D10 SOLAR DECATHLON STUDIO
ADAPTIVE FACADE TEAM

PROCESS BOOKLET
PROFESSOR KIHONG KU
MAY 12, 2021

Interdisciplinary Design + Experimental Architecture Studio

Solar Decathlon China Y-Project: Adaptive Facade Team

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Solar Decathlon China

Y-Project:
Adaptive Facade Design

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Nicholas Lockard
Ryan McMahon
Cevan Noell
Eric Rushinski
Anthony Sclafani
Jack Whalen

Project presented to the Faculty of the Department of Architecture
College of Architecture and the Built Environment
Thomas Jefferson University

In partial fulfillment of the requirements for the degree of
BACHELOR OF ARCHITECTURE

Arch-508 / Design 10: Material Futures
Faculty: Associate Professor Kihong Ku, DDes
Philadelphia, Pennsylvania

INTRODUCTION

DESCRIPTION

The Solar Decathlon China Y-Project Adaptive Facade Team is comprised of 11 students from Thomas Jefferson University's College or Architecture and the Built Environment. The team focused on designing a double skin facade for a net-zero energy house over the course of two semesters in collaboration with students and faculty at Xi'an Jiaotong - Liverpool University (XJTLU) and Zhejiang University of Illinois at Urbana-Champaign Institute (ZJUI). The collaborative nature and scale of the international project enforced interdisciplinary learning between architecture, landscape architecture, civil engineering, electrical engineering, industrial design, and business majors across the world. Additionally, the team collaborated with industry professionals and manufacturers for guidance regarding the many facets of the adaptive facade design.

The result of the collaboration will be a full scale construction of the house in Zhangjiakou, China in October of 2021 and will be exhibited through the 2022 Beijing Winter Olympics.

ADVISORS

Kihong Ku- Studio Professor, TJU
Marco Cimillo- XJTLU Faculty
Petra Stanev- Stanev Potts Architects
Ryan Lohbauer- Stanev Potts Architects
John Shields- Point B Design
Alex Worden- StudioTJOA
Audrey Worden- StudioTJOA
Florian Meier- Knippers Helbig
Matthew Naugle - New Hudson Facades
Matthew Cleary- Sage Glass
Bjoern Beckert- Fabritecture

GRANTS

The project is funded by the Eileen Martinson '86 Capstone Experience Grant as well as a grant from XJTLU. The team was granted $5,000 from the Martinson fund and an additional $5,000 from XJTLU which created the momentum for students to create physical prototypes that otherwise would not be possible. These funds have allowed the class to have a deeper understanding of the materials and assemblies of the adaptive facade design. Thank you to both Eileen Voynick and XJTLU for supporting our prototyping.

Funding Material Purchases: ETFE, polycarbonate, acrylic, gaskets, EPDM, wood, aluminum extrusions, and fasteners.

FACADE TEAM

Olivia Birritteri
Student Team Lead

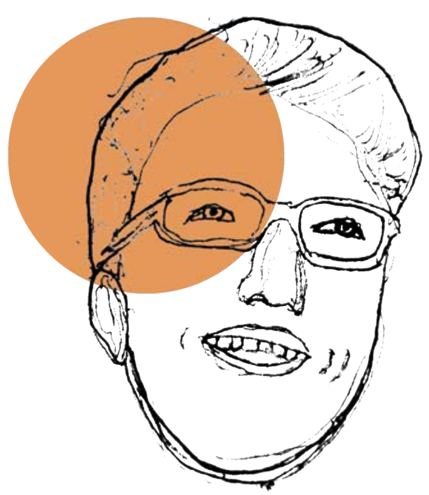
Cynthia Baublitz

Norm Engel

Saif Hussein

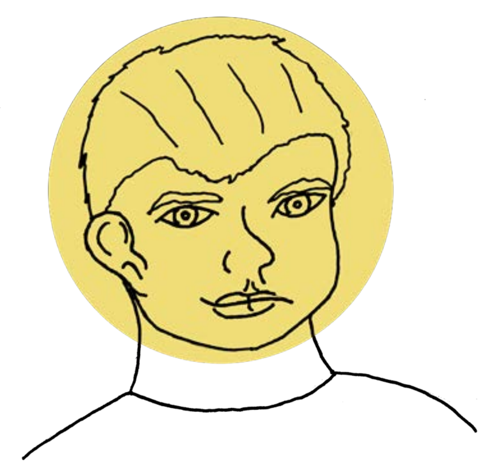
Matt Ledner

Nick Lockard



Ryan McMahon

Cevan Noell



Eric Rushinski

Anthony Sclafani

Jack Whalen

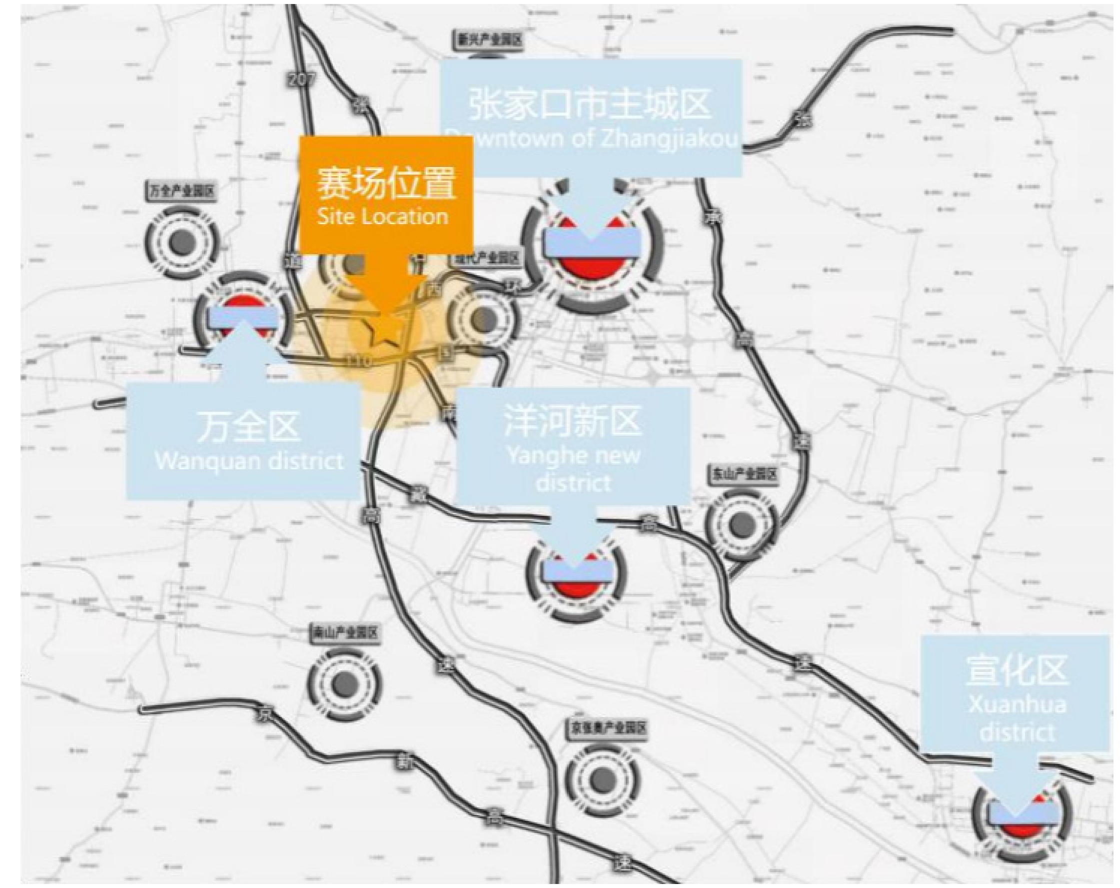
DESIGN PROMPT

Thomas Jefferson University's Design 9 & 10 studios for architecture were tasked with designing an adaptive double skin facade for the proposed Y-Project house design. Sited in Zhangjiakou, China, the climate is characterized by cold winters and moderate summers and would require high thermal mass/insulation, natural ventilation, internal heat gain, and passive solar direct gain.

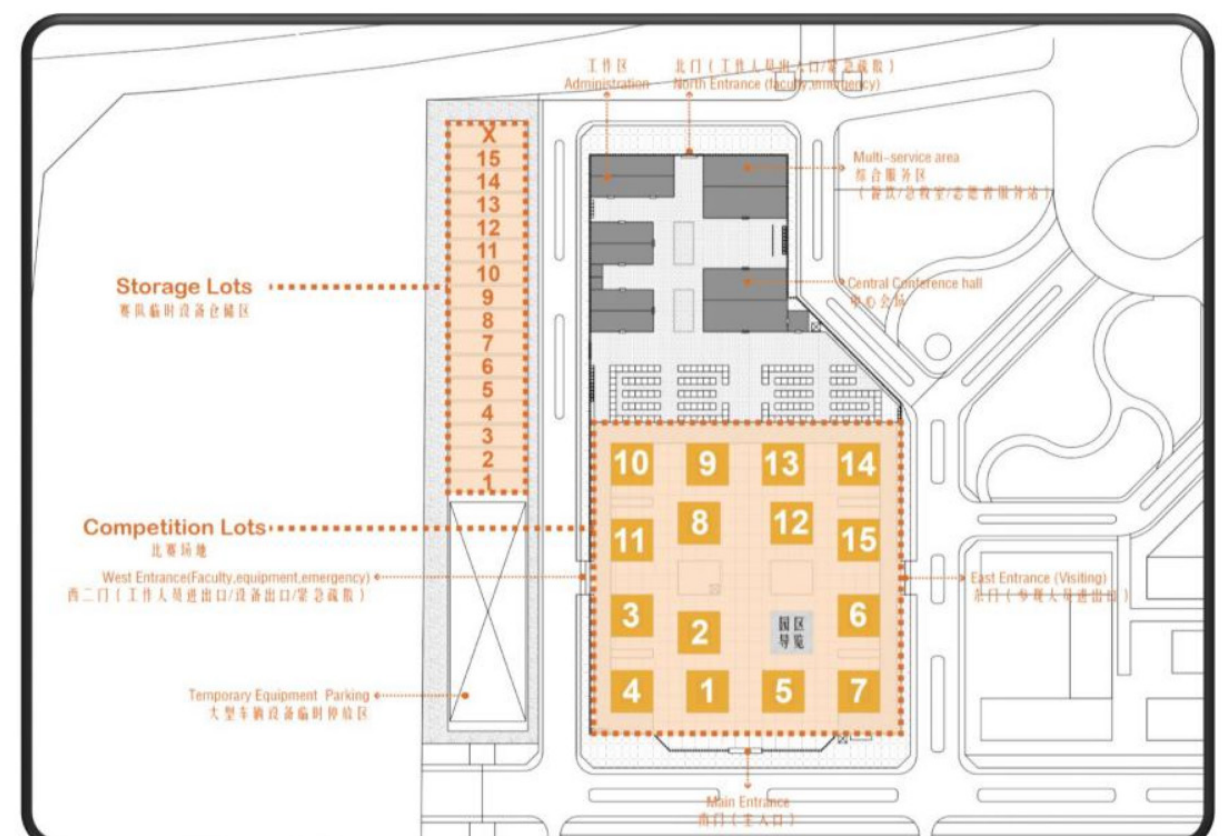
The design intent for the double skin was to create an air buffer space that would be passively heated by solar heat gain. Preheated air would be taken in by the building's HVAC systems to reduce heating loads.

The project site is located in a open lot where the house and other SDC projects will be constructed. Site number 1 will be the location of the house and will have to consider daylighting reduction from the east and west.

With these concepts and parameters in mind, the team generated several proposals to synthesize poetic, tectonic, and technical aspects of the overall design goals of the Y-Project.

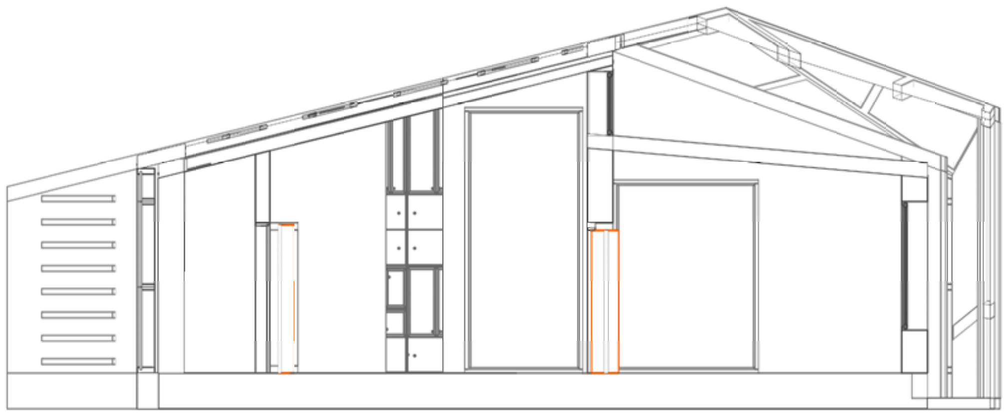


ZHANGJIAKOU, CHINA

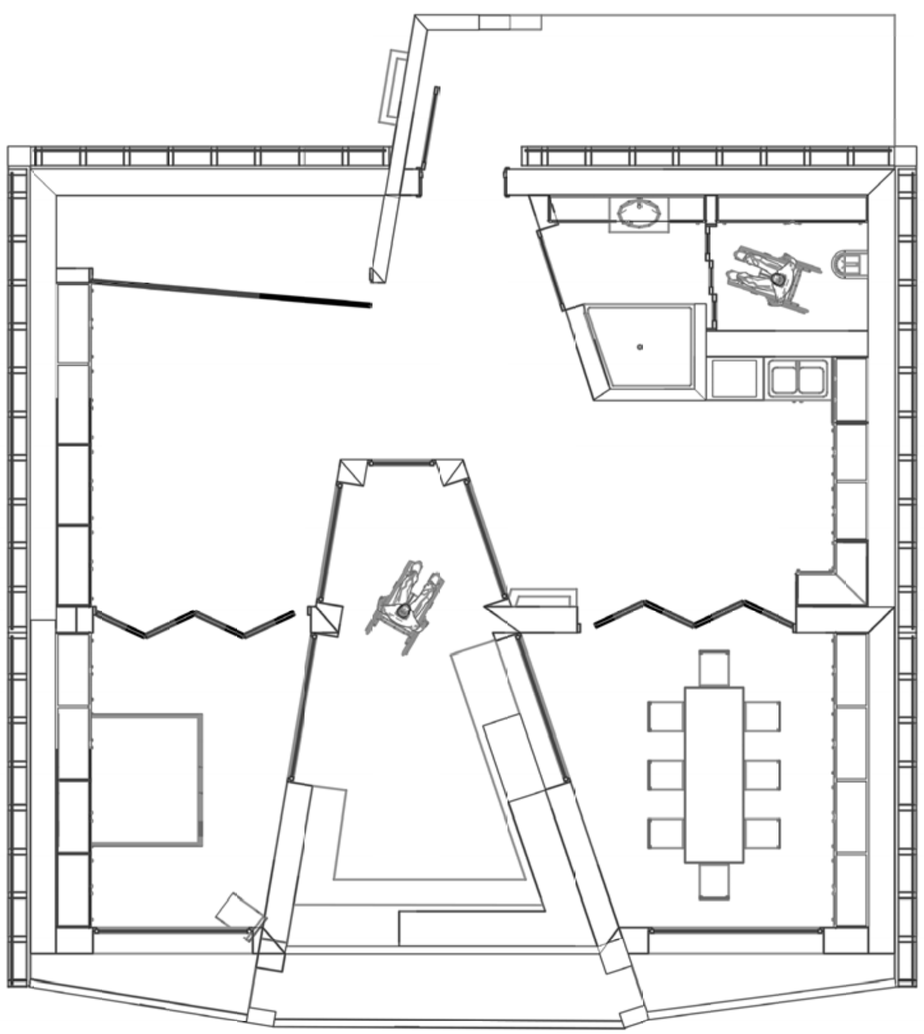


SITE PLAN

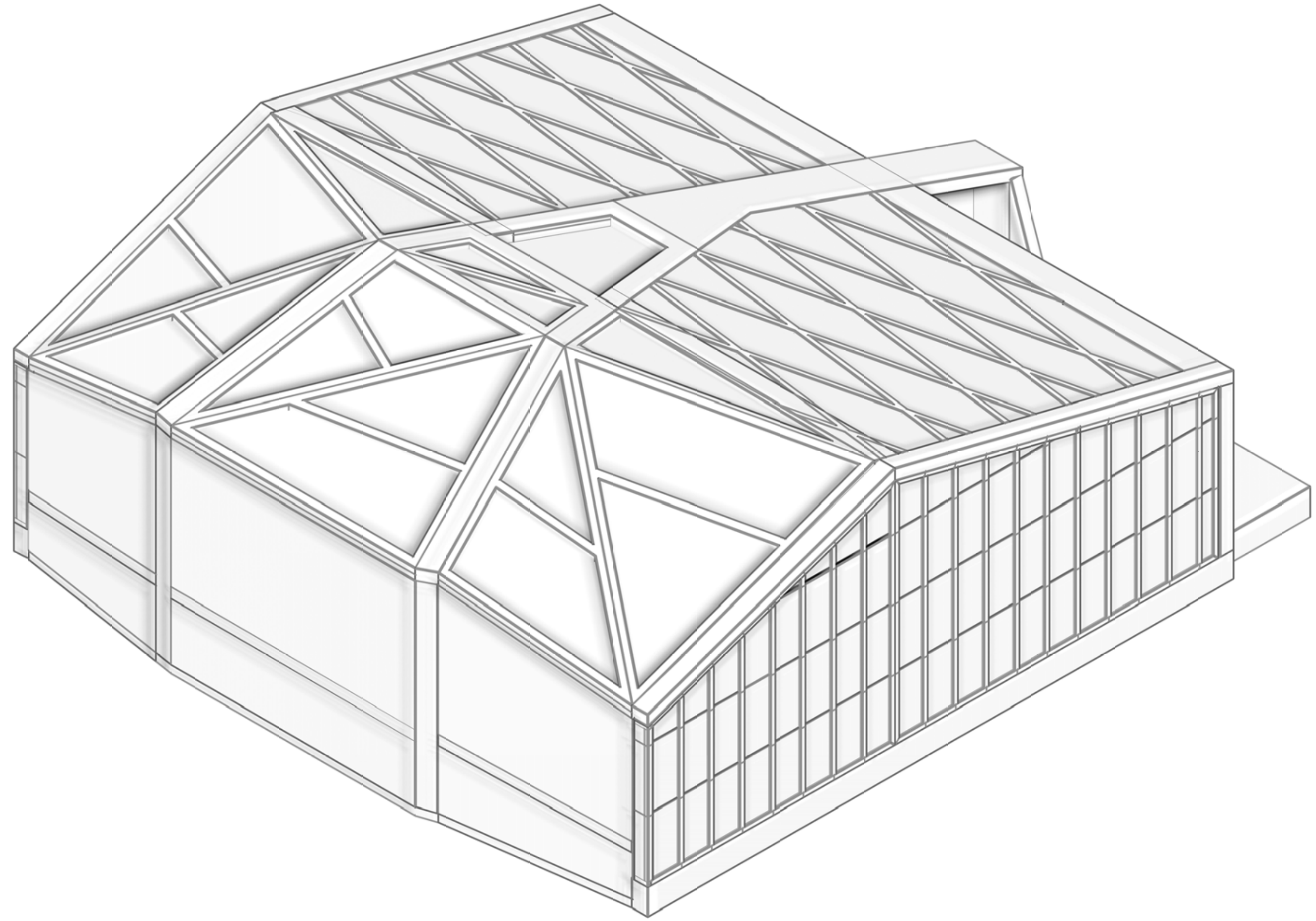
Graphics by SDC



SECTION THROUGH WEST SIDE BAY



PLAN



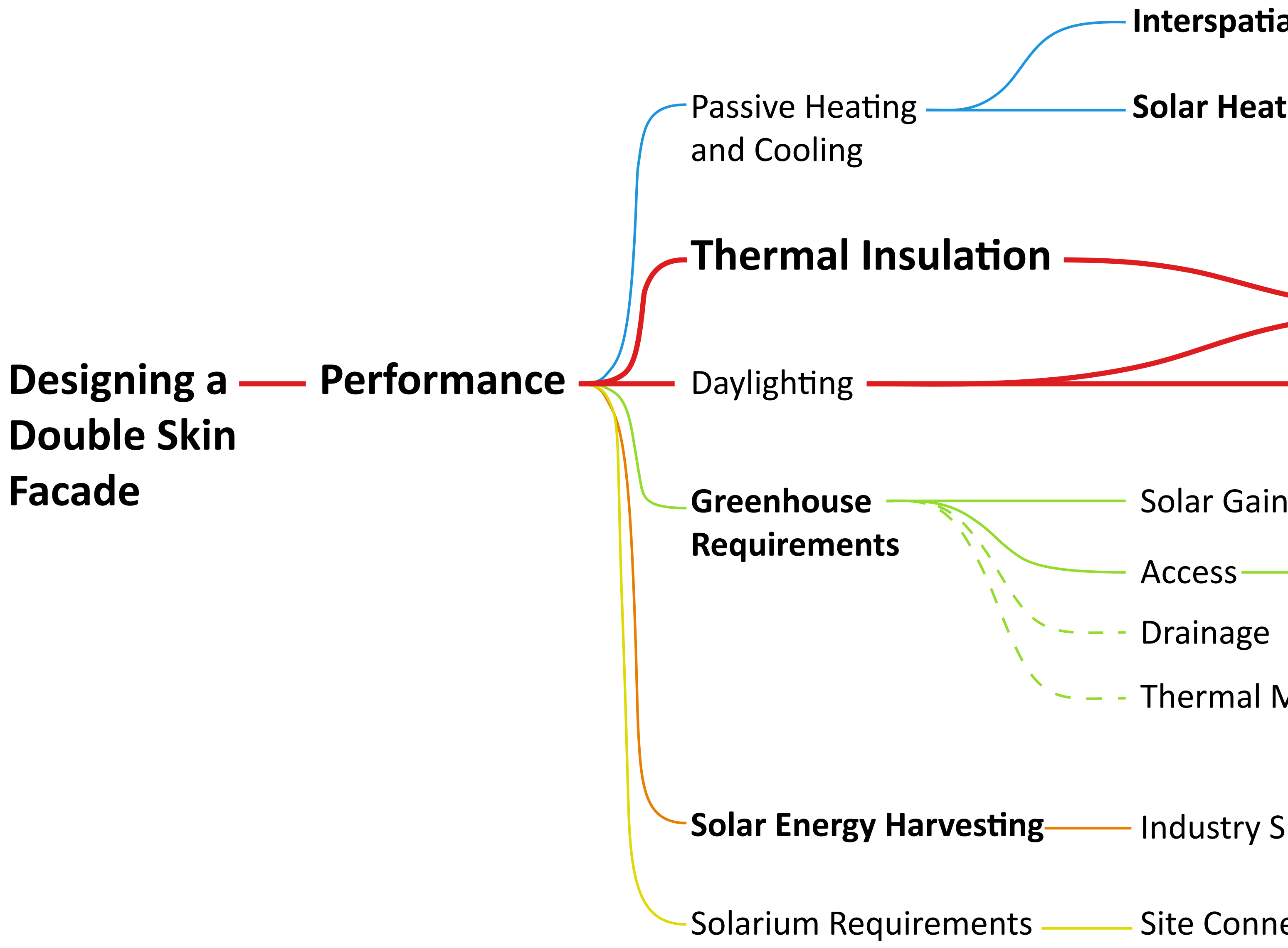
AXONOMETRIC

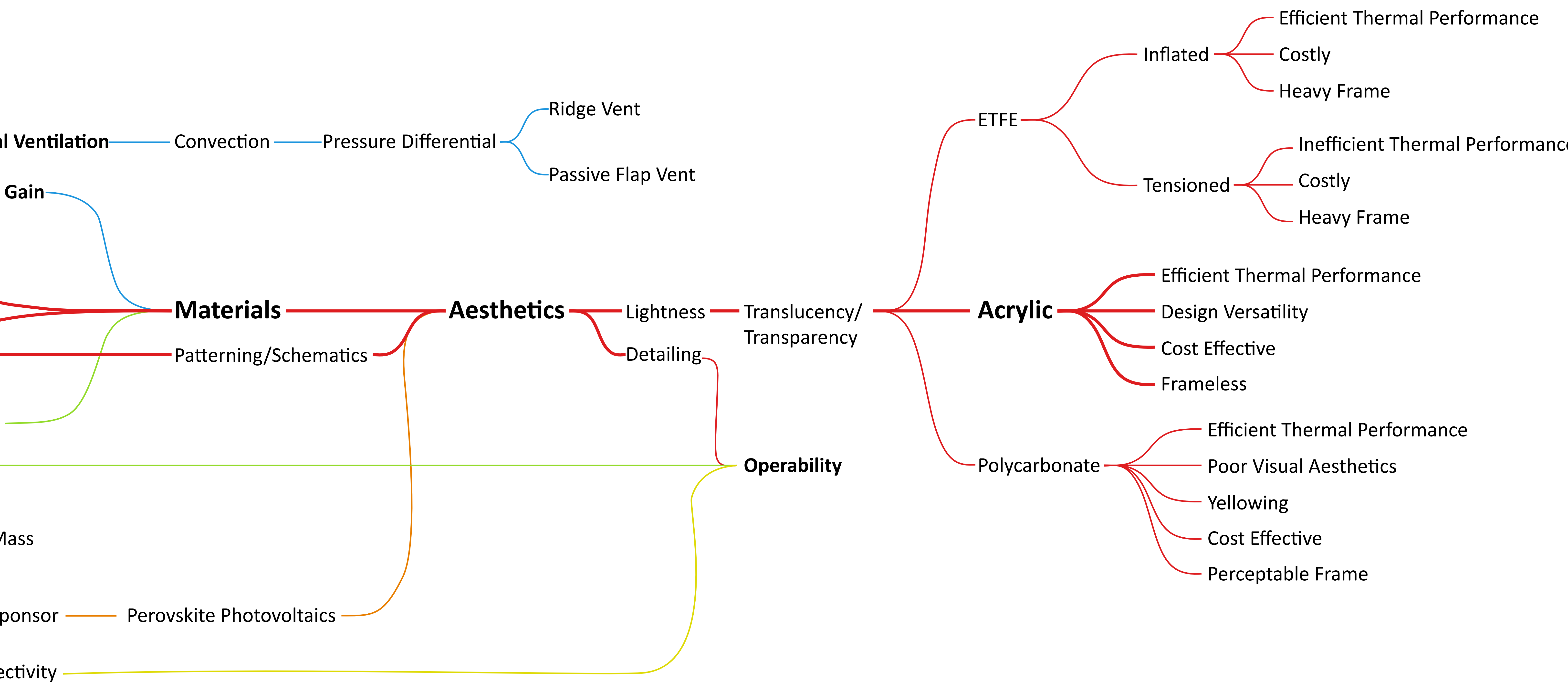
PROCESS TREE

The process tree depicts the steps and considerations taken throughout the design of the double skin adaptive facade. The process began with determining the performance characteristics that the facade would have to accomplish. This concept of the facade as a vertical greenhouse informed the selection of materials and schematics that affected the aesthetics as well as other performative needs.

