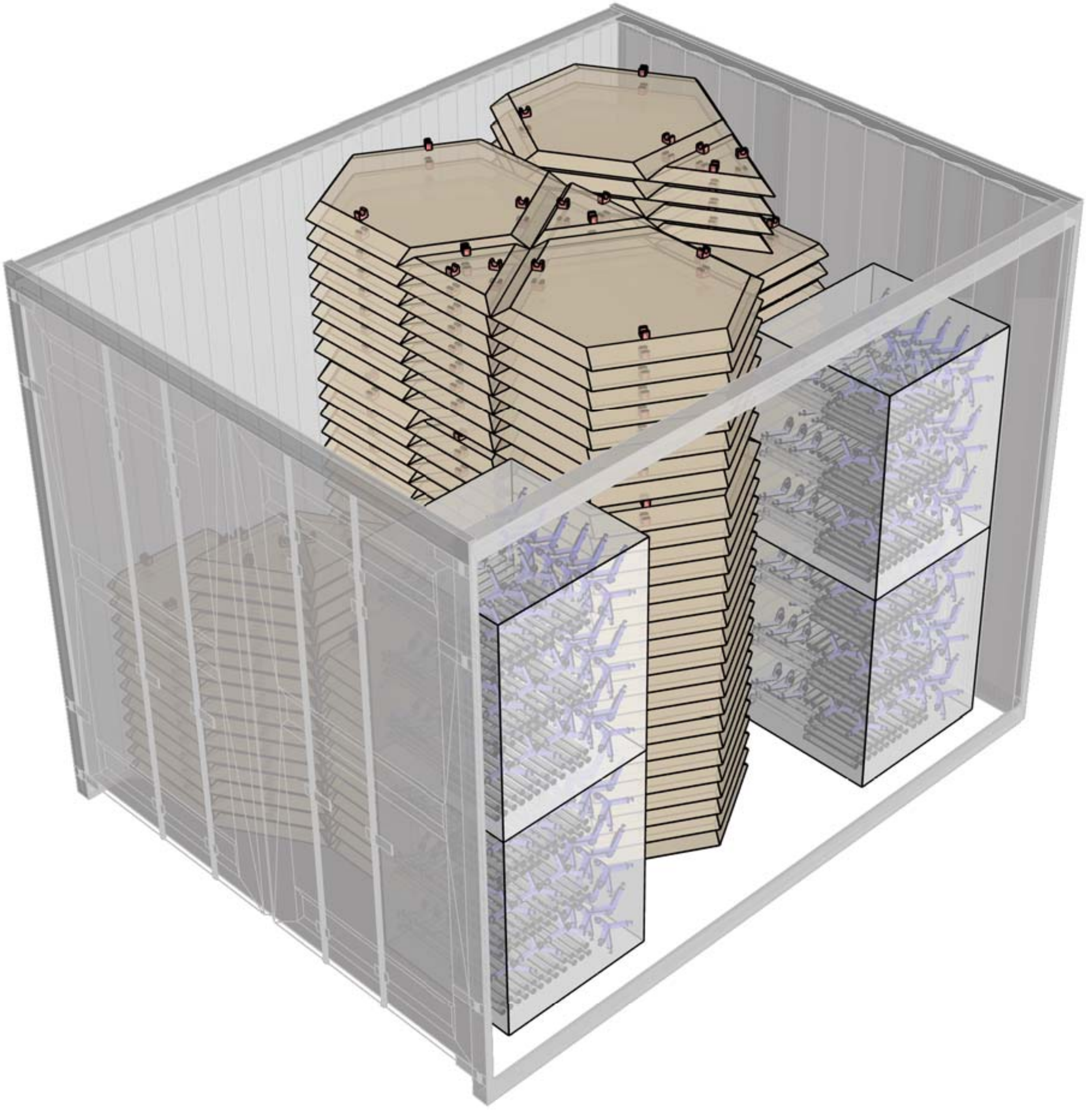












11.0 LITERATURE REVIEW

"I think the biggest innovations of the 21st century will be at the intersection of biology and technology. A new era is beginning."