The material choices affected performance characteristics as well. With translucent/transparent materials being utilized, a greater need for passive cooling is needed as the need for solar heat gain could be too intense for certain times of year.

Most important to towards the end of the process was the constraints of budget and construction. This required the team to quickly iterate and evaluate alternative materials that would accomplish the qualities of the design intent. While the realization of these constraints were daunting at first but brought about new opportunities for design.




Efficient Thermal Performance
Inflated
Costly
Heavy Frame
Ridge Vent
ETFE
l Ventilation
Convection
Pressure Differential
Inefficient Thermal Performance
Passive Flap Vent
Tensioned
Costly
Gain
Heavy Frame
Efficient Thermal Performance
Materials
Aesthetics
Lightness
Translucency/
Transparency
Acrylic
Design Versatility
Patterning/Schematics
Detailing
Cost Effective
Frameless
Efficient Thermal Performance
Operability
Polycarbonate
Poor Visual Aesthetics
Yellowing
Mass
Cost Effective
Perceptable Frame
ponsor
Perovskite Photovoltaics
ectivity

SCHEMATIC DESIGN

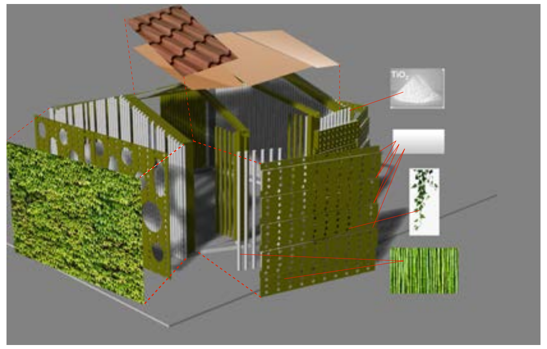
SMOG EATING FACADE

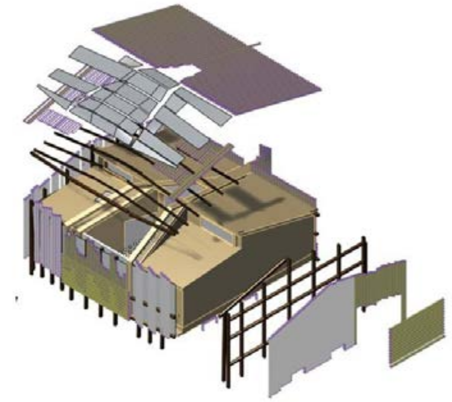
ACTUATING BI-FOLD FACADE

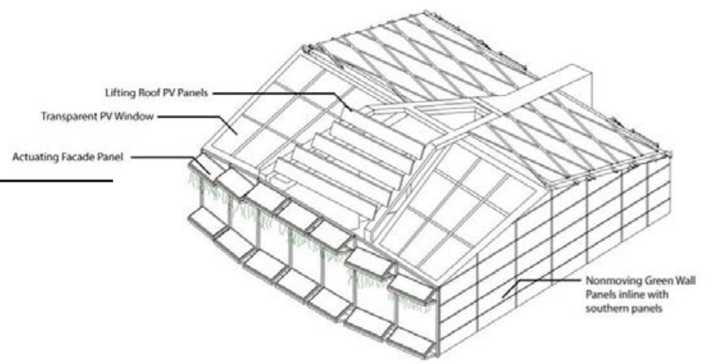
FLECTO FIN FACADE

MODULAR HEX FACADE

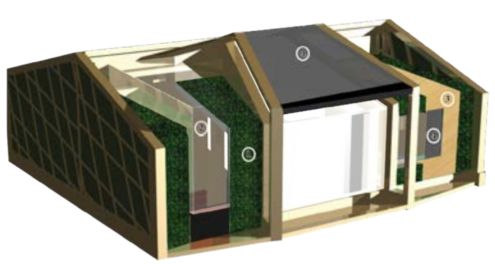
ETFE FACADE

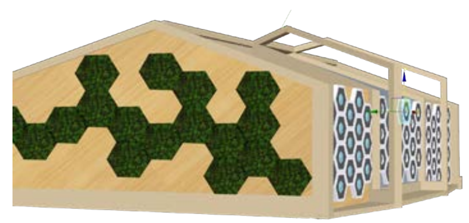


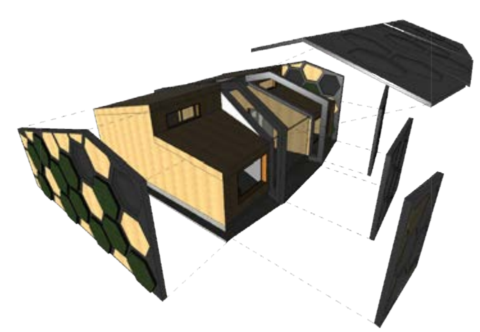


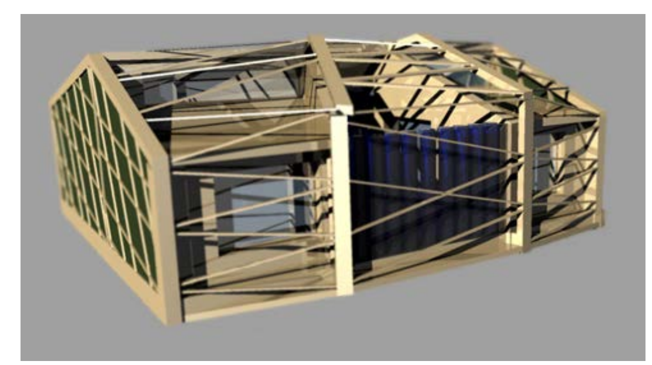


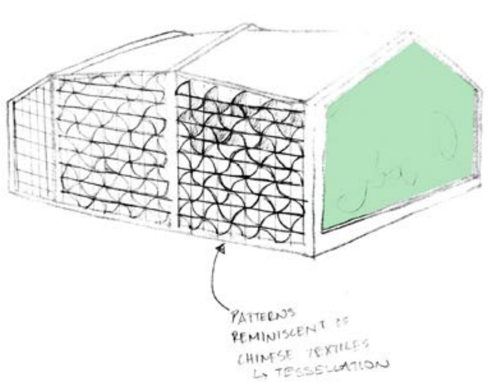
Lifting Roof PV Panels
Transparent PV Window
Actuating Facade Panel
Nonmoving Green Wall Panels inline with southern panels



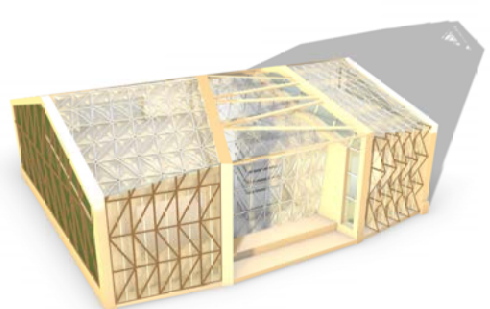


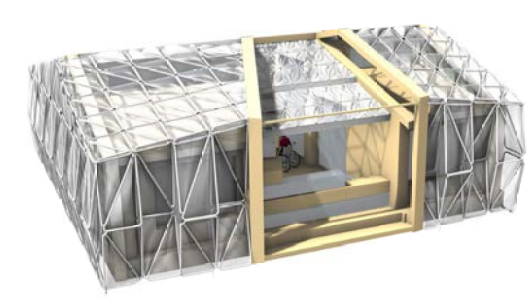






PATTERNS REMINISCENT OF CHINESE TEXTILES
↳ TESSELLATION





SCHEMATIC DESIGN

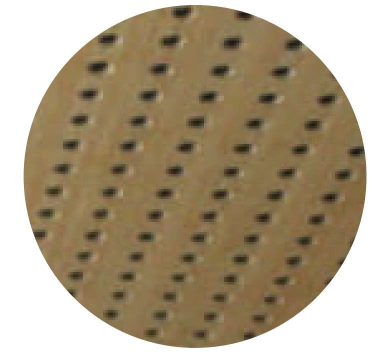
SMOG EATING FACADE

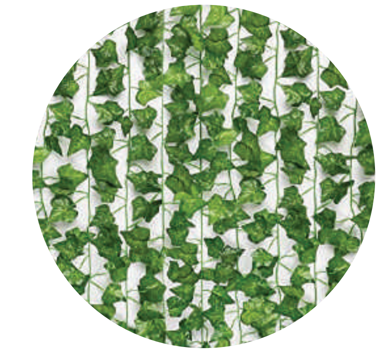
The materiality of this proposal is heavily aligned with local materials as well as sustainable design. The exterior of the structure consisted of a bamboo stalk facade. Past the outer layer is a shading screen built of perforated bamboo. The screen system itself will feature the chemical compound Titanium Dioxide. Titanium Dioxide or TiO2 has been scientifically found to improve air quality. This method of shading creates a relationship between the shading structure itself; the bamboo, and the supporting self-sustaining greenery.

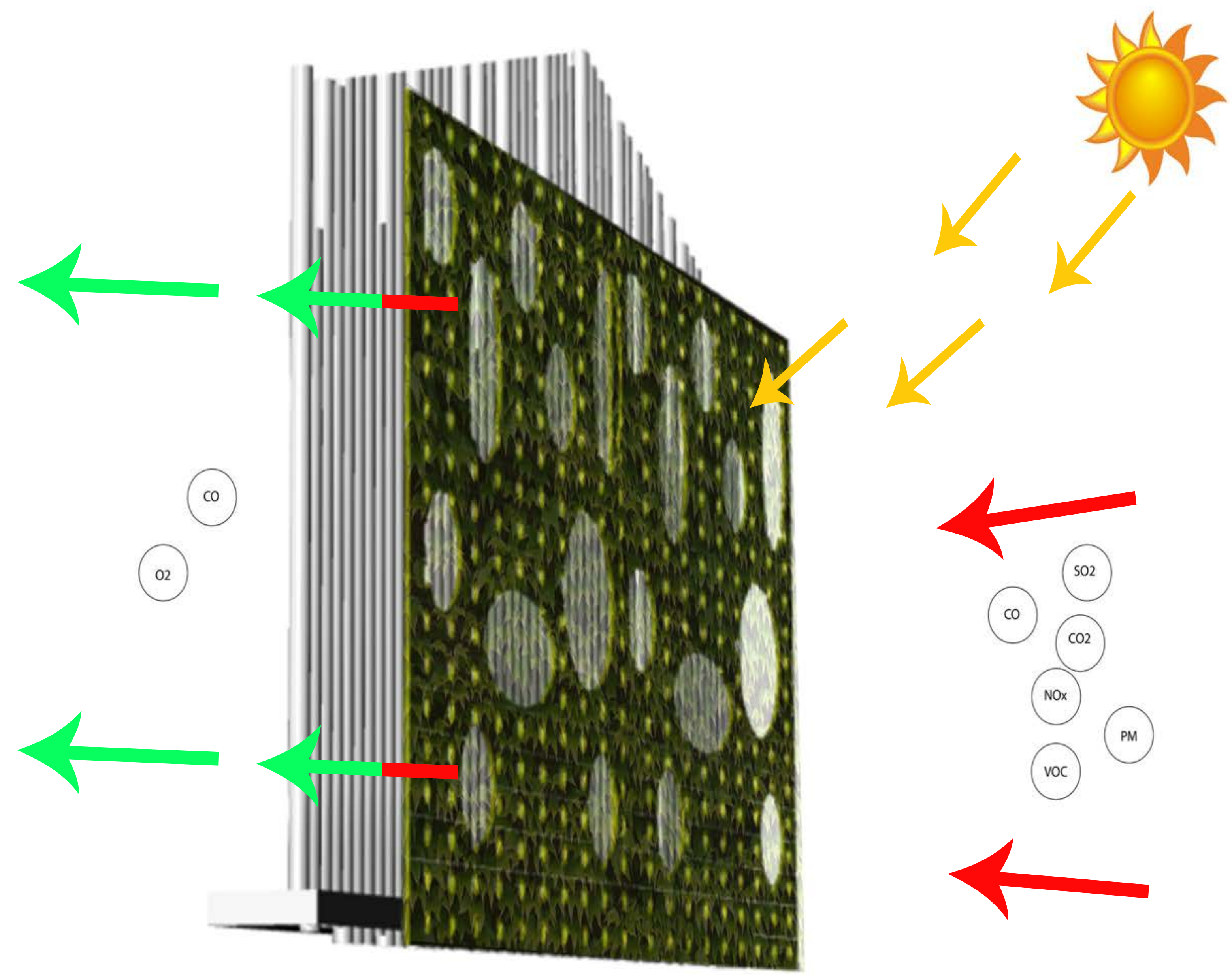
“Photo-catalysis is a type of catalysis that results in the modification of the rate of a photo-reaction – a chemical reaction that involves the absorption of light by one or more reacting species - by adding substances (catalysts) that participate in the chemical reaction without being consumed”. We changed the layout of the walls to intertwine with one another, a means of weaving bamboo to create resting points for plants to grow on the façade. Green is allowing plants to grow while gray is where the Tio2 will be located.

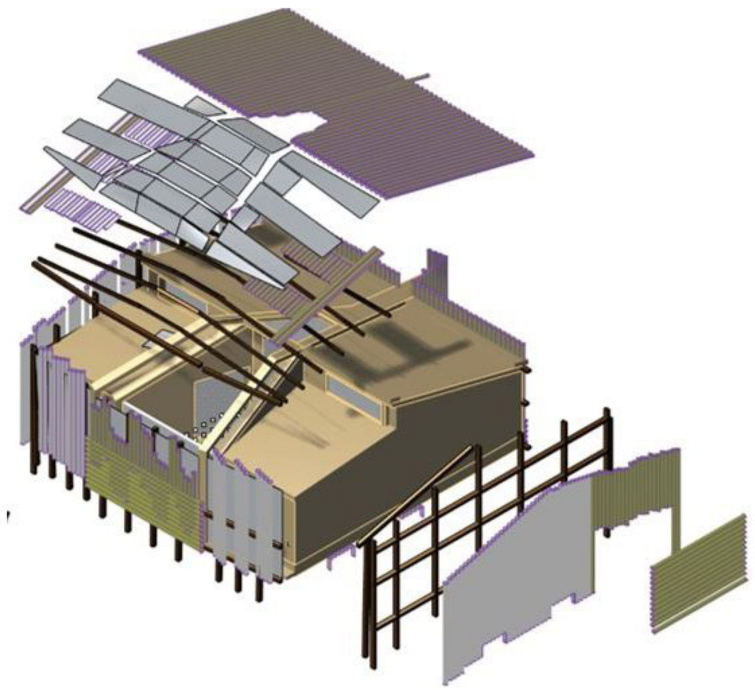
FACADE + SHADING

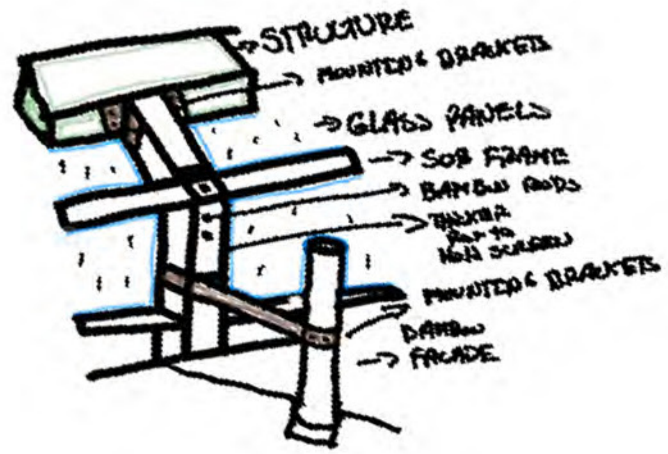

Bamboo Facade

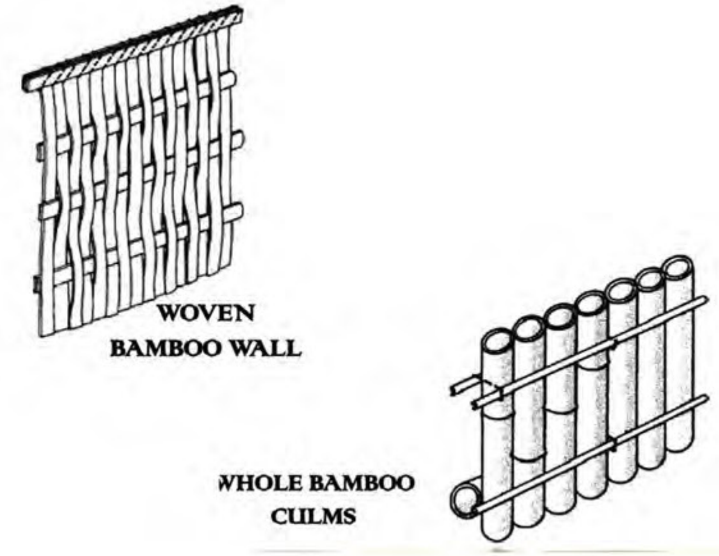

Perferated Bamboo Screen

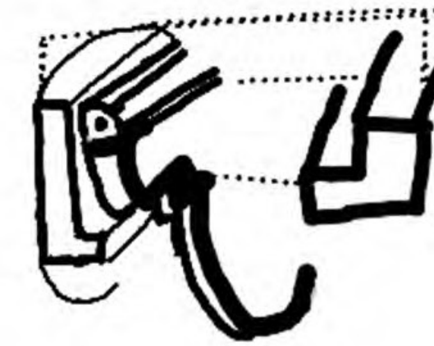

Ivy Green Wall System

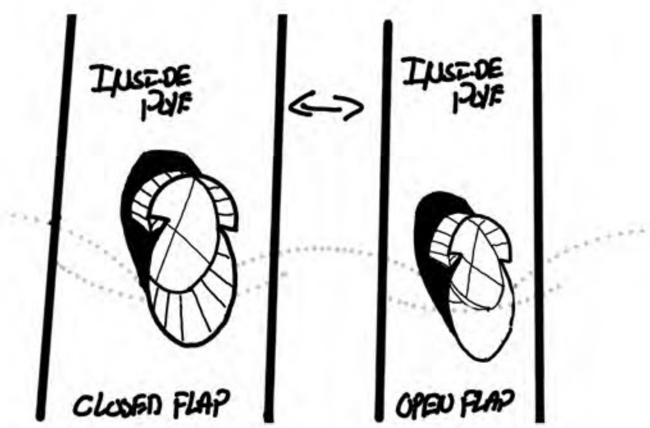


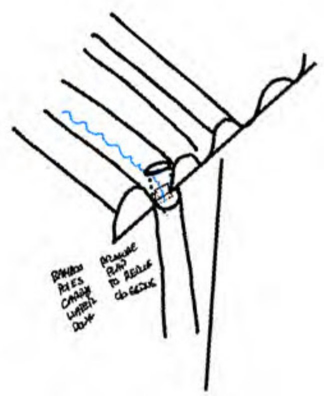


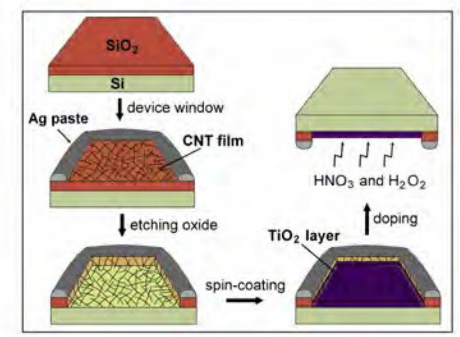




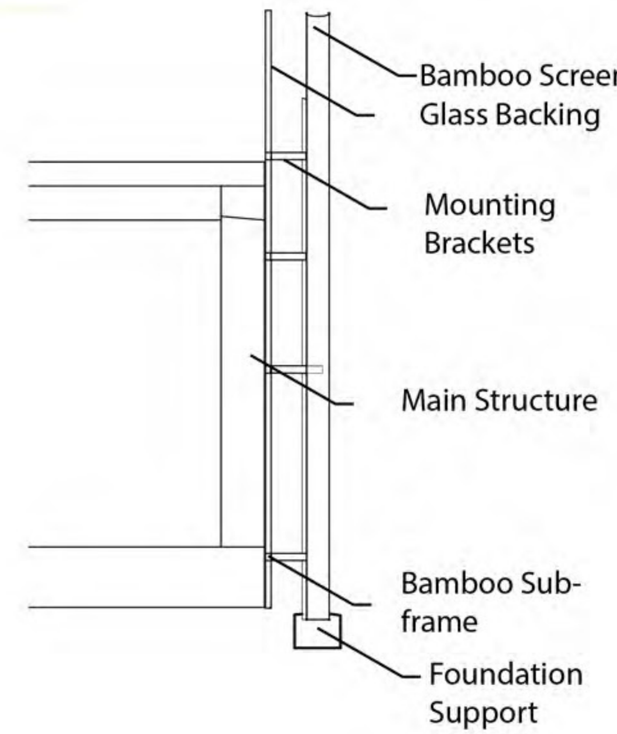


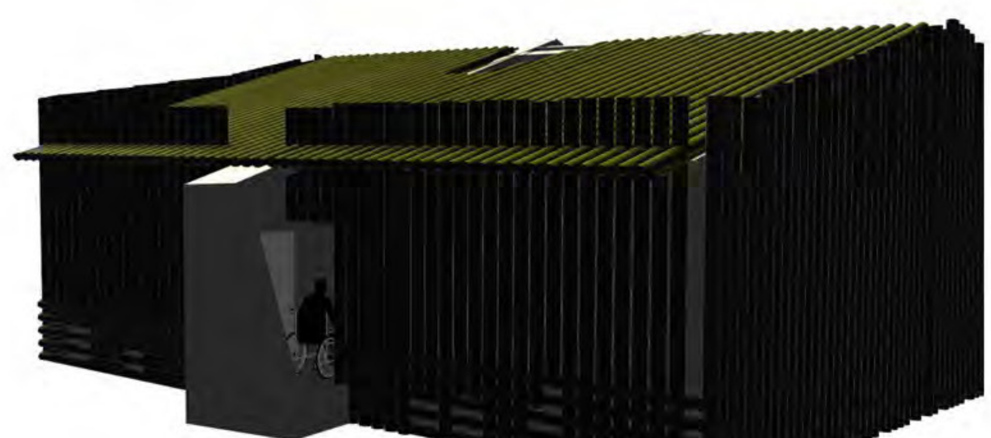


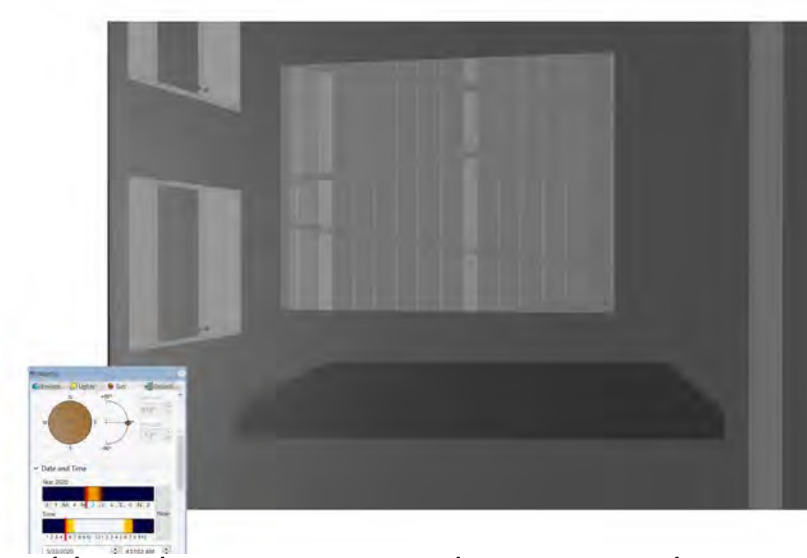




"TiO2-Coated Carbon Nanotube-Silicon Solar Cells with Efficiency of 15%"
https://www.nature.com/articles/srep00884