-Steve Jobs

INTRODUCTION

In the past 200 years, humanity has been the major contributor to climate change. There isn't one person, one city or one country to blame. It's all of humanity that has caused this drastic change to occur. Today environmentalists, scientists and other voluntary organizations are doing all they can to save our planet. As designers, we can contribute in changing the trends from the way we live today to living sustainably to finally achieving ecological living. Biomimicry is an area of study that is informed by 3.8 years of R&D on evolution. This study offers innumerable solutions that help designers collaborate with other disciplines, producing designs inspired by nature.

This literature review analyzes the subject of biomimicry, evolution in the past couple decades, the design approach that comes from understanding biomimicry, emergence of digital technology and fabrication and the dependence of biologically inspired design on the digital age. Further, the review focuses on the change that can be bought about in interior architecture and design by examining certain existing and proposed projects designed using biomimicry principles approaches and manufactured using digital technology and fabrication.

The three major changes that we need to bring about in our designs, if the grand project of humanity is to endure are: achieving radical increase in resource efficiency, shifting from a fossil fuel economy to a solar economy and transforming from a linear, wasteful and polluting way of using resources to a completely closed loop model in which all resources are stewarded in cycles and nothing is lost as waste.

KEYWORDS

Biomimicry, biomimetic, bioinspired, ecological design, post-digital age, digital technology, digital fabrication, CAD, CAM, integrative design.

INTRODUCTION TO BIOMIMICRY

BI-O-MIM-IC-RY (from the Greek bios, life, and mimesis, imitation)

Biomimicry is an approach to innovation that seeks sustainable solutions to human challenges by emulating nature's time-tested patterns and strategies.[1]

Biomimicry's core idea is, as Janine Benyus says, treating nature as model, measure and mentor. Using nature as model, we can get ideas from organisms to solve our problems. Whatever we are trying to do, there are usually several organisms that have evolved successful strategies to do it. Applying nature as measure, we can look to the natural world to see what is possible. Taking nature as mentor, we are able to recognize that we are part of a larger system, and that we should treat nature as a partner and teacher rather than as a resource to be exploited.

Nature as model: Biomimicry is a new science that studies nature's models and then imitates or takes inspiration from these designs and processes to solve human problems.

Nature as measure: Biomimicry uses an ecological standard to judge the rightness of our innovations. After 3.8 billion years of evolution, nature has learned: What works. What is appropriate. What lasts.[5]

Nature as mentor: Biomimicry is a new way of viewing and valuing nature. It introduces an era based not on what we can extract from the natural world, but what we can learn from it.[5]

NATURE'S LAWS, STRATEGIES AND PRINCIPLES

Nature runs on sunlight, uses only the energy it needs, fits form to function, recycles everything, rewards cooperation, banks on diversity, demands local expertise, curbs excesses from within and taps the power of limits.[5]

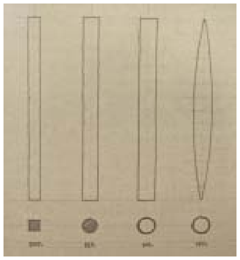


Figure 1

Nature makes extremely economical use of materials, and this is normally achieved through evolved ingenuity of form. Using folding, vaulting, ribs, inflation and other measures, natural organisms have created effective forms that demonstrate astonishing efficiency.

Nature follows the 'less material – more design' paradigm. For example, if one takes a square cross-section of a solid material with a side dimension of 24mm (Figure 1), it will have the same bending resistance as a circular solid section of diameter 25mm with only 81.7 per cent of the material. Similarly, a hollow tube with only 20 per cent of the material of the solid square can achieve the same stiffness. The material has been removed from areas close to the neutral axis and placed where it can deliver much greater resistance to bending – achieving the same result but with a fraction of the material.

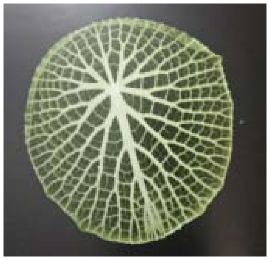


Figure 2

Figure 2 shows the X-ray image of an Amazon water lily leaf showing an example of how robust structures are created in nature with a minimum of materials. The network of ribs stiffens the large area of leaf without adding material. Nature is abundant in examples that demonstrate this structural principle: hollow bones, plant stems and feather quills to name just a few.[6]

Nature used the material as its system. The book 'Biomimicry in Architecture' edited by Michael Pawlyn, explores the potential of the subject in the built environment.

BIOMIMICRY IN DESIGN

Biomimicry is the conscious emulation of nature's genius. It is an interdisciplinary approach that brings together two often-disconnected worlds (biology and design). The practice of biomimicry seeks to bring time-tested wisdom of life to the design table to inform human solutions that create conditions conducive to life. Biomimicry connects us in ways that fit, align, and integrate humans into the natural processes of earth.

LEVELS OF BIOMIMICRY

Biomimicry Primer published by the Biomimicry Institute, divides the levels of Biomimicry into natural form, natural process and natural ecosystem. These levels can be used by any design field and not specific to the built environment.

Natural Form: mimicry of the hooks and barbules of an owl's feather to create a fabric that opens anywhere along its surface. Or you can imitate the frayed edges that grant the owl its silent flight. Copying feather design is just the beginning, because it may or may not yield something sustainable.
Natural Process: The owl feather self-assembles at body temperature without toxins or high pressures, by way of nature's chemistry. The unfurling field of green chemistry attempts to mimic these benign recipes.

Natural Ecosystem: The owl feather is gracefully nested—its part of an owl that is part of a forest that is part of a biome that is part of
a sustaining biosphere.

Through an examination of the levels mentioned in the Biomimicry Primer and other existing biomimetic technologies available, Architect and professor Pedersen Zari has come up with three levels of mimicry: the organism, behavior and ecosystem. These levels are related to the design of the build environment. The organism level refers to a specific organism like a plant or animal and may involve mimicking part of or the whole organism. The second level refers to mimicking behavior, and may include translating an aspect of how an organism behaves, or relates to a larger context. The third level is the mimicking of whole ecosystems and the common principles that allow them to successfully function.

Within each of these three levels described by Zari, a further five possible dimensions to the mimicry exist. The design may be biomimetic for example in terms of what it looks like (form), what it is made out of (material), how it is made (construction), how it works (process) or what it is able to do (function).[9]

BIOMIMICRY THINKING - APPROACHES TO DESIGN

Biomimicry thinking provides context to where, how, what, and why biomimicry fits into the process of any discipline or any scale of design. There are four steps in which a biomimicry lens provides the greatest value to design process: scoping, discovering, creating, and evaluating.[5] In biomimicry, scoping includes identifying the functions and context factors that will guide ones search for models in nature that will guide as inspiration. Discovering is immersing oneself in the selected topic in nature to reach a better understanding. Creating is the third phase, where the information from scoping and discovering helps formulate a design solution. The final step is to evaluate if the design is true to natures design principle.

Challenge to Biomimicry

Throughout literature, this approach has different names as "Design looking to biology"[9], "Top-down Approach", "Problem-Driven Biologically Inspired Design", and "Challenge to Biology". They all mean the same and they also point the way designers look to nature and organisms for design solutions. It is a specific path through Biomimicry Thinking. This is useful for scenarios when a specific problem is at hand and seeking biological insights.[12]

Biology to Design

Just like the previous approach, this also has different names and expressions such as "Biology influencing Design"[9], "Bottom-Up Approach"[10], "Solution-Driven Biologically Inspired Design"[11] and "Biology to Design"[12]. This approach is another path through Biomimicry Thinking. This is most appropriate when the process initiates with an inspirational biological insight (including Life's Principle) that is then manifested as a design.[12]

INTRODUCING DIGITAL FABRICATION

The digital age has radically reconfigured the relationship between conception and production, creating a direct link between what can be conceived and what can be constructed. Projects today are not only born out digitally, but they are also realized digitally through "file-to-factory" processes of computer numerically controlled (CNC) fabrication technologies.