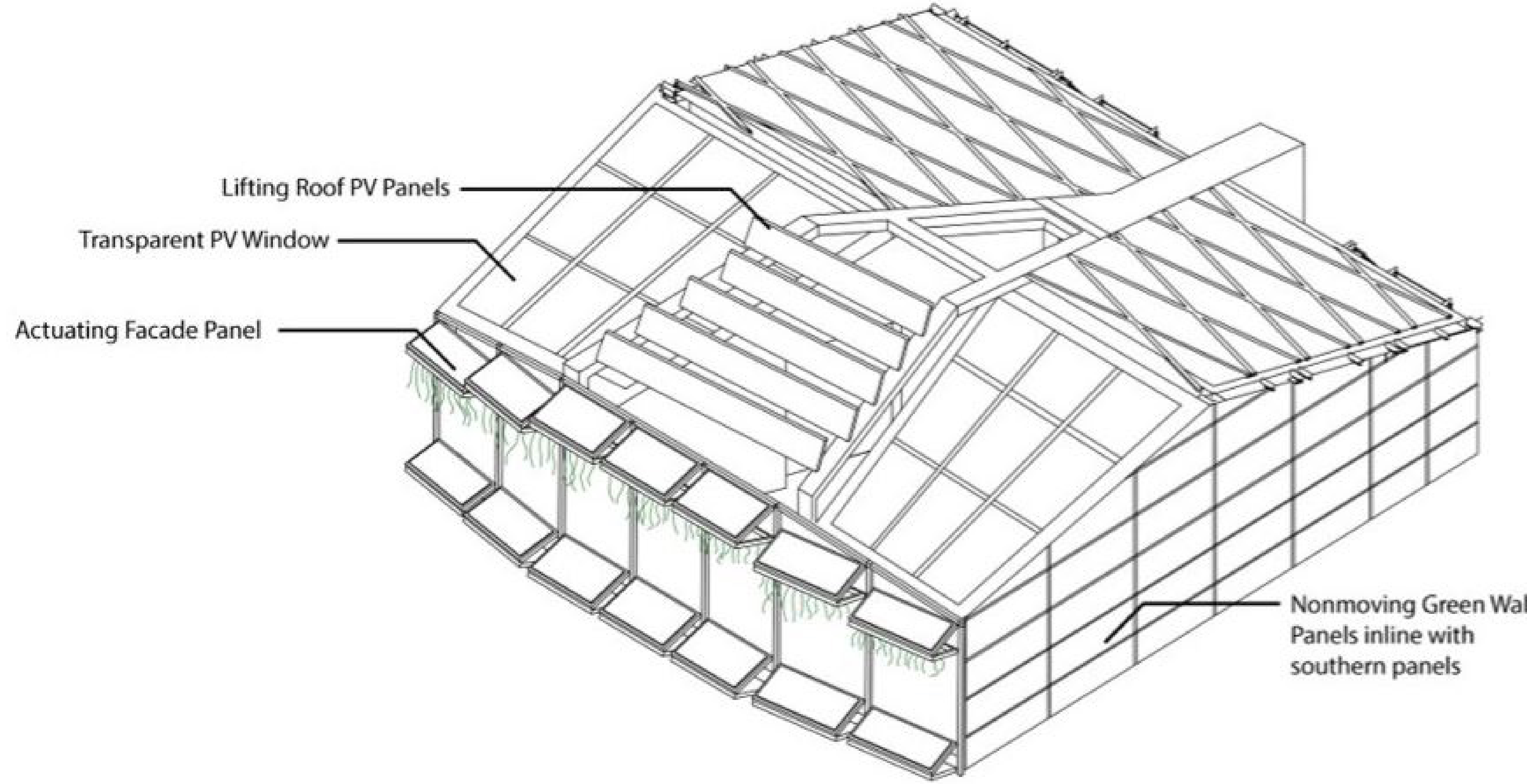


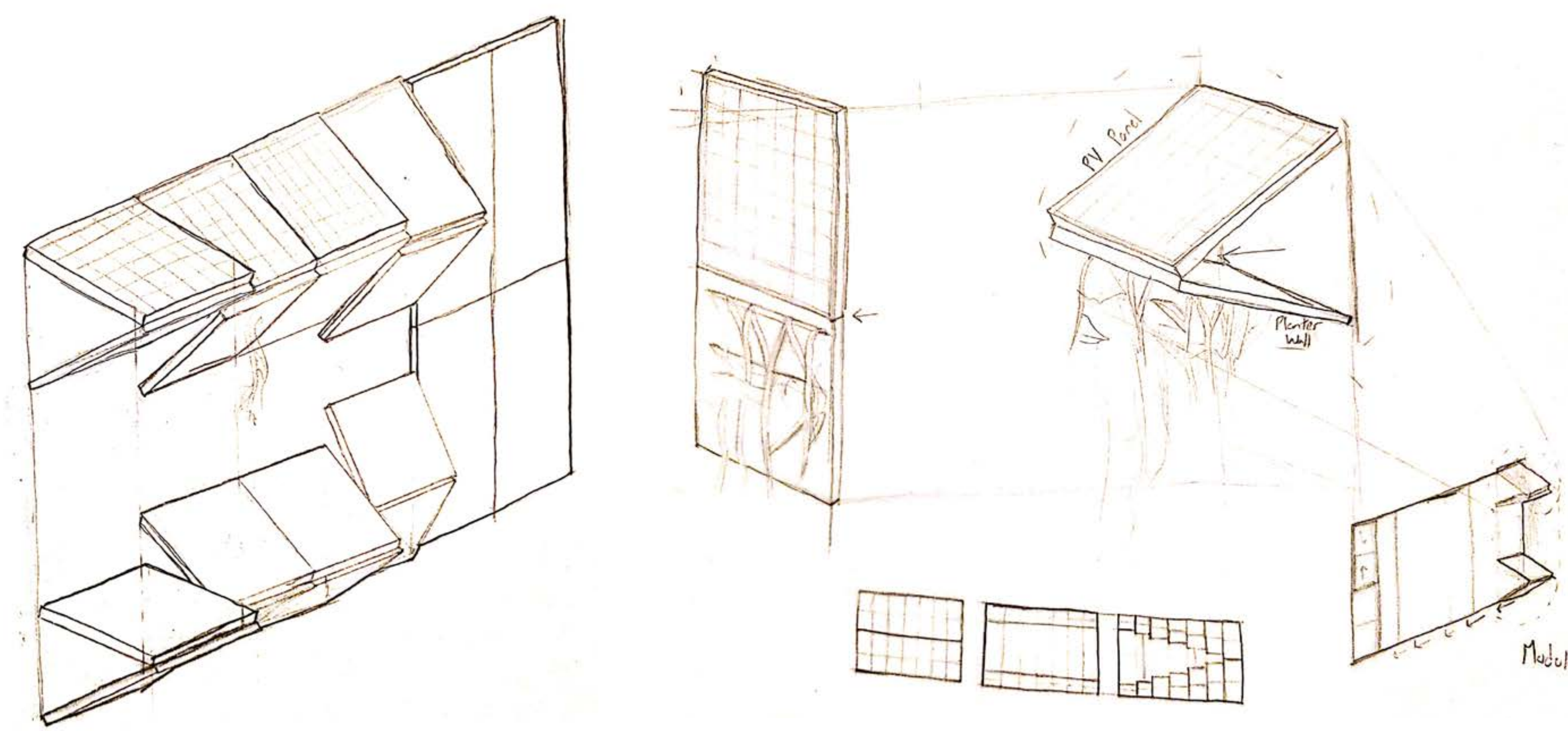
SCHEMATIC DESIGN

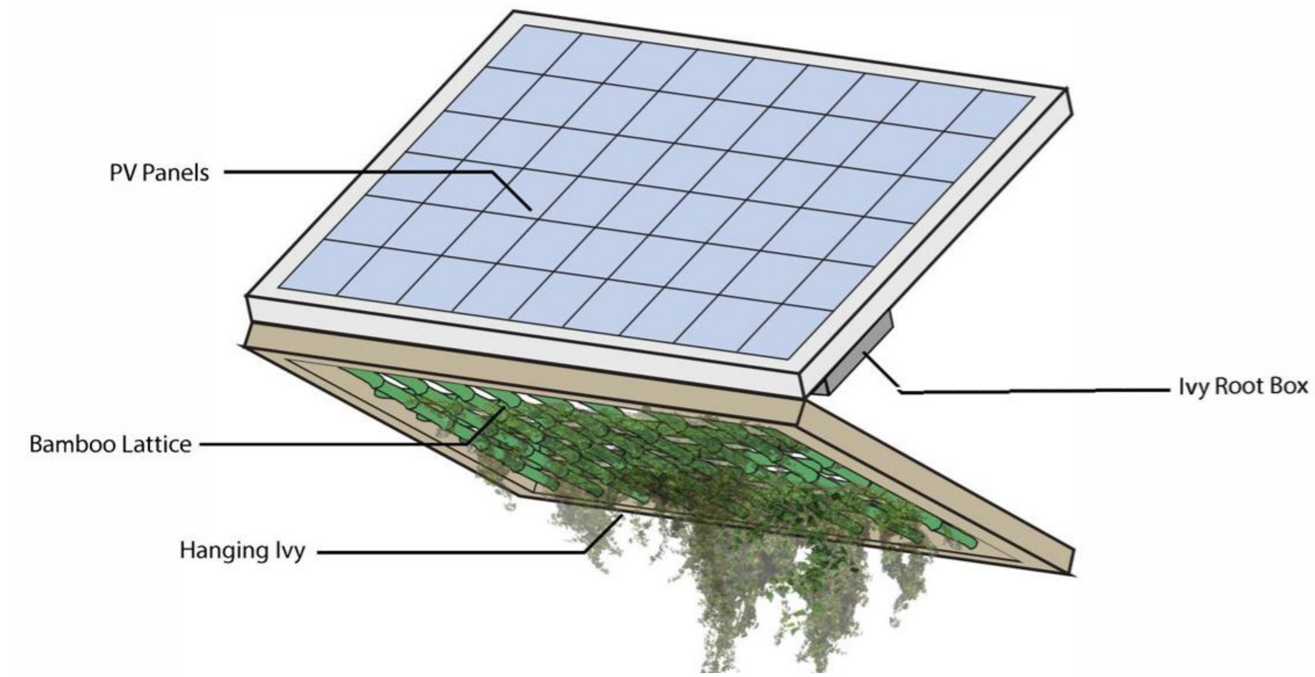
ACTUATING BI-FOLD FACADE

In this early proposal, we focused on the role of sun, views and interactivity. The proposal suggests a kinetic façade system in 2 parts, an upper PV panel and a lower bamboo lattice that houses hanging ivy. When open, the, PVs catch better angles of sunlight, and provide a canopy of shade for the residents on the other side of the wall, when closed, the panels can catch lower angle sun and shut out any unwanted views from the exterior, creating a more direct boundary.

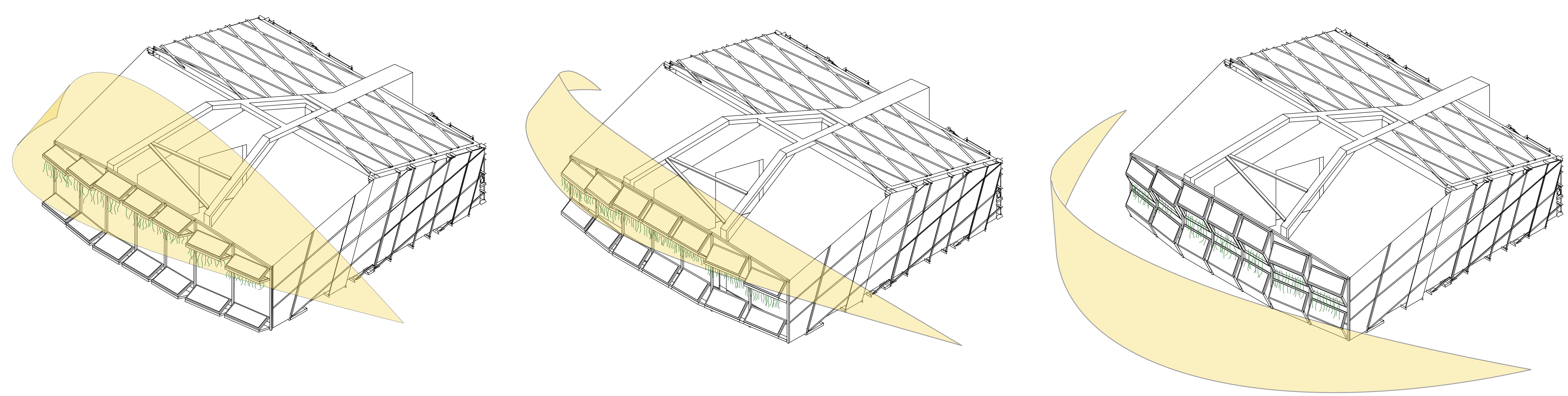
In the proposal, the individual panels would operate independently, creating a dynamic space and play of form around the project. The panels would extend onto portions of the southern roof to generate even more energy and provide dynamic shading at different points in the day. Portions from this proposal would be reconsidered later on in the final proposal as the mechanism for the solarium doors.






PV Panels
Ivy Root Box
Bamboo Lattice
Hanging Ivy


Summer-72 Degree Angle
Spring / Autumn-49 Degree Angle
Winter-26 Degree Angle



SCHEMATIC DESIGN

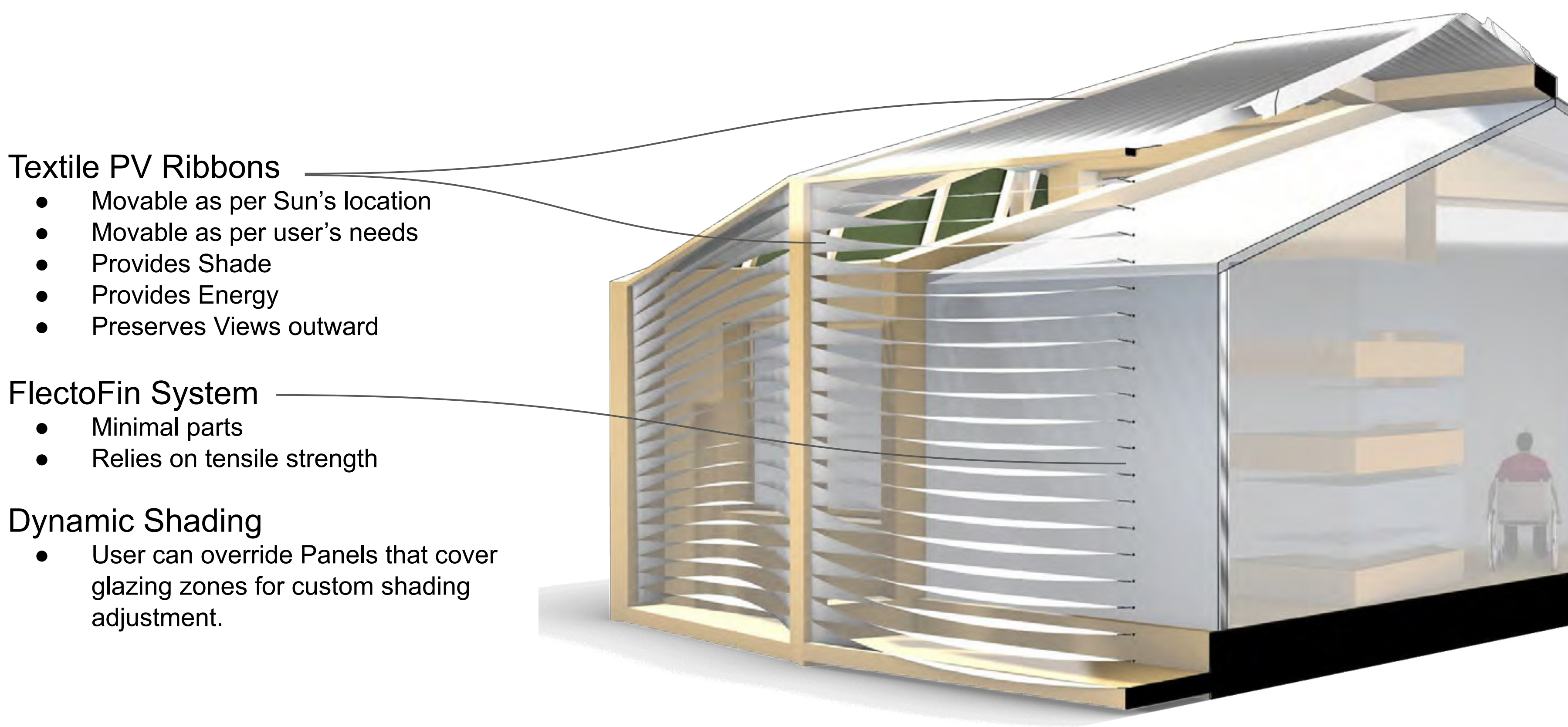
FLECTO FIN FACADE

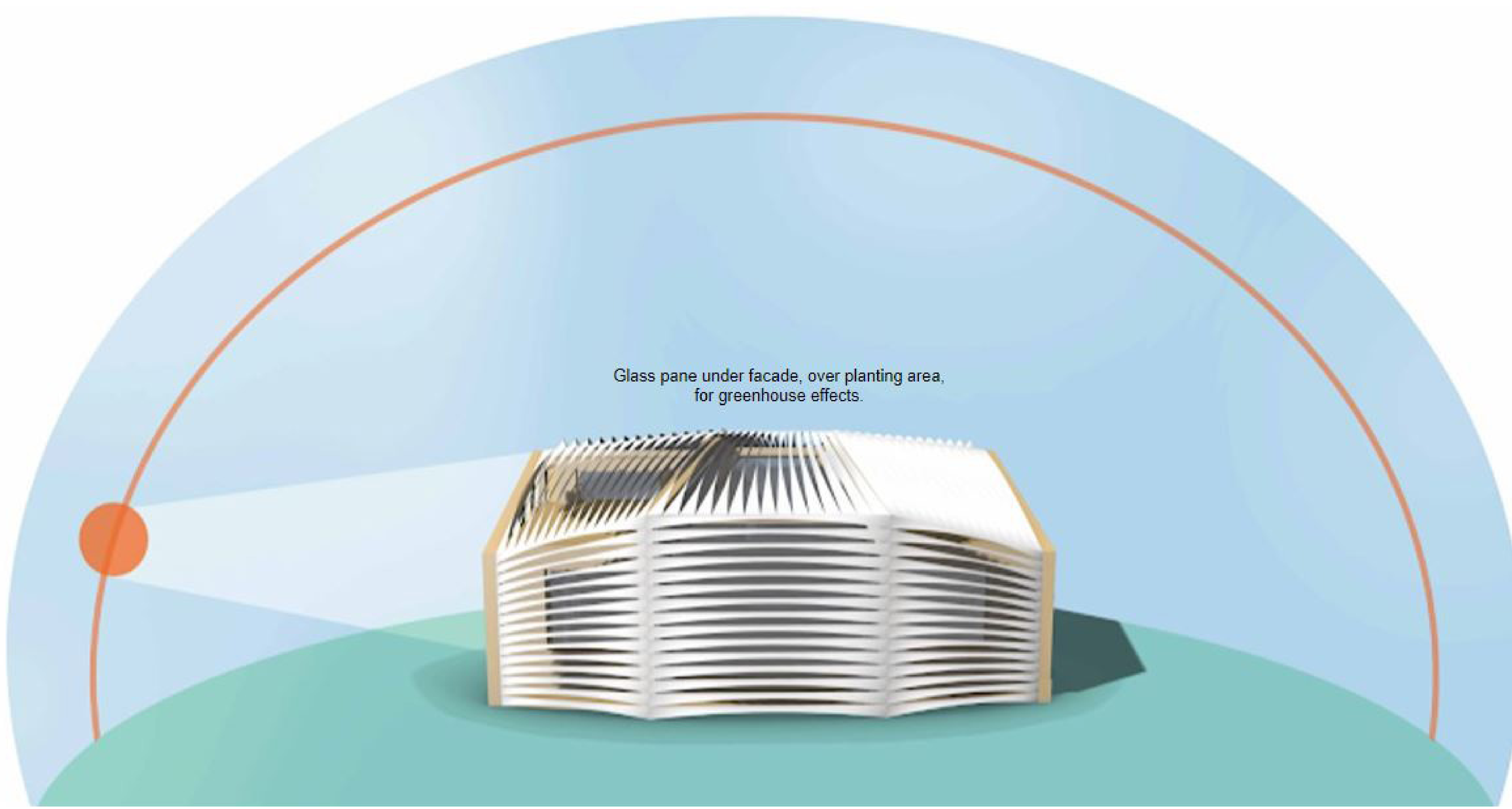
The materiality of this proposal was very malleable and easy to manipulate. The goal was to research a shading system that was reactive to its environment, while providing sufficient lighting through the proposed building structure. What stood out about Flectofin is that based on the necessary shading required, the material could be adjusted by applying force to both ends of the singular panel or fin which is called a hinge-less flapping mechanism. Its elastic flexibility allows the thin membrane to perform as efficient as possible while creating a parametric aesthetic.