Over the past decade, architecture has seen the (re) emergence of complexly shaped forms and intricately articulated surfaces, enclosures, and structures. Design and production are fundamentally enabled by the capacity of digital technologies to accurately represent and precisely fabricate artifacts of almost any complexity. The challenges of constructability left designers with little choice but to become closely engaged in fabrication and construction, if they were to see their projects realized.

Building contractors who used the 'analog' norms of practice and prevalent orthogonal geometries and standard, repetitive components, were reluctant to take on projects they saw as apparently unbuildable or, at best, with unmanageable complexities. The 'experimental' architects had to find contractors and fabricators capable of digitally driven production, who were often not in building but in shipbuilding. They had to provide, and often generate directly, the digital information needed to manufacture and construct the building components. So, out of sheer necessity, the designers of the digitally aided age, who often produce 'blobby' architecture became closely involved in the digital making of buildings.[13] A potentially promising path to integrative design emerged.

Architect and Professor Kolarevic refers to 'integrative design' as an alternative approach to design, in which methods, processes, and techniques are discovered, appropriated, adapted, and altered from 'elsewhere', and often 'digitally' pursued. This approach is similar to Biomimicry Thinking proposed by the Biomimicry Institute. The designers who engage design as a broadly integrative endeavor fluidly navigate across different disciplinary territories, and deploy algorithmic thinking, biomimicry, computation, digital fabrication, material exploration, and/or performance analyses to discover and create a process, technique, or a product that is qualitatively new.

Design Precedent – combining Biomimicry with Digital Fabrication

HygroSkin designed by Achim Menges, Oliver David Krieg and Steffen Reichert is a good precedent for integrative design (shown in figure 3). The hygroscopic principle of a spruce cone demonstrates an inherent morphing behavior where the cone bracts are opened when dry and closed when wet. This system inspired Architect Achim Menges to create a climate responsive architectural skin that is able to alter its shape passively by drawing on information and energy from the environment.

The pavilion's envelope is a load-bearing structure and also acts as a sensitive skin, is computationally derived from the elastic bending behavior of thin plywood sheets. The materials inherent capacity to form conical surfaces is employed in combination with 7-axis manufacturing processes to construct 28 geometrically unique components housing 1100 humidity responsive apertures.

Figure 3
This project builds on over six years of design research experience investigating the biomimetic principles offered by the spruce cone to develop climate responsive architectural systems that do not require any sensory equipment, motor functions or even operational energy input. The research enables the use of wood, one of the oldest and most common construction materials, as a climate-responsive, natural composite.

A nature-imitating search for new ideas based on biological precedents holds much promise as a generative driving force for digitally driven contemporary design as it addresses sustainability as a defining socio-economic and cultural issue today. All of the developments are part of the perceived broader shift towards integrative design as an emerging trajectory for design as it enters a post-digital phase and where it embraces ideas, concepts, processes, techniques, and technologies inspired from nature.

CONCLUSION

Biomimicry has been used by other design industries, most of whom follow one of the levels of mimicry explained in the paper. Interior Designers who are interested in using biomimetic approaches to design must develop a deeper understanding of nature. There is more to nature than just its formalistic characteristics to achieve the principles of biomimicry. Different approaches to design using biomimicry thinking has been discussed. The studied precedent follows a design to biology approach. This precedent is a good example to show the combination of biomimicry and digital fabrication is changing the way designers think of designs. The processes followed can help interior designers use nature's processes in interiors.

Biomimicry is a philosophical approach that can lead to novel ideas and innovative solutions that have many potential advantages, one of the main ones being – achieving ecological sustainability as in nature.

11.1 ENDNOTES

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12.0 INITIAL PROJECT REFERENCES

12.1 PROJECT REFERENCES FOR AN ORGANISM LEVEL OF BIOMIMICRY

1) **Biodigital Chair** by Genetic Architecture Office, Spain.

- Inspired by Salvador Dali's quip that the future of architecture 'will be soft and hairy'.
- Designed for public spaces that represent new fabrication standards and require neither models nor molds.
- Optimal design determined by parametric design tools.
- This living component of work both enhances its function-making a more enjoyable outdoor seat-and reflects its 'organic' origins.