The goal of this proposal was to create 6 different framing bays of flectofin and based on its location in terms of the sun each bay would react separately to the sun. These ribbons would not only allow views out but also allow enough sunlight within the structure. Along with the sunlight it would allow for ventilation throughout the building based on the reaction necessary by the sun. These ribbons terminate at East and West primary structures to allow for a better aesthetic and ventilation.

Fig.22-24: Kinematic facade of the Thematic Pavilion EXPO 2012 in Yeosu, South-Korea.
Architects: soma-architecture, Vienna; Engineer for Kinetic Facade: Knippers Helbig, Stuttgart, New York.

Fig.5: Simulation of the deformation in finite elements.





OPEN

HALF OPEN

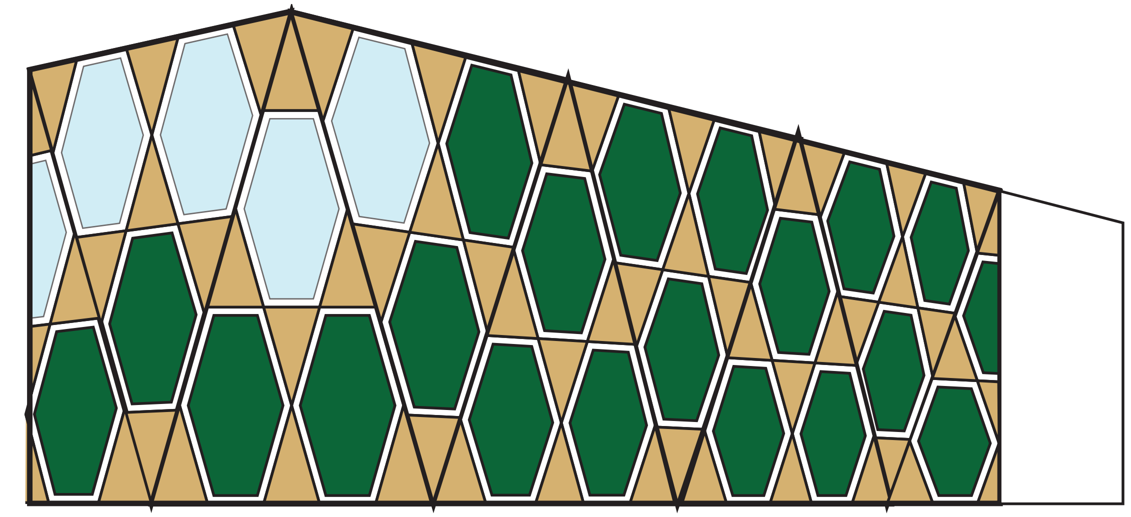
CLOSED

SCHEMATIC DESIGN

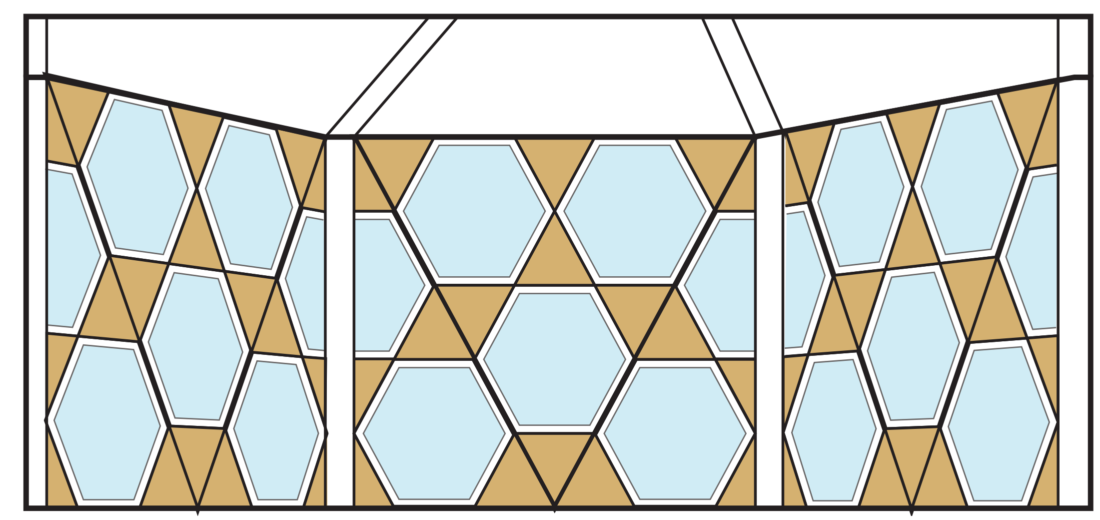
MODULAR HEX FACADE

The goal of this proposal was to create adaptable and easily swappable panels that “plug and play” into the façade secondary structure. These modules would directly respond to the needs of the interior spaces. Where greater light transmission is required, translucent panels could be introduced. Where shading is required our operable “aperture” panel would allow variable light exposure. While the water trombe modules would allow the introduction of thermal mass.

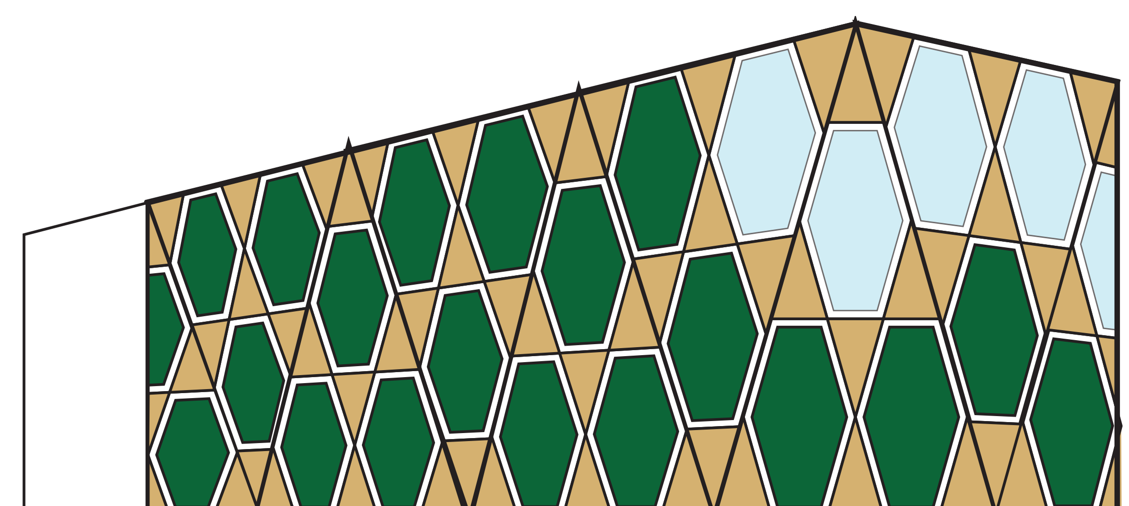
The benefit of the hexagonal tiling layout in this proposal was to introduce modularity to the Y-House, as well as simple construction by having repeatable manufacturable units. In the elevations shown, the different tiles coordinate with the relevant façade. As seen on the Southern façade, trombe hex panels would be utilized to store heat for the structure via passive solar gain.



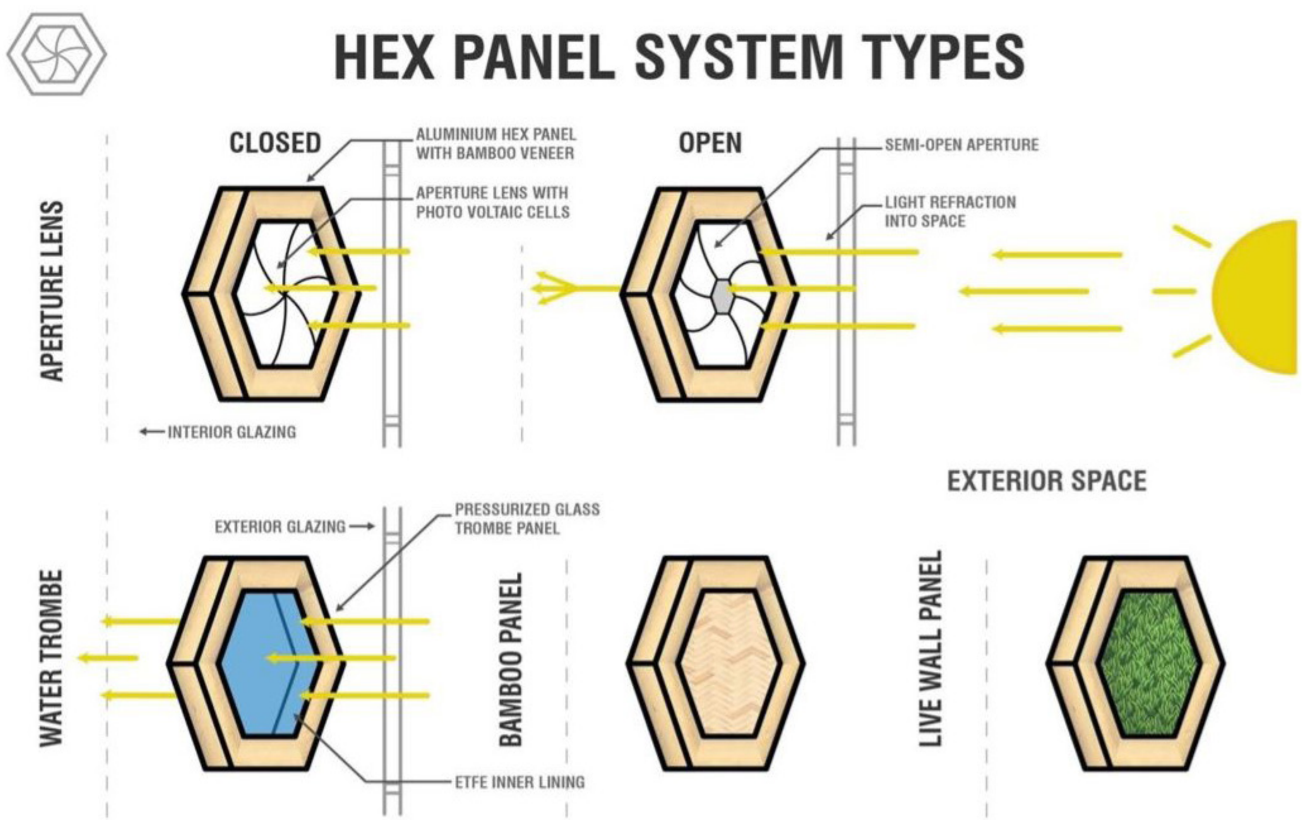
EAST ELEVATION

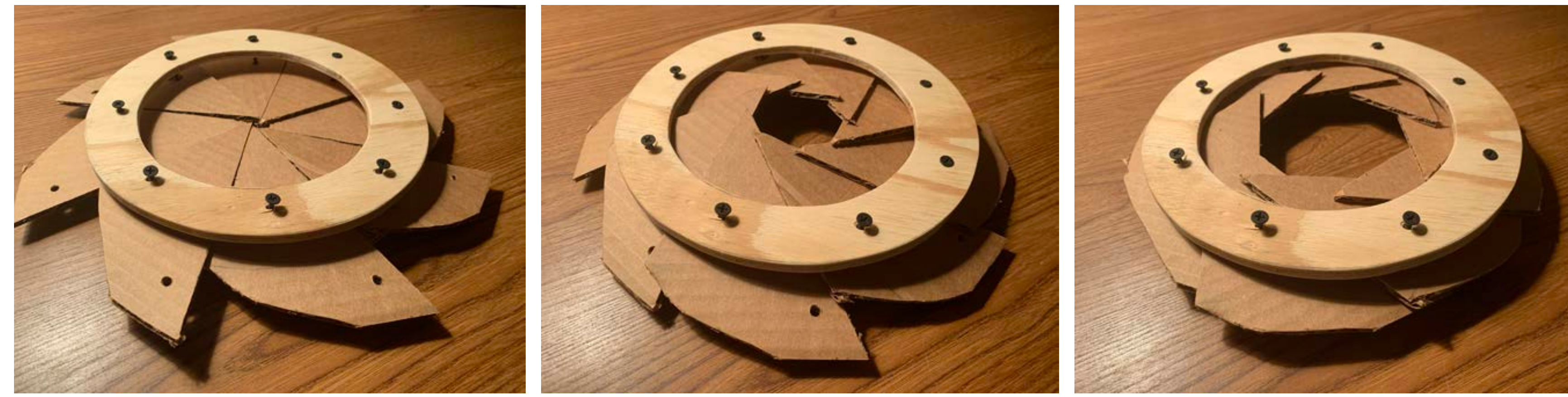


SOUTH ELEVATION



WEST ELEVATION





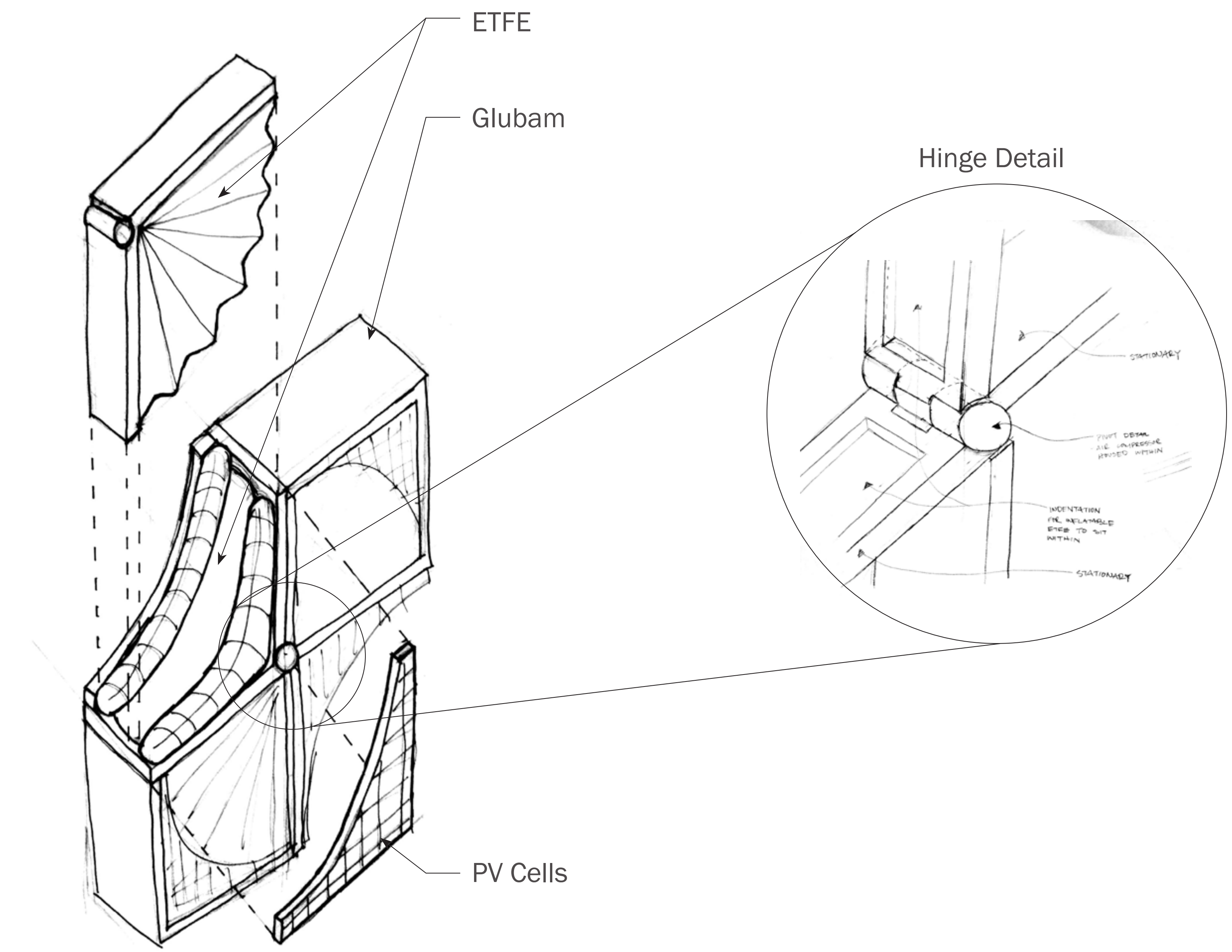
Western facade with live wall panel and clerestory

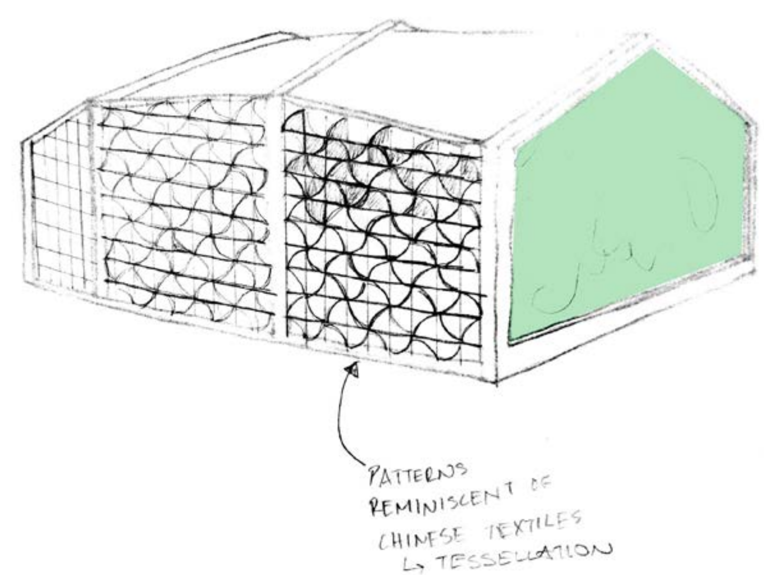
SCHEMATIC DESIGN

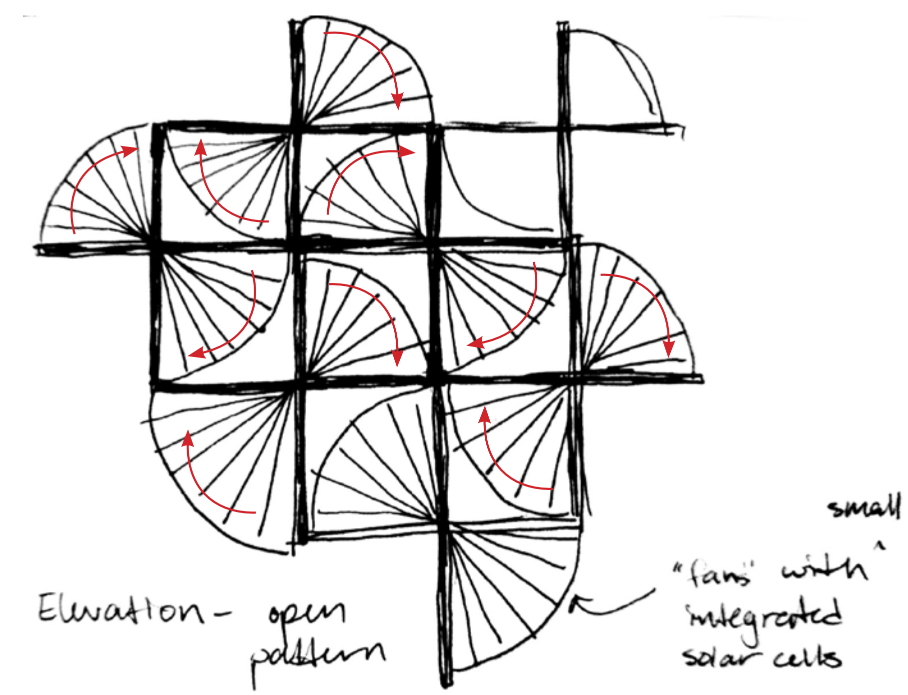
ETFE FACADE

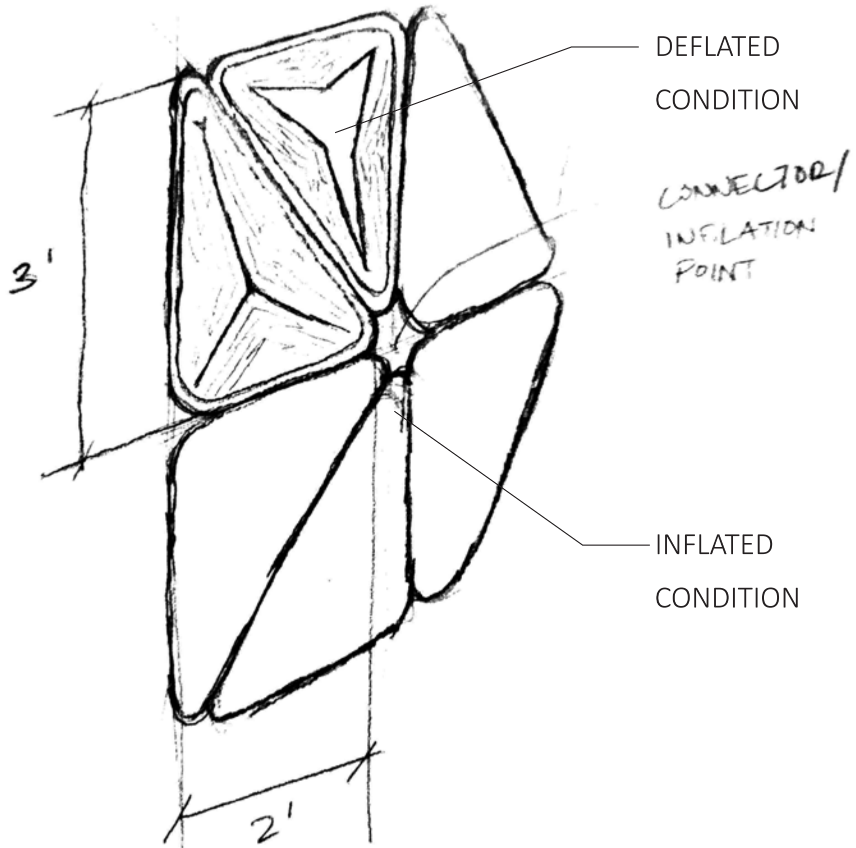
The proposed “Y-Project” of the Solar Decathlon China uses sustainable and renewable materials indicative of the vernacular to create a structural framework for a technologically innovative and sustainable way of living. The design for a double skin adaptive facade takes precedent from this strategy. It serves to communicate the re-imagination of material use to create smart, passive, and adaptive systems.

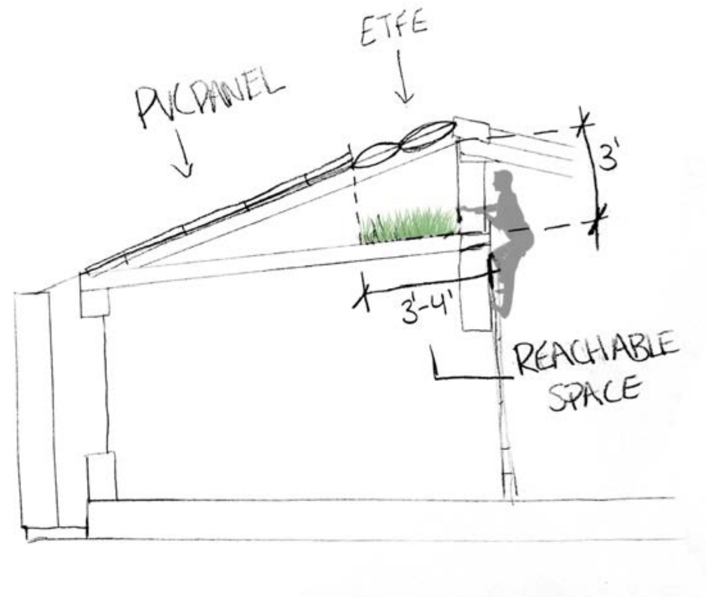
ETFE and bamboo were the primary materials used in the design, where the pneumatic ETFE system creates strong thermal insulation in winter, but can be deflated in warmer months to allow for natural ventilation. Bamboo is re-imagined as a woven or textile shading system that can open to allow for solar gain or close to provide shading. The form and patterning is indicative of the vernacular tessellation patters of Chinese windows but can adjust its form depending on environmental conditions.