2) **Entropy Carpet** by Interface (in collaboration with Biomimicry Guild)

- The team was inspired by the random but harmonious forest floor.
- Laid randomly which reduces installation waste to a large extent.
- Quality control checks were eliminated cause of the idea of imperfection no longer existed.
- Repairs were easier and it was possible to even out wear by rotating the tile.

3) **Lillian van Daal's 3D-Printed Chair**

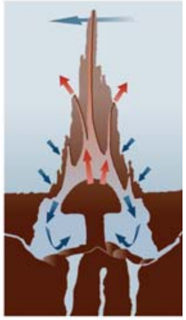
- Inspired by biological cellular systems such as bone, van Daal identified 3D printing as a key enabling technology that would allow her to engineer furniture from a single material yet be able to introduce local soft and hard regions by manipulating material density through design.
- Circumnavigates the intense and logistics and the resulting energy and resource consumption.

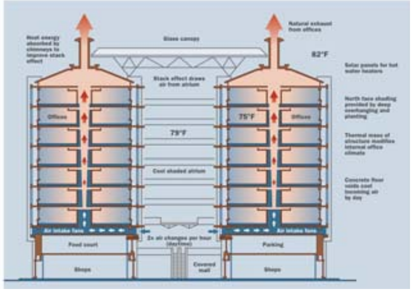
12.2 PROJECT REFERENCES FOR A BEHAVIOR LEVEL OF BIOMIMICRY

1) **Metropolis Booth** by Urban A&O

- This project merges contemporary digital practice with an ambitious ecological imperative, demonstrating the two are powerfully commensurate.
- Living showcase of form, function and sustainability.
- Light-weight monolithic skeletal structure.
- Framed in an egg crate assembly of interlocking recycled/recyclable white plastic fins.

2) **Eastgate Center** by architect Mike Pearce





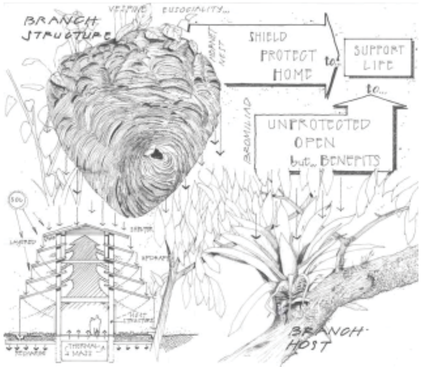
- Inspired by termite mounds that maintains comfortable conditions close to the equator without mechanical cooling.
- Zero waste construction with solar powered air-conditioning.
- Have external shading devises that minimize solar gain.

12.3 PROJECT REFERENCES FOR AN ECOSYSTEM LEVEL OF BIOMIMICRY

1) **Biomimetic Building: ’Island of Light’** by Tonkin Liu

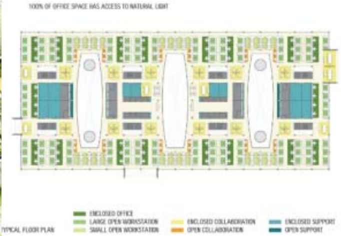
- Cruise-ship terminal in Taiwan.
- Architect describes the design as follows: The structural ‘Forest’ makes poetry out of the need to create cool space in a hot climate. By day, a filtered, dappled light fills the hall, covering the surface of the ‘Hill’ and by night trees glow from within.
- The design is based on clear and rational principles of providing comfortable conditions for the building users in a low-energy way.

2) **Lavasa** (Urban Design Project) by HOK



- Challenge was to design buildings in Lavasa, India which receives up to 11m of rain each year.
- The above sketch shows how locally adapted species, such as the bromeliad, provided a number of sources of design inspiration including the idea of cascading roof surfaces to catch and evaporate rainfall.

3) **Process Zero: Retrofit Resolution** by HOK



- Challenge: To make a 1960’s construction energy efficient.
- Reduces current energy demand by 84%.
- While generating 16% of the remaining energy on site.
- Web of pipe work that carries Algae on the south facade. This absorbs harmful emissions from the freeway and provides shade to parts of the interior.

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