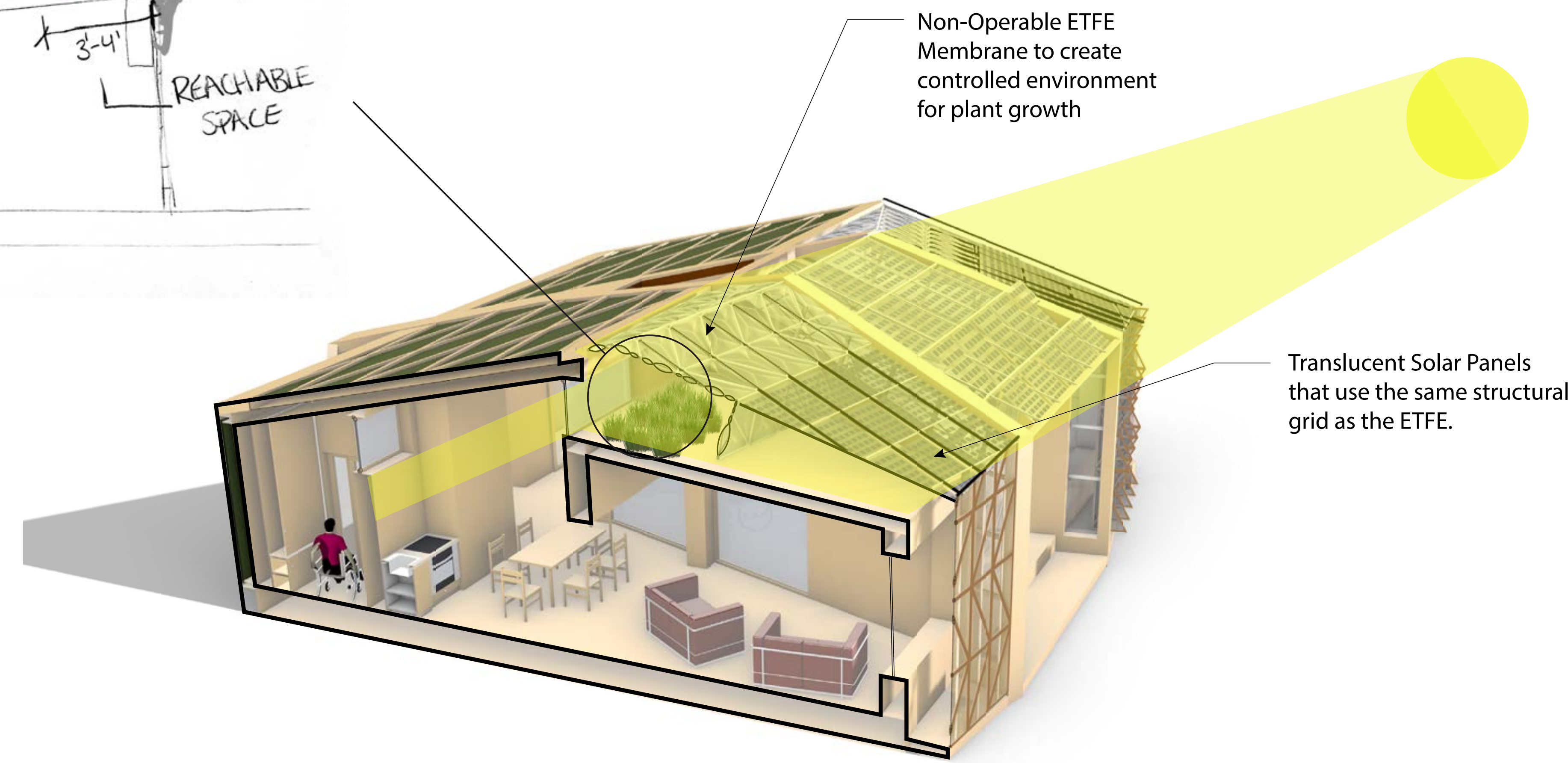




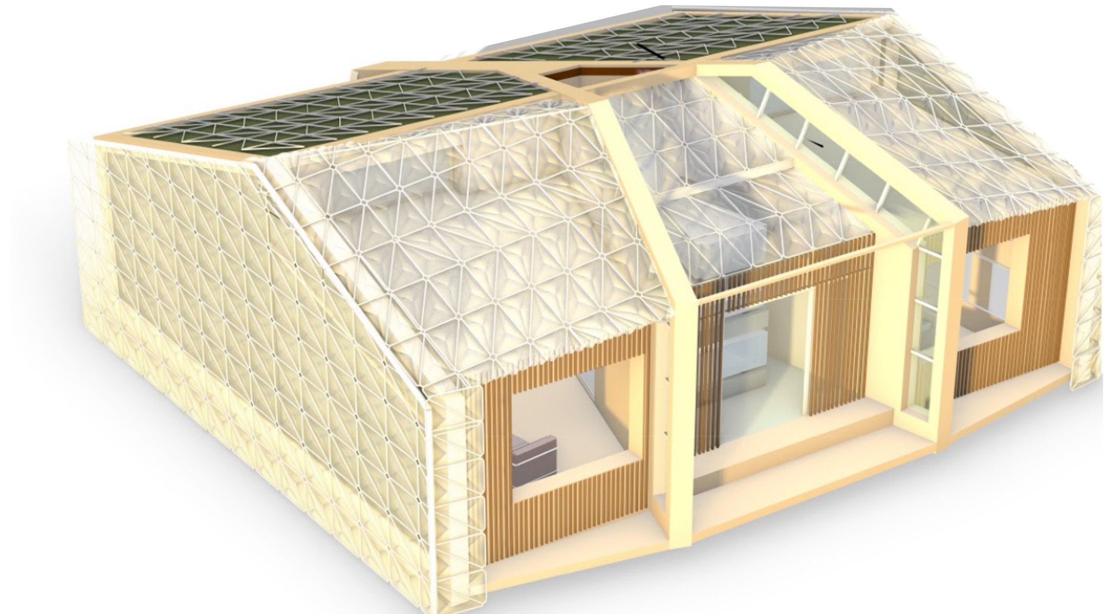


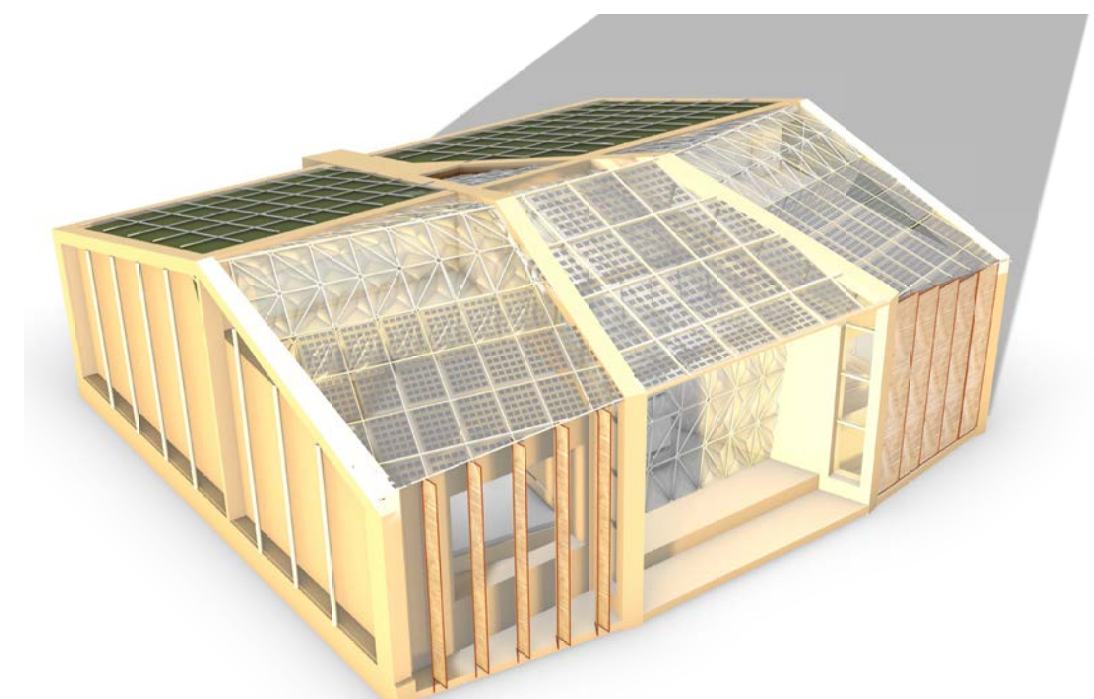







Prototype by Cynthia Baublitz





SCHEMATIC DESIGN

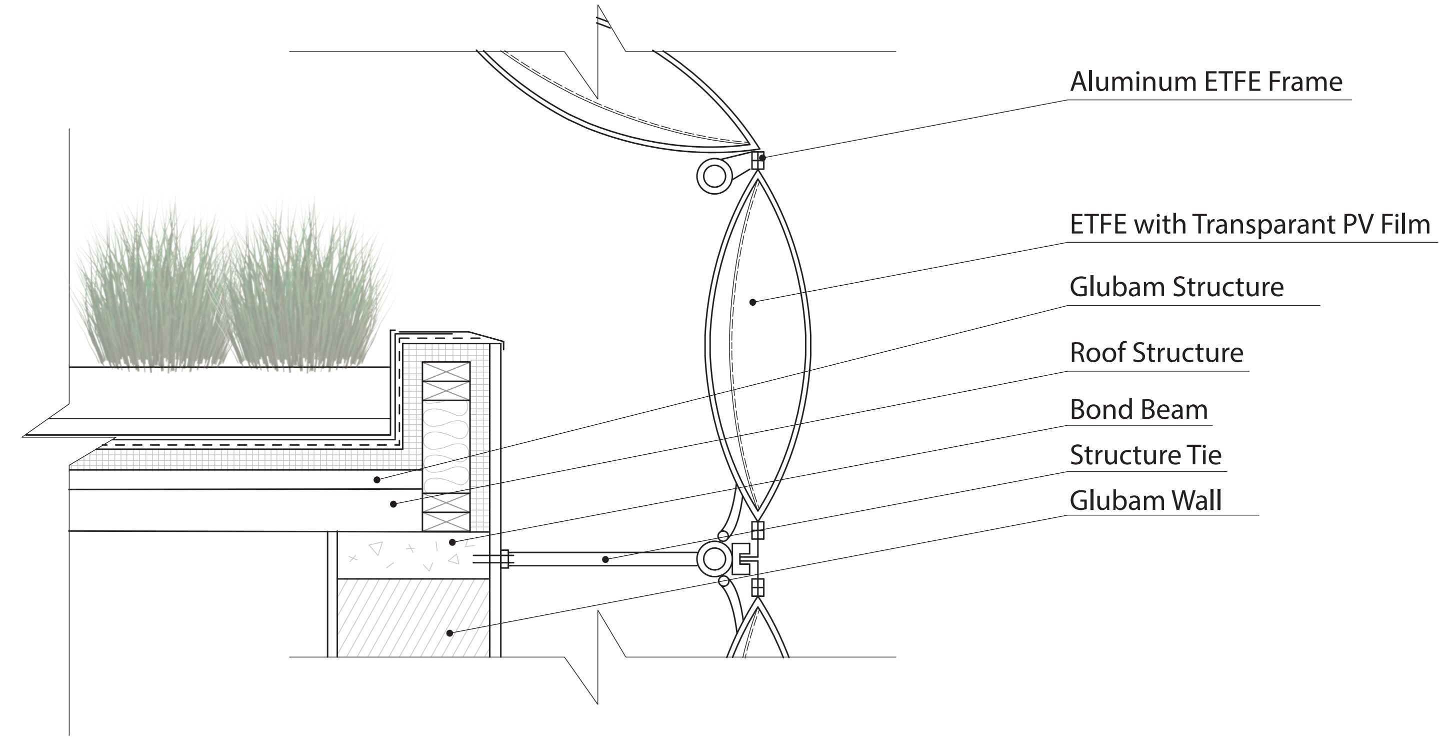
ETFE FACADE

Out of the five initial facade proposals, the ETFE concept moved forward because of its ability to use materials to passively heat the buffer space. In addition, the ETFE could be expanded upon the entirety of the building to act as a vertical greenhouse to protect the vegetation for the harsh climate.

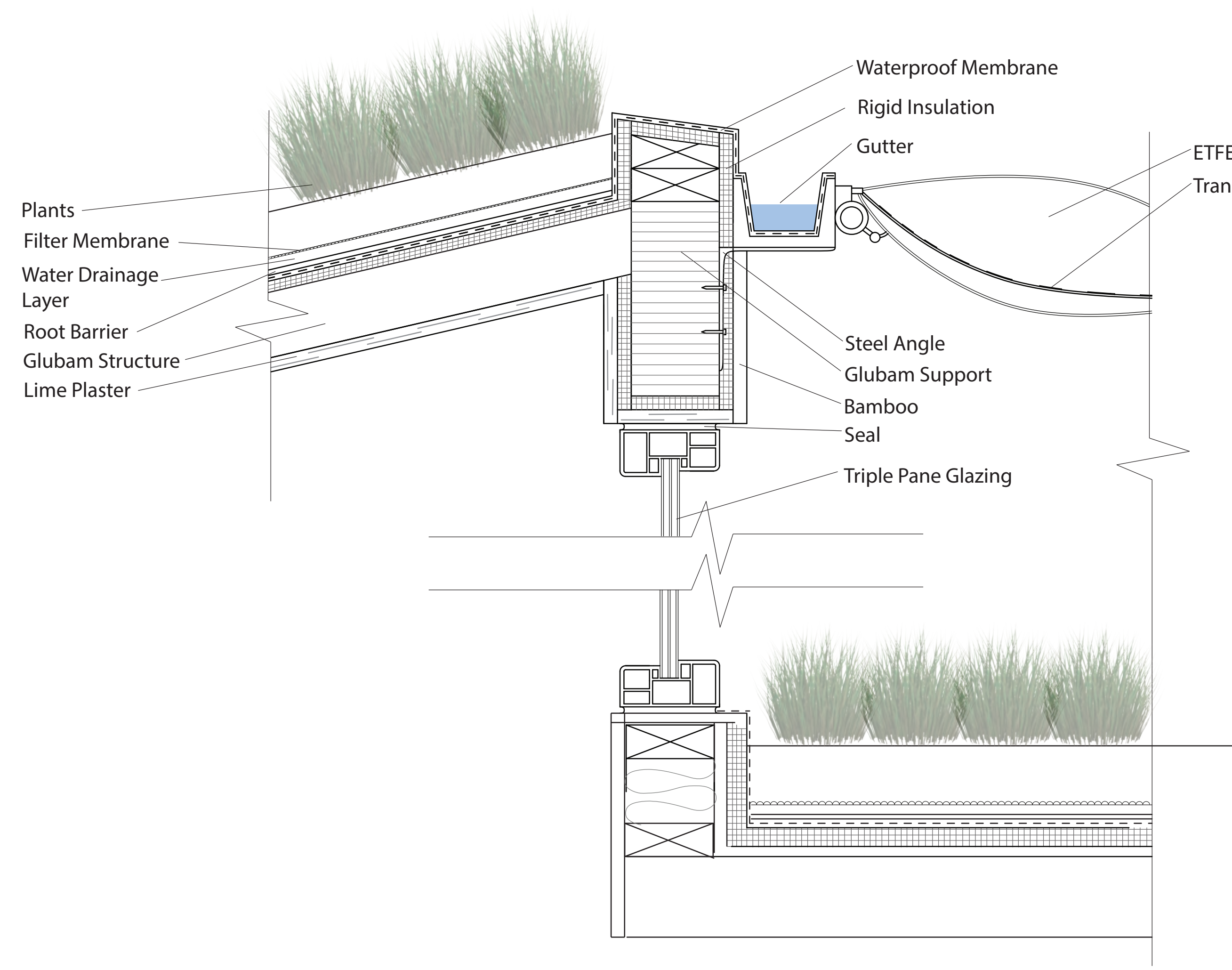
Schematic design begins to detail how the facade might be applied to the building. Detail drawings develop a language of tectonics to be carried out within the facade design of the Y-Project.

Systems such as adjustable shading mechanisms actuated by inflating and deflating ETFE layers, PV incorporated ETFE panels, inflating and deflating ETFE for ventilation, and glass with printed PVs are all potential strategies for smart and passive strategies within the facade.

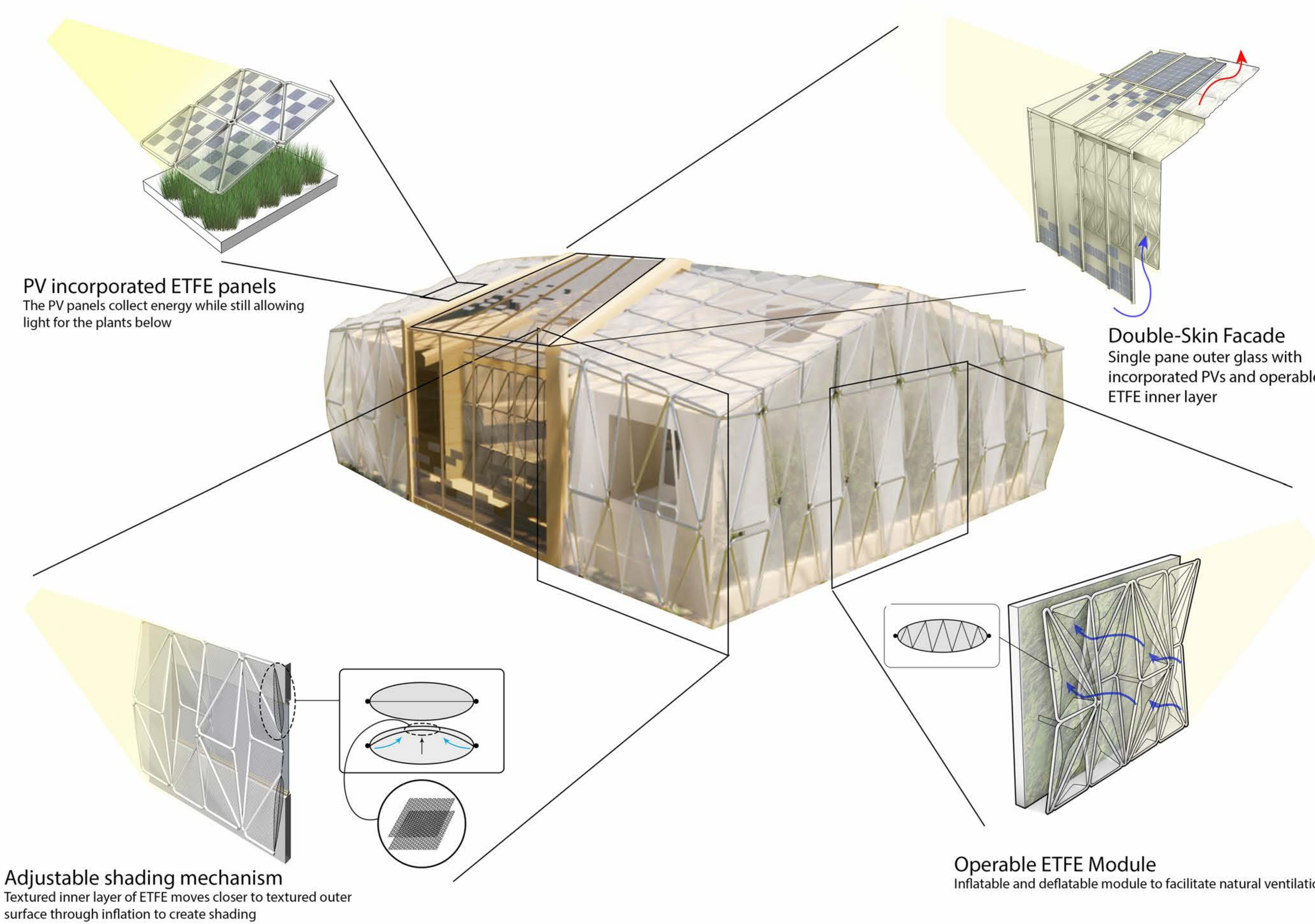
Sections depicting the solarium spaces as well as spaces on either side begin to address passive heating and cooling strategies for the different times of year.



SOUTH WALL TO ROOF DETAIL



RIDGE DETAIL

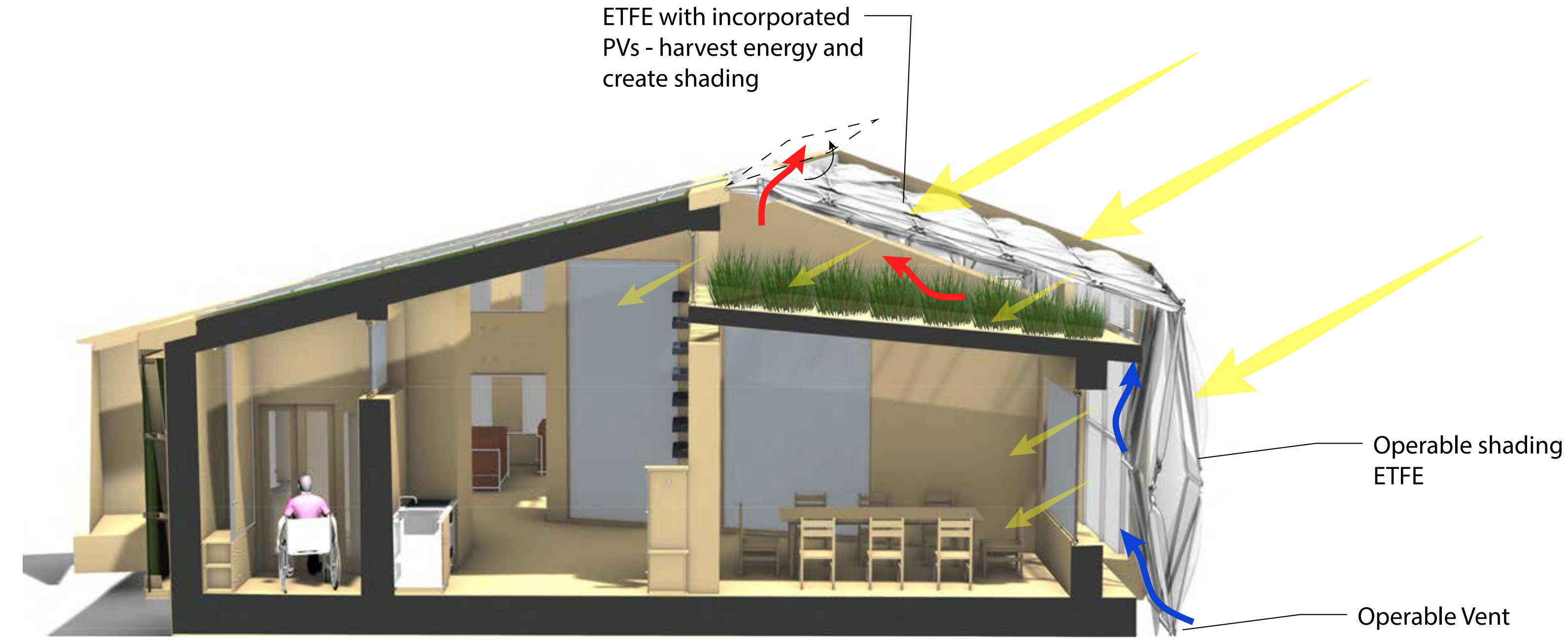

PV incorporated ETFE panels
The PV panels collect energy while still allowing light for the plants below
Double-Skin Facade
Single pane outer glass with incorporated PVs and operable ETFE inner layer
Adjustable shading mechanism
Textured inner layer of ETFE moves closer to textured outer surface through inflation to create shading
Operable ETFE Module
Inflatable and deflatable module to facilitate natural ventilation

SCHEMATIC DESIGN

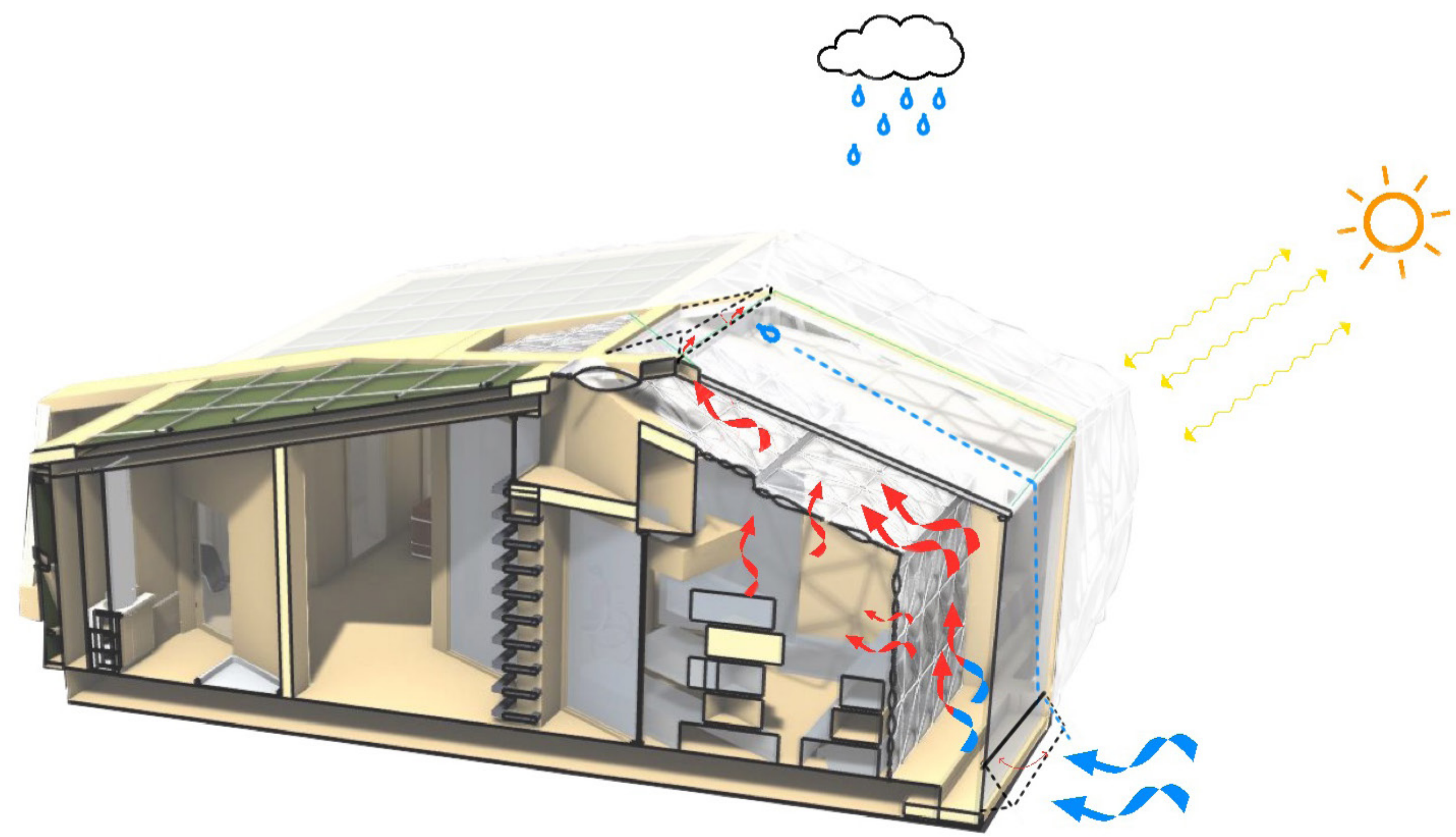
ETFE FACADE - PASSIVE STRATEGIES

The ETFE was chosen for its transparent/translucent properties which would facilitate solar heat gain to occur within the double skin. Recognition for the need of passive ventilation was very early as heat gain in moderate months would be too great.

The center solarium utilized a glass outer layer to prevent water from seeping through the inflating and deflating ETFE layer beneath. The deflated ETFE and the operable glass elements would allow natural ventilation to take place.



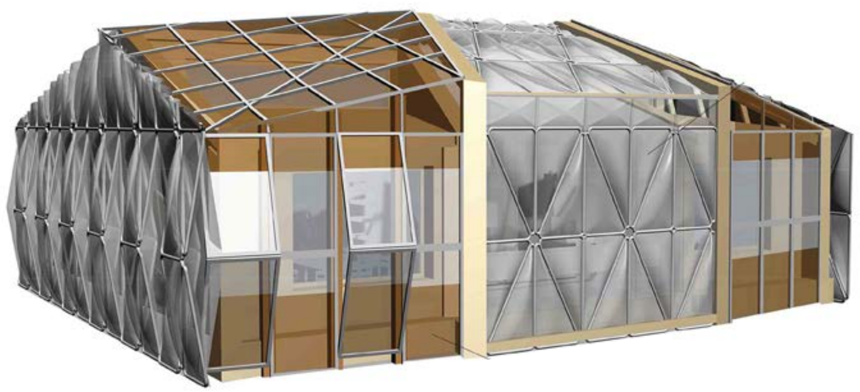
SECTION THROUGH SIDE BAY

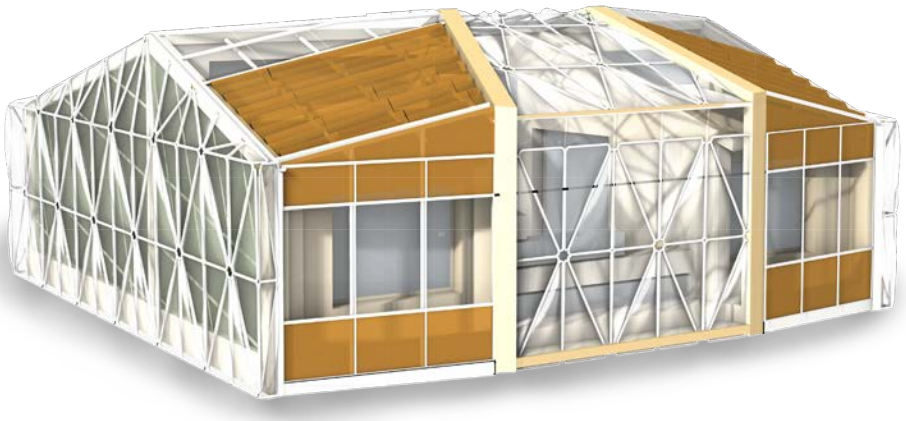


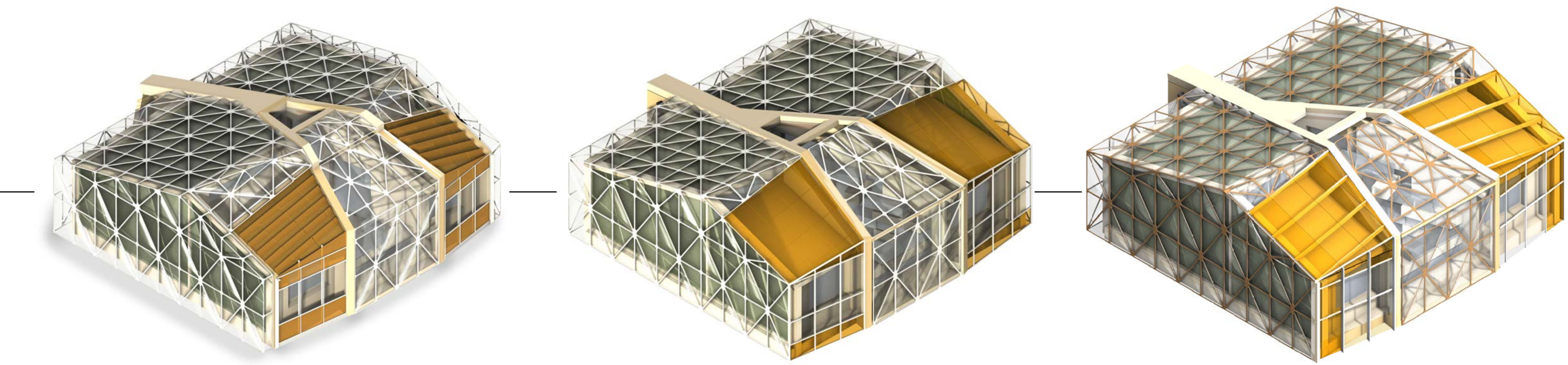
SECTION THROUGH SOLARIUM

The schematic design process and submission of the Y-Project establishes a conceptual and formal language. In locations where there is vegetation, there is a layer of protective second skin of ETFE to create a vertical greenhouse. In addition, it also establishes the center solarium on the southern facade as the central feature of the building that is framed by the “Y” structure that wraps from north to south. To articulate this language visually, a material that differs from the ETFE wrapping is chosen to highlight the solarium while still maintaining solar heat gain. Passive strategies for solarium space is developed.

DESIGN DEVELOPMENT





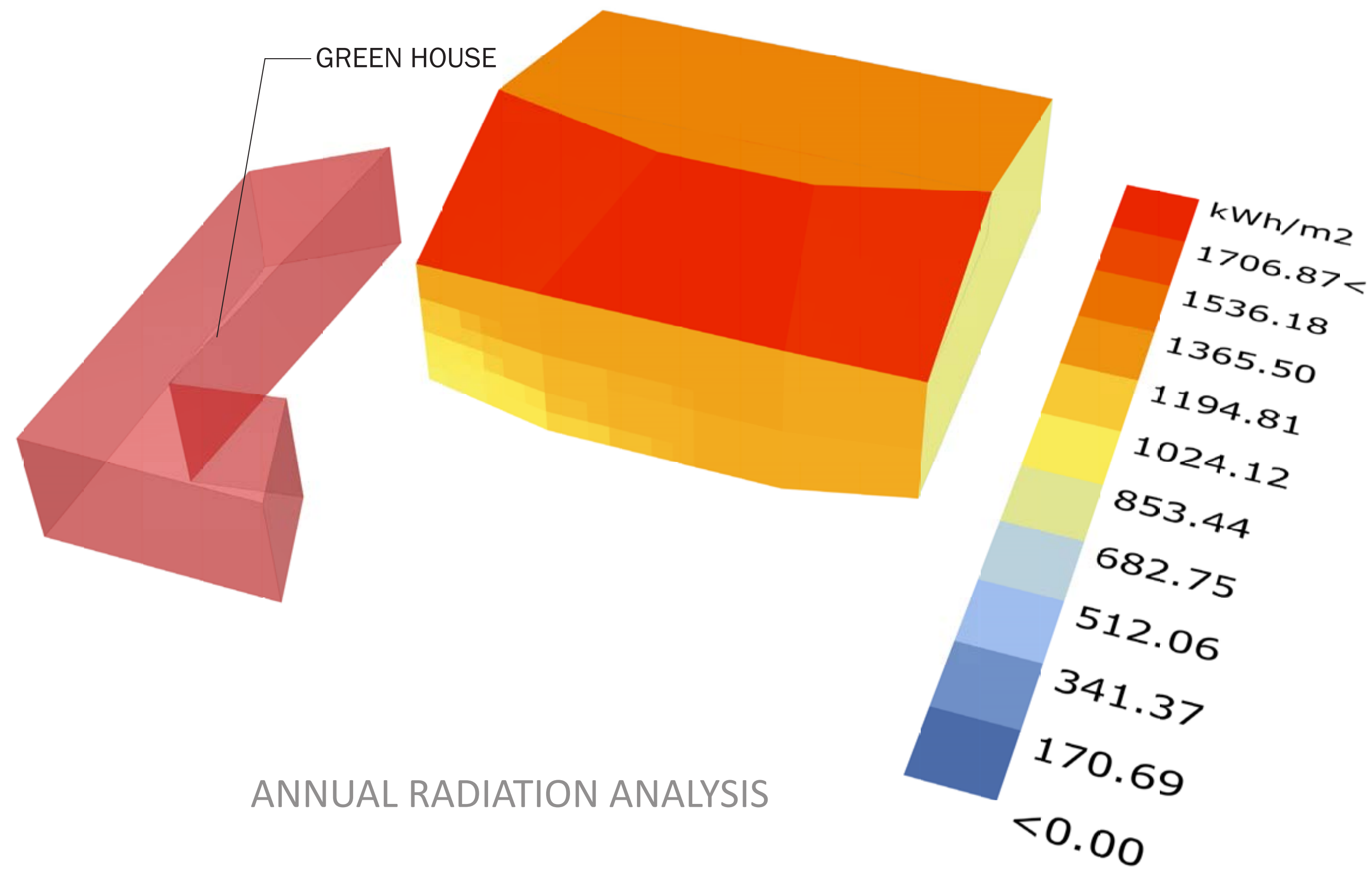


DESIGN DEVELOPMENT

ETFE FACADE - PASSIVE STRATEGIES

Early on, the team recognized the importance of digital analysis in determining the aesthetic and effectiveness of the project. Through programs such as DIVA for Rhino 6, we were able to create both daylight and radiation analyses for the initial proposal. Through DIVA, efficient sun angles and sun paths were analyzed to evaluate the effects of the ETFE proposal on the interior daylighting.

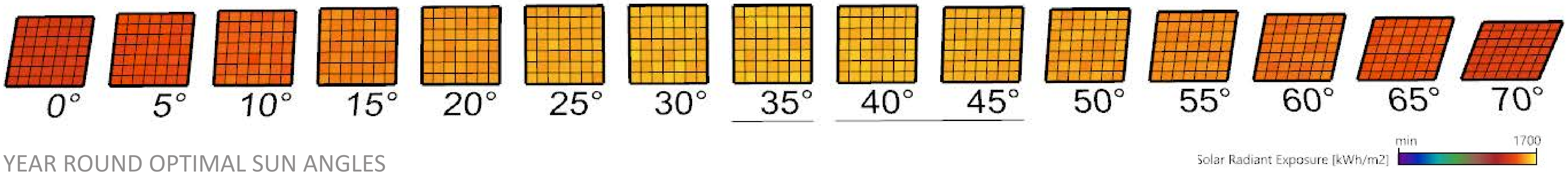
At the top of page 29 are sun studies created to discover the correct angle for the southern roof to be directed at; both year-round, and during the competition period. After consultation, we determined that between 35° and 40° would be optimal.



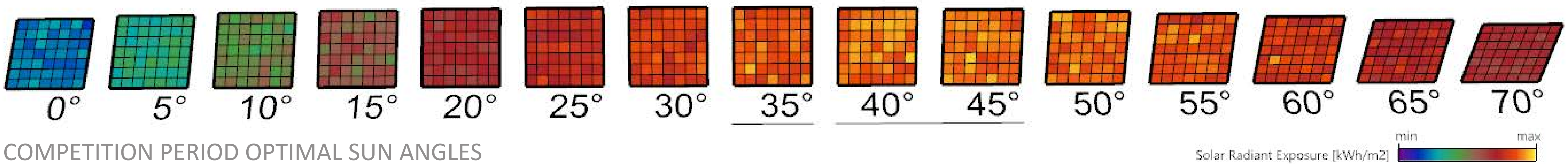
ANNUAL RADIATION ANALYSIS

EQUINOX AT 9:00am DAYLIGHT ANALYSIS

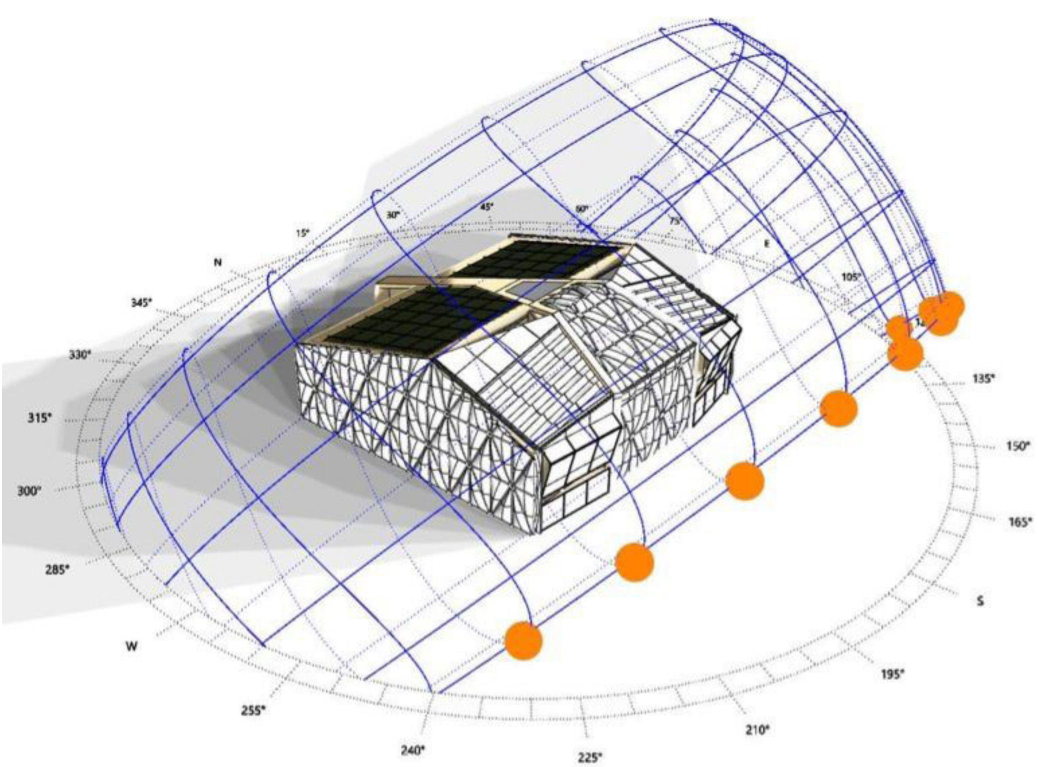
EQUINOX AT 9:00am DAYLIGHT FALSE COLOR



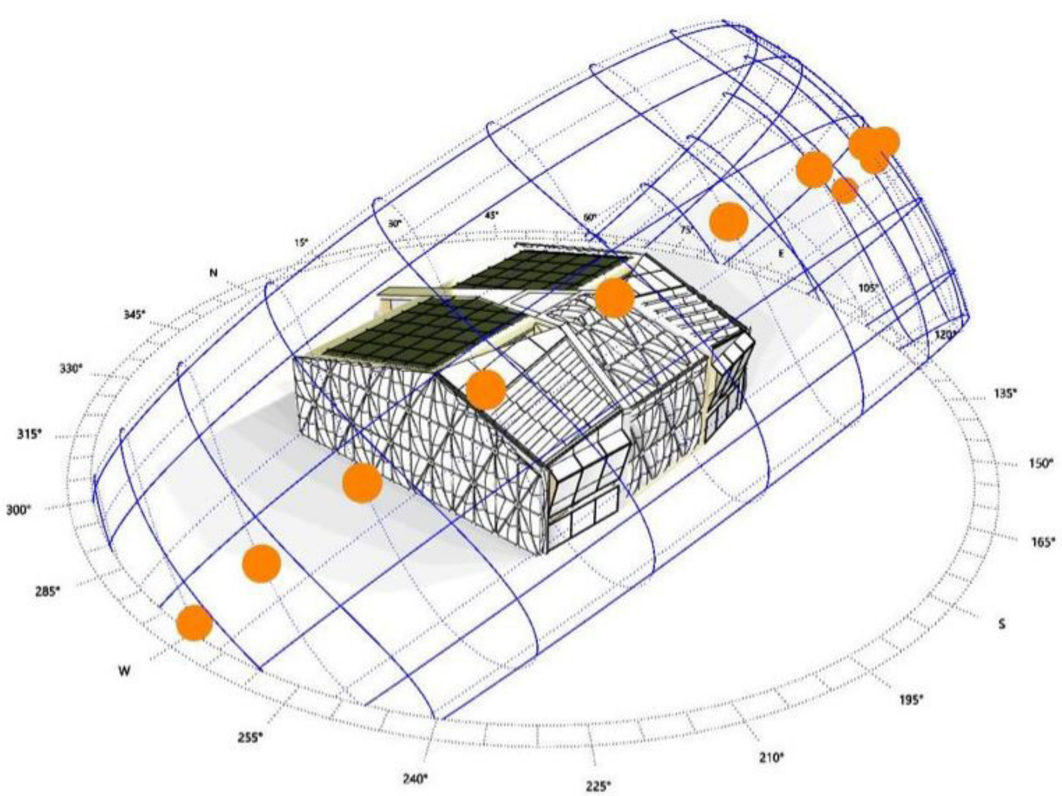
YEAR ROUND OPTIMAL SUN ANGLES



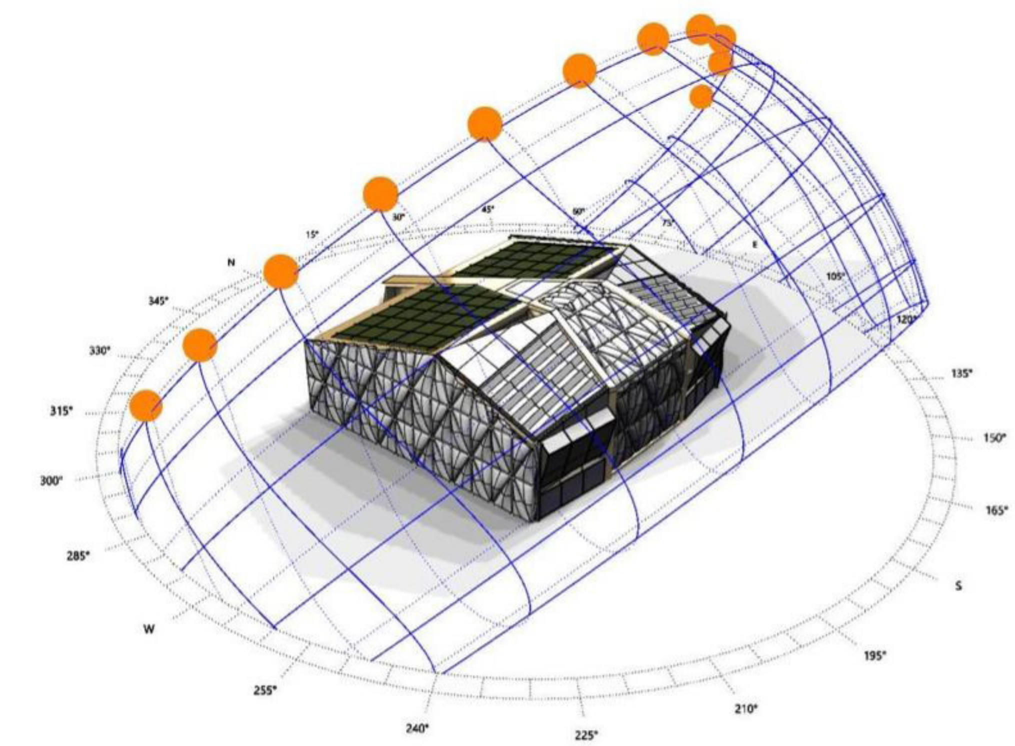
COMPETITION PERIOD OPTIMAL SUN ANGLES



JANUARY SUN ANGLE



MARCH/SEPTEMBER SUN ANGLE



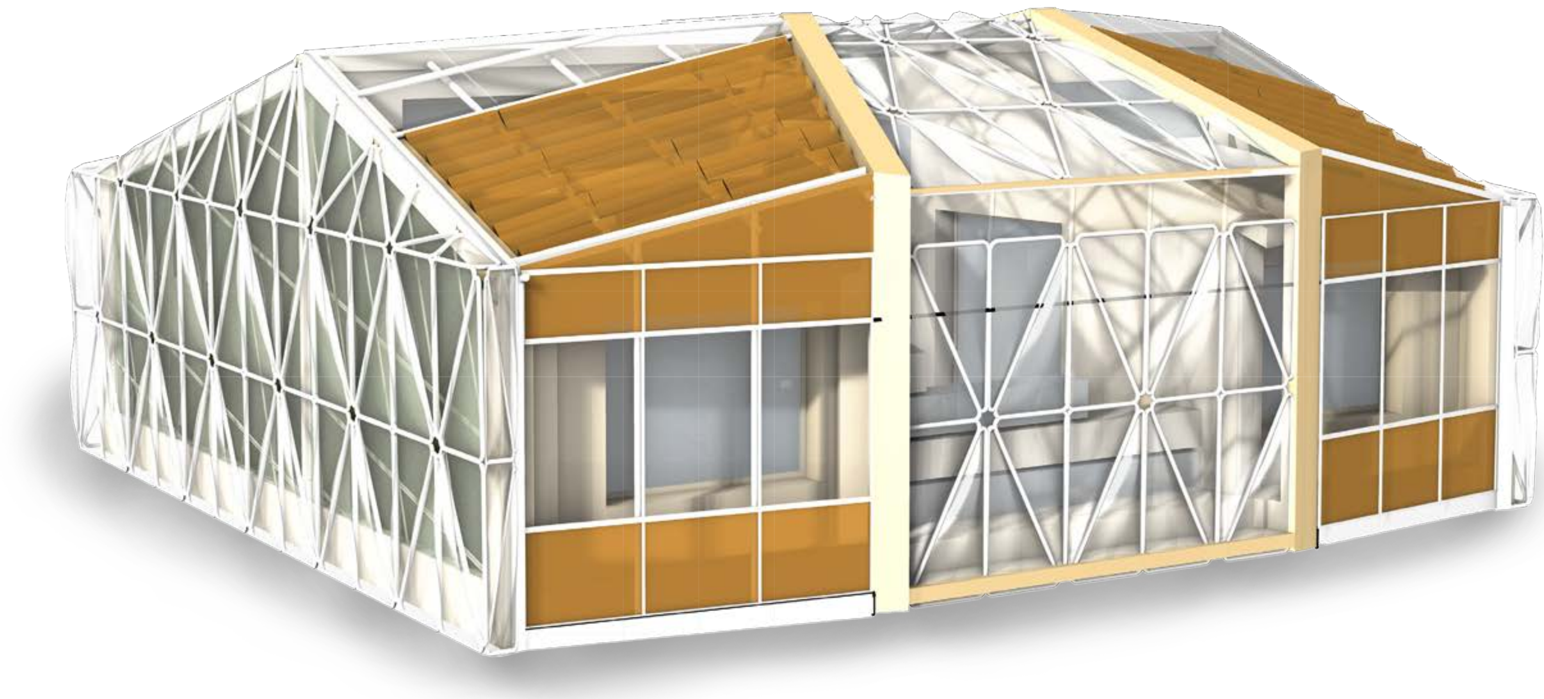
JUNE SUN ANGLE

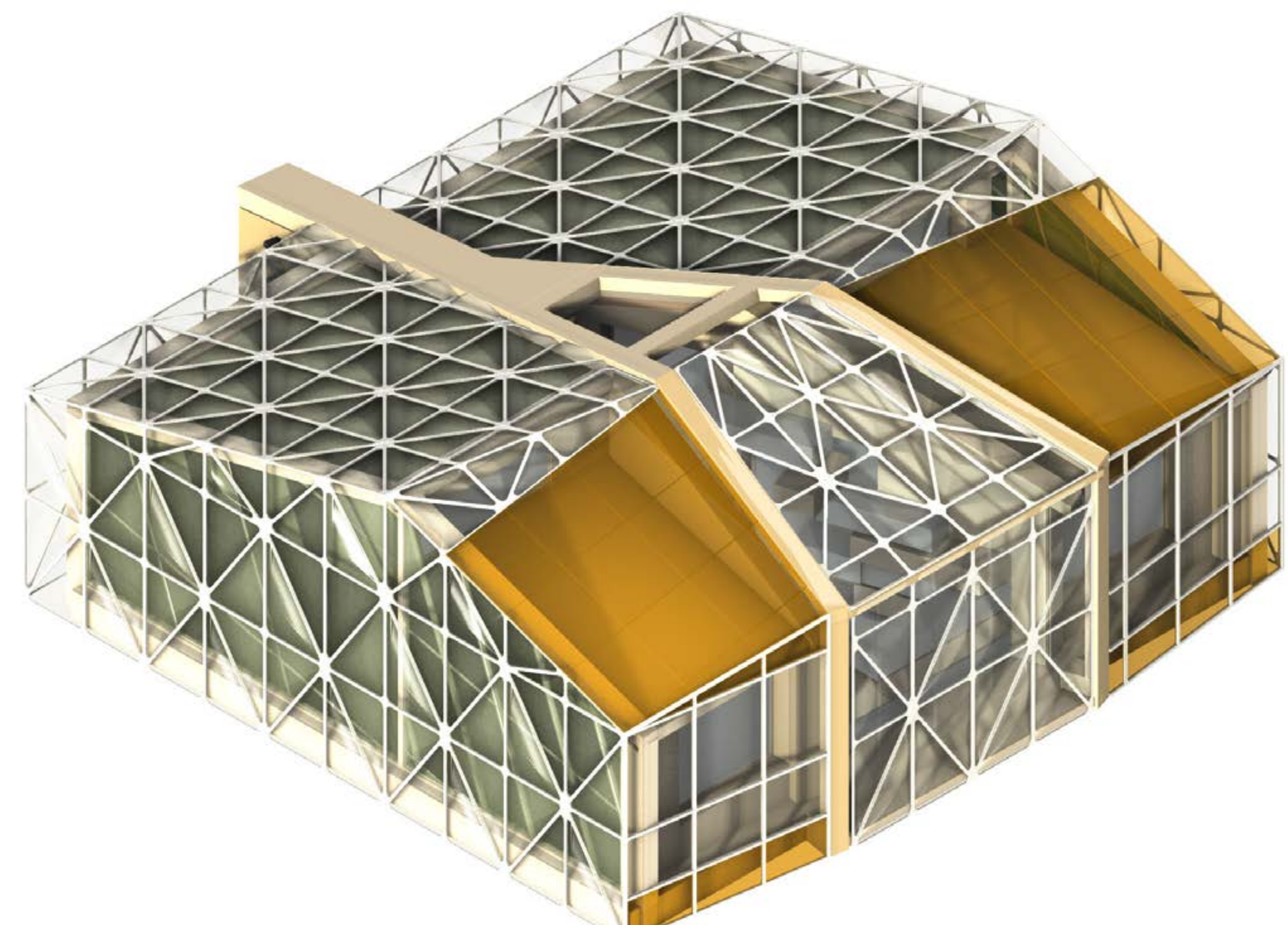
DESIGN DEVELOPMENT

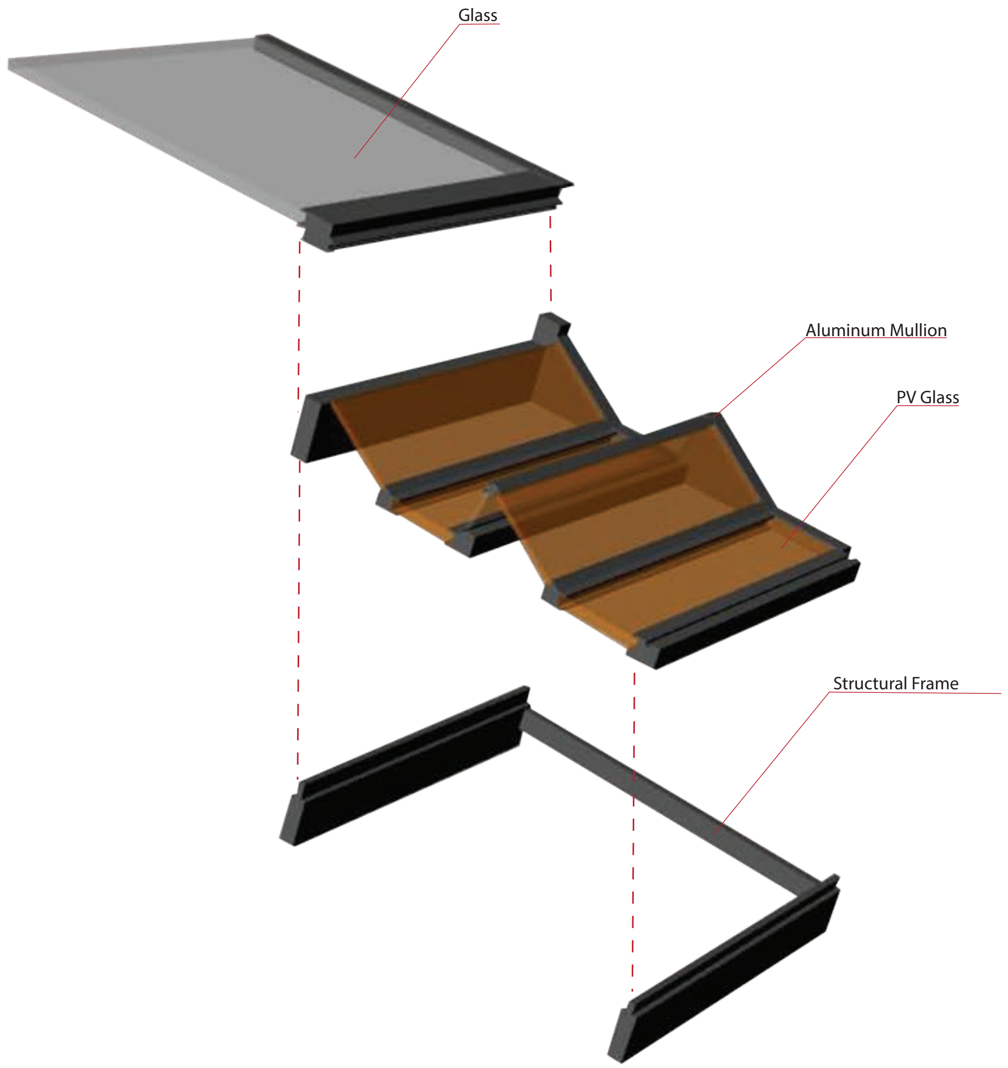
ETFE FACADE - PASSIVE STRATEGIES

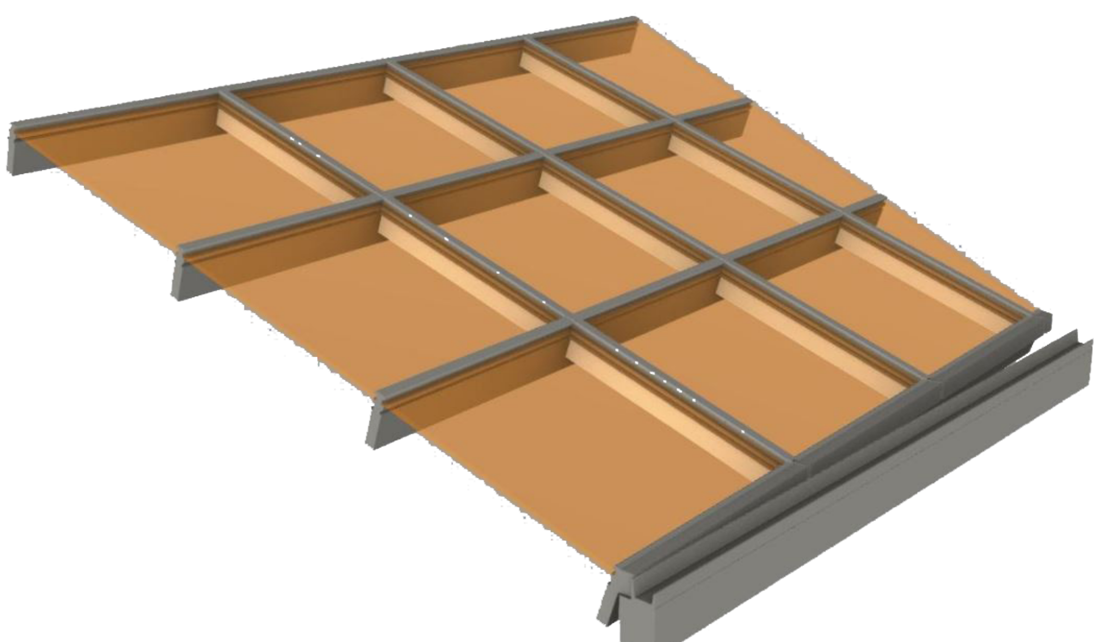
A number of solar studies were conducted in order to verify the direction and intensity of yearly sunlight. Based upon the information gained from the studies, a cohesive photovoltaic glass concept was developed. The side-bay photovoltaic roof underwent many different iterations. Initially, a mechanically opening and closing translucent PV panels using a worm-gear system was considered. This would have allowed the PVs to adjust to yearly solar conditions. This was rejected for its complexity as well as its need for multiple motor systems. Instead, a static mounted system was selected.

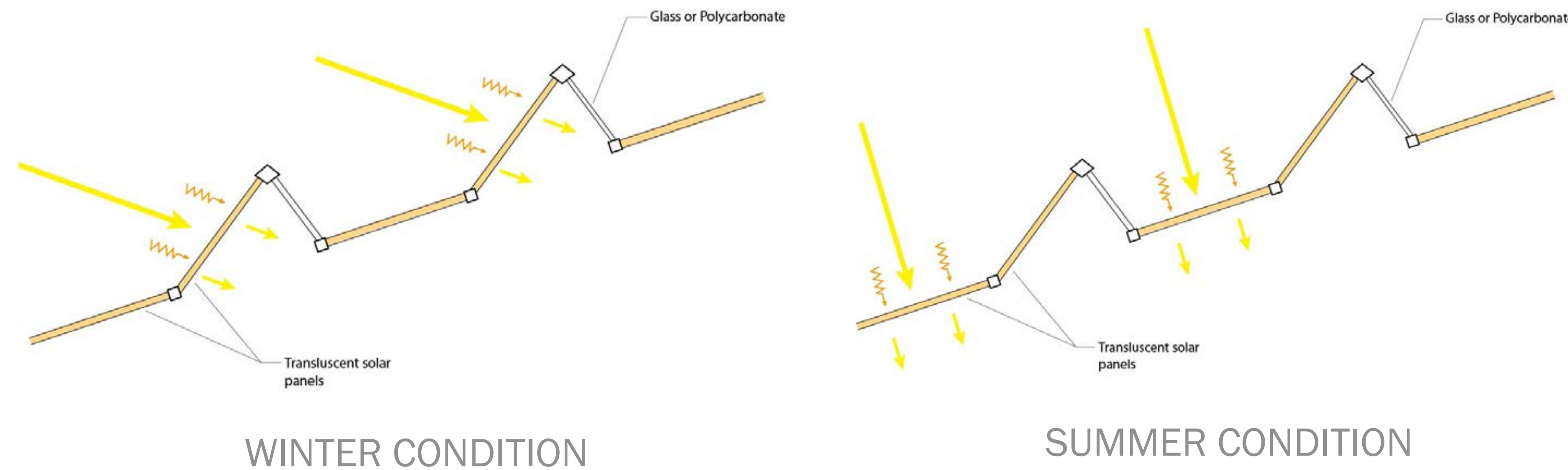
A study undertaken later on determined that ultimately, a flat PV-glass system would function better than a sawtooth arrangement. The flat arrangement would perform better as shadows cast from other raised panels would be eliminated and larger panels would be more efficient. The final design is a more simple mullion-less glass roof.

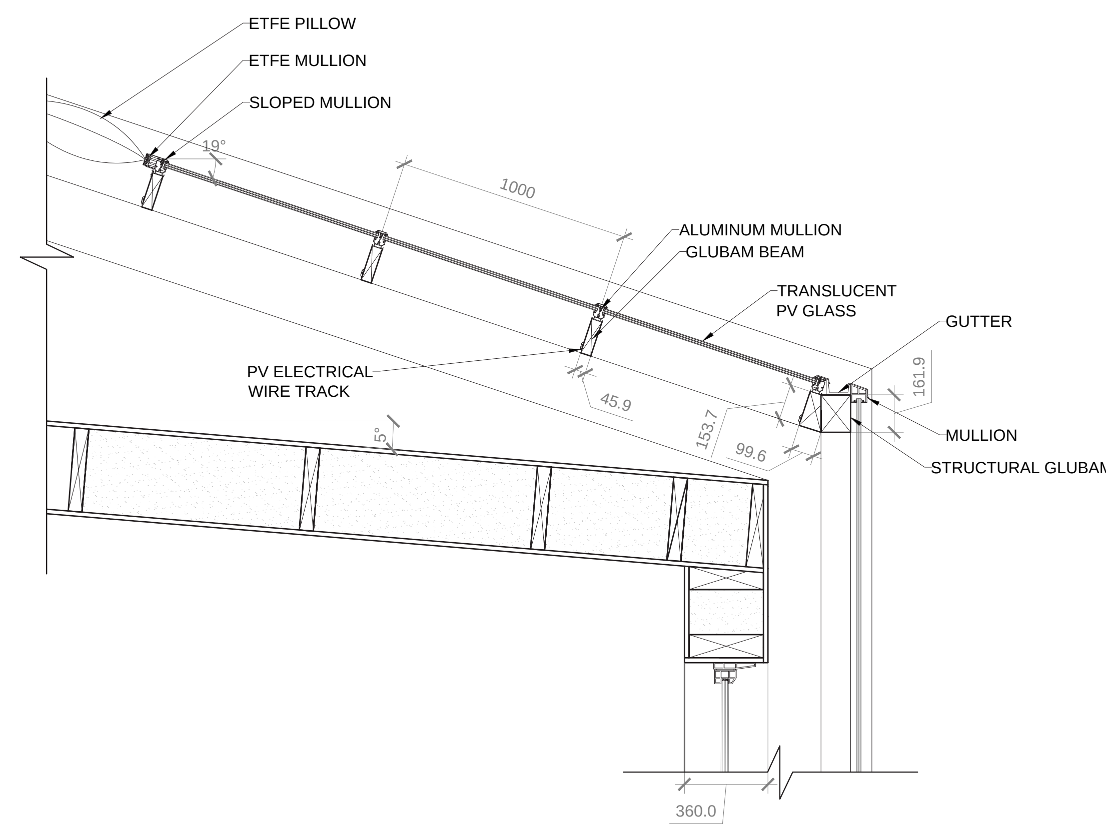










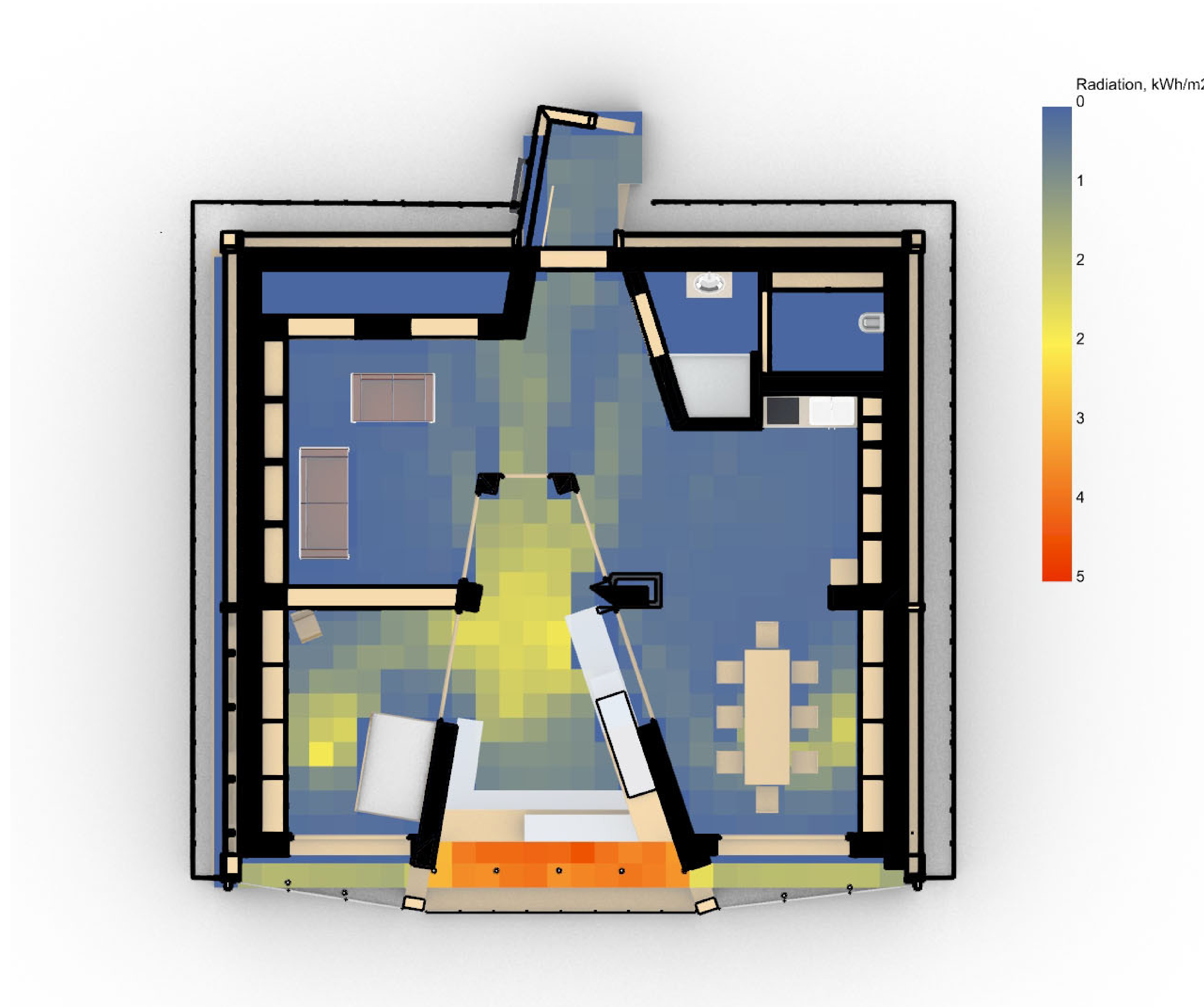


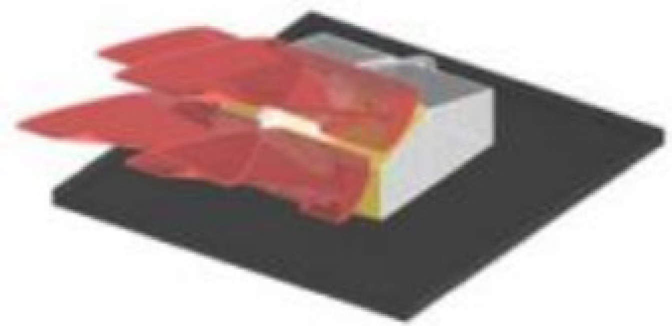
1 SECTION DETAIL
SIDE BAY ROOF TO WALL
SCALE 1:20

DESIGN DEVELOPMENT

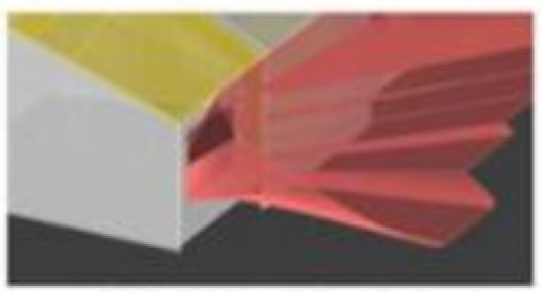
SOLARIUM - PASSIVE STRATEGIES

Continuing our studies within DIVA and other programs, interior studies on the radiation of sunlight into the space affirmed our beliefs that the double skin performed acceptably. Solar fan studies were collected by team members at XJTLU and were given to the façade team to help determine the locations of the PVs.

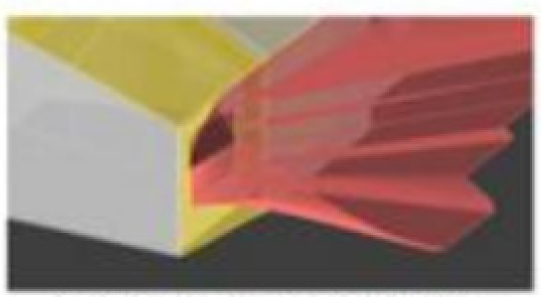




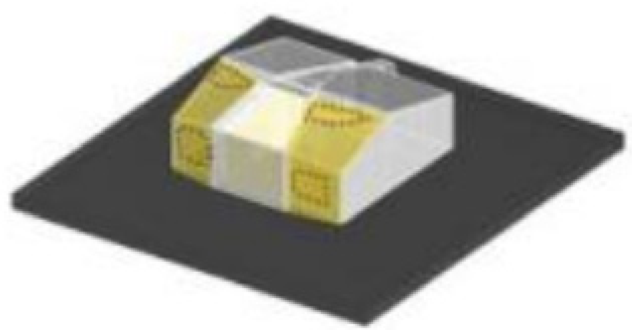
Solar Fan Test Results



solar fan test on the window

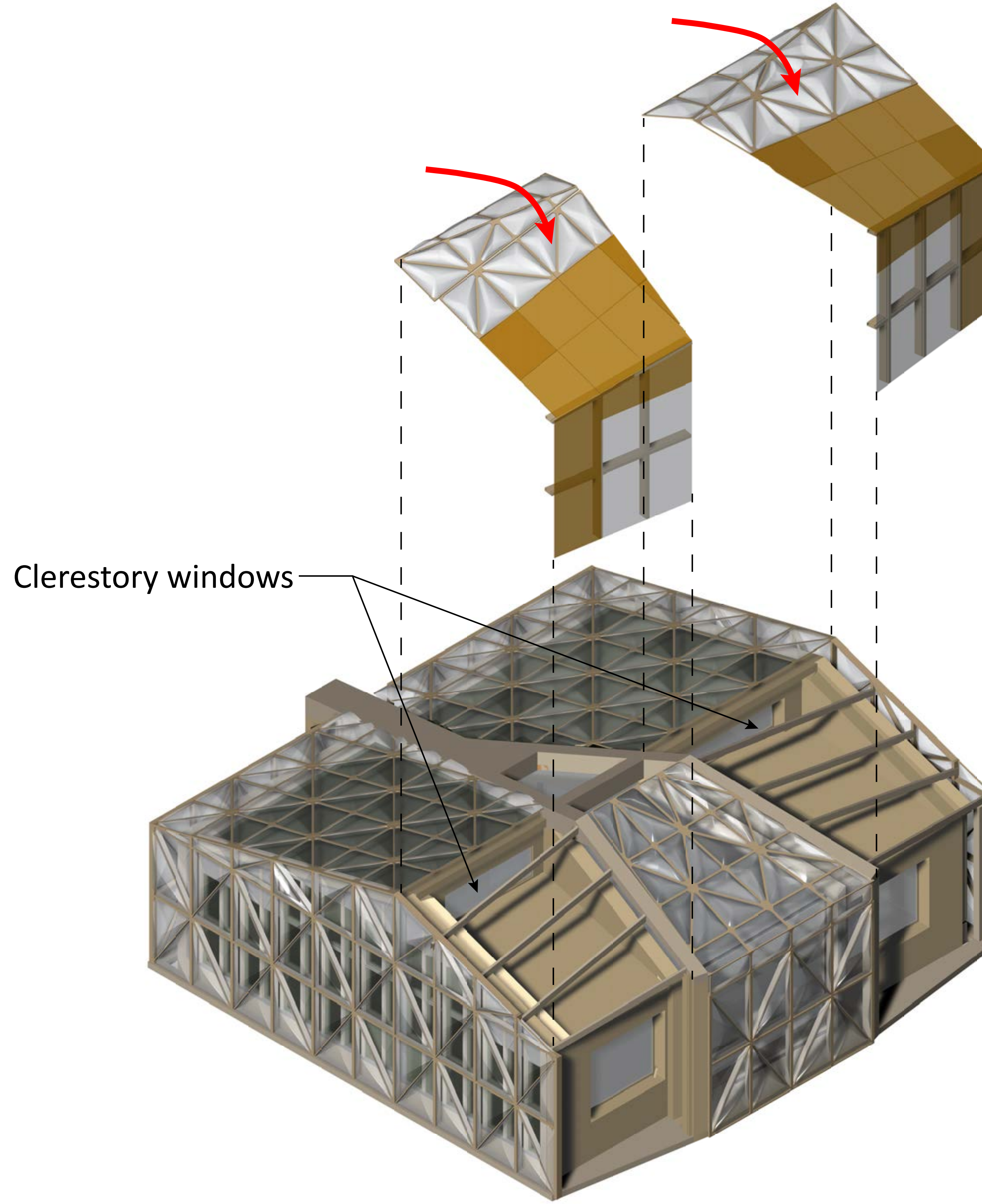


determine the transparent area on the outer layer



Transparent Areas for Illumination on the Outer Layer

Diagrams by Energy Modeling and Simulation - SDC Y-Project

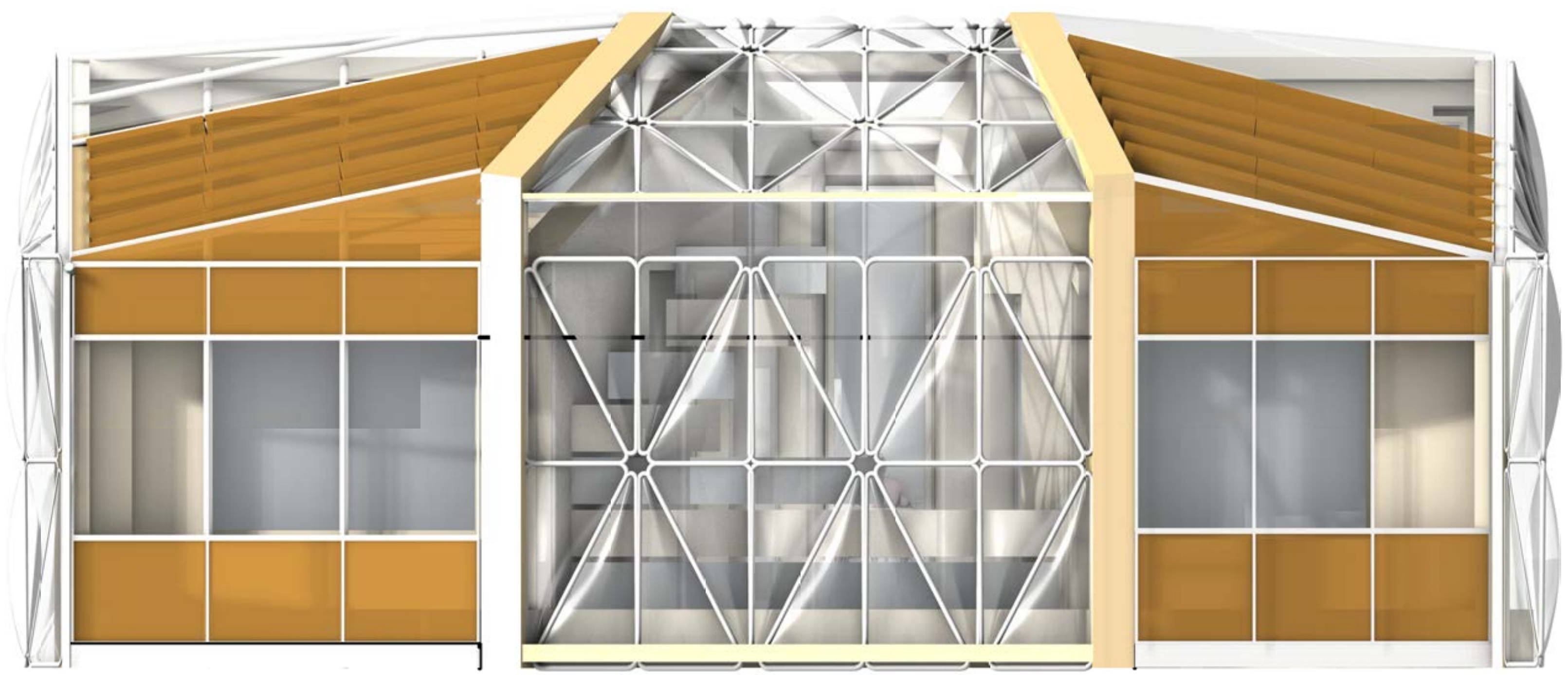


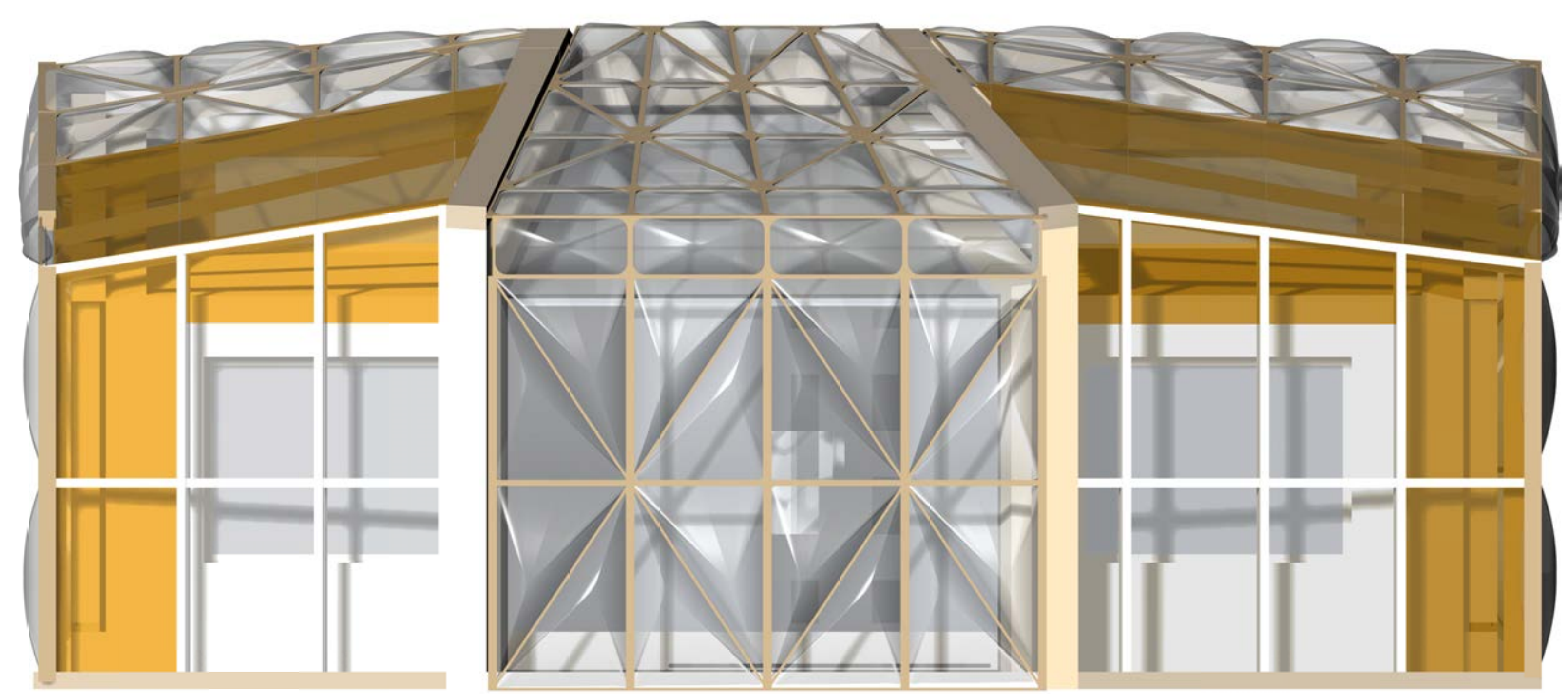
DESIGN DEVELOPMENT

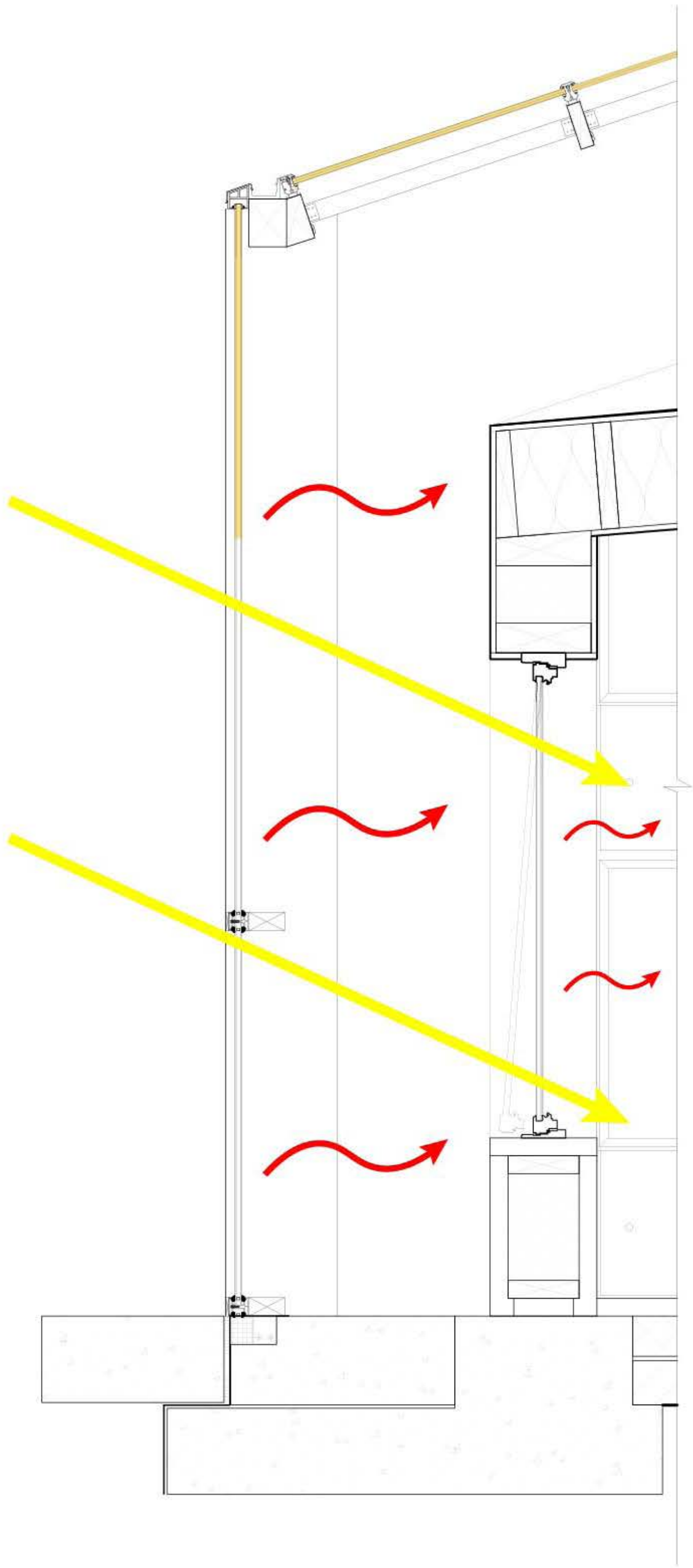
ETFE FACADE - PASSIVE STRATEGIES

The side bays underwent several changes over the course of the schematic design process, some of these changes related to the placement and positioning of the photovoltaic glass on both the walls and roof. In particular, the façade required the determination of which areas would collect the most sunlight for the largest part of the day. Considering natural views from the interior, areas of the southern façade in front of the inner window were kept transparent.

Another early concept was to create an operable window system for the side bay facade with the intention of creating passive heating and cooling that could be maintained at will. The system would have utilized a bi-folding window on a track system. Ultimately, this concept was not included as part of the final design but was used for the solarium's bi-folding door.







SIDE BAY SCHEMATIC WALL SECTION

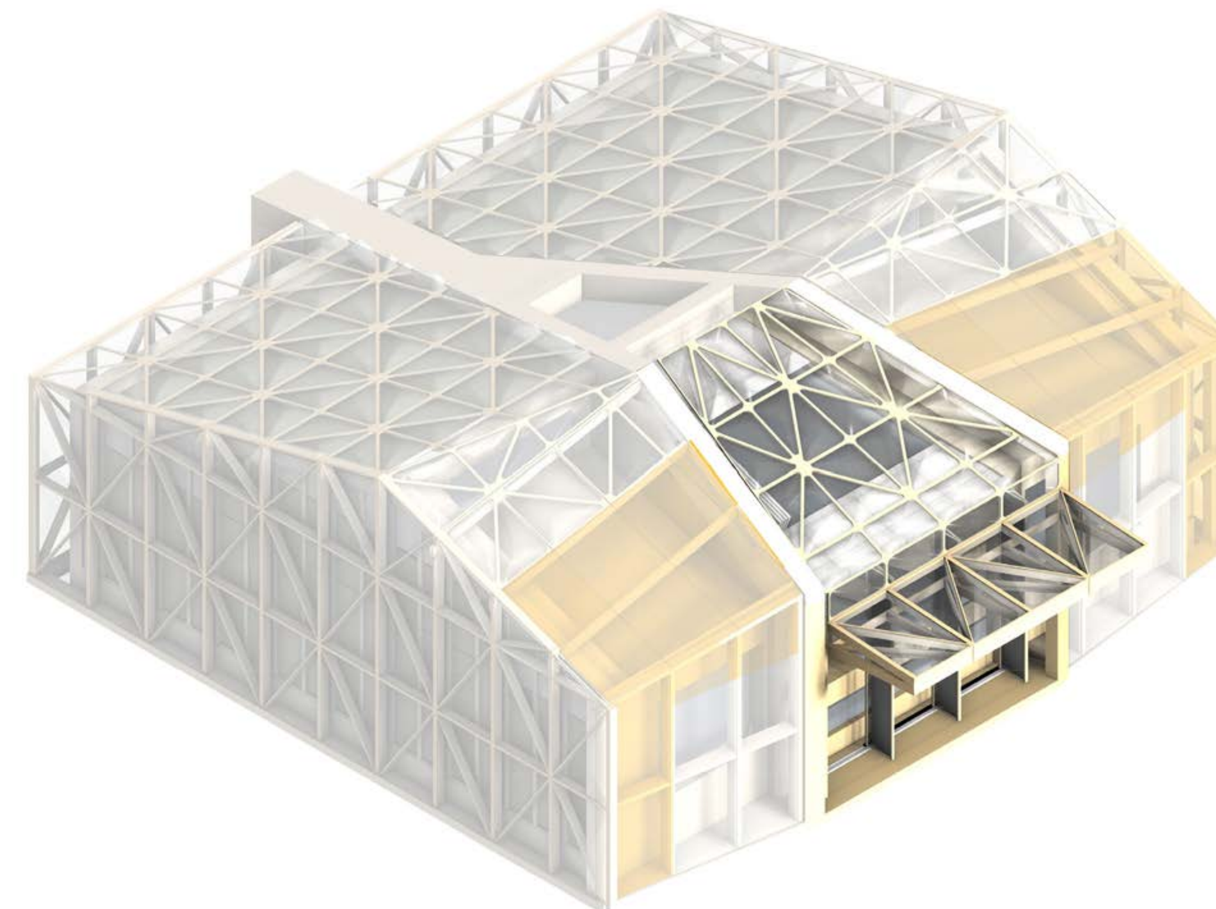
DESIGN DEVELOPMENT

SOLARIUM - PASSIVE STRATEGIES

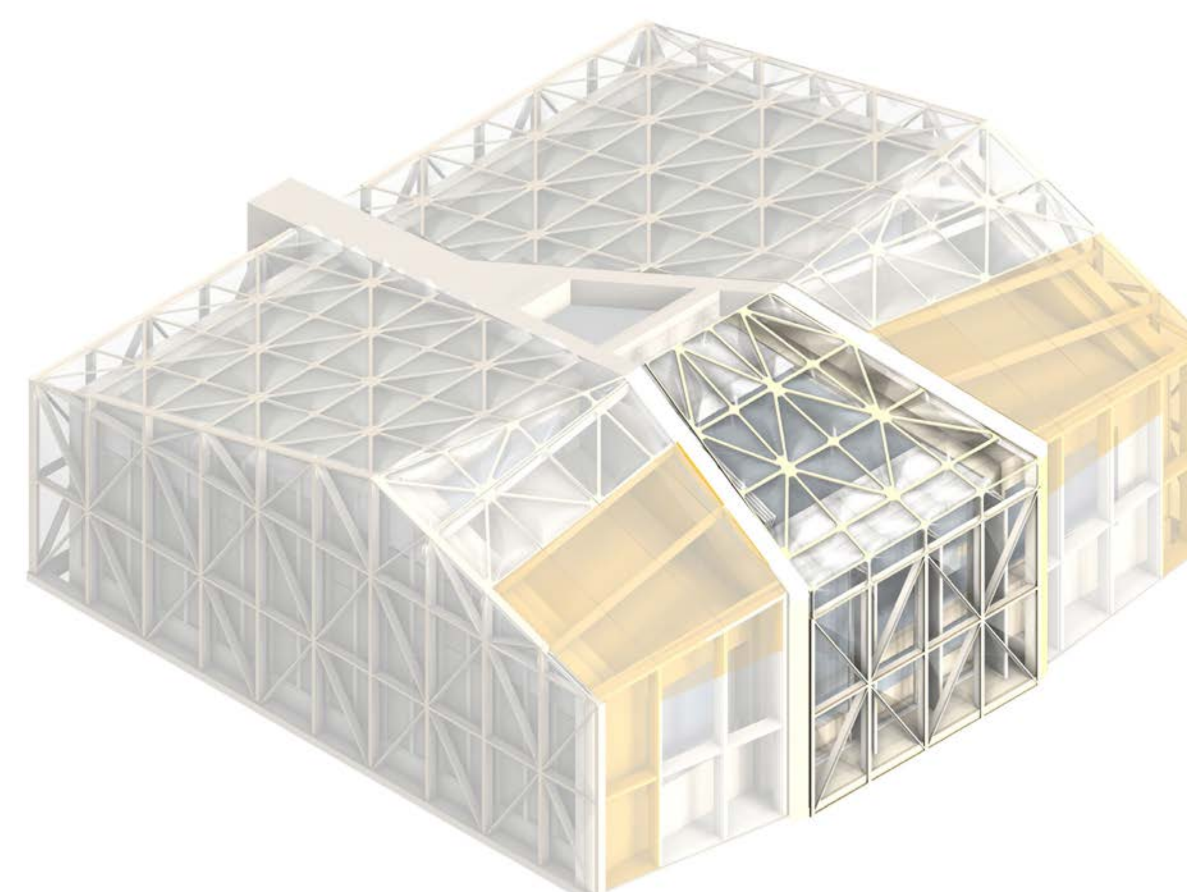
The solarium is developed around a double skin system utilizing glazing for the interior layer and ETFE for the outer layer. The properties of the glazing allows for clear views out and helps to create an airtight seal. The ETFE outer skin is transparent as well but is prioritized for the insulation properties it provides when inflated. The frame for the inner layer is based on aluminum extrusions while the exterior is looking to use glubam to express the inner structure of the building and the exposed Y.

The two layers are both operable allowing for a seamless connection from inside to outside. The inner sliding door system allows for the panels to be moved to the sides without leaving mullions behind. The outer wall is a vertical bifold door, which operates on a pulley system that will allow for people and air to circulate through the space.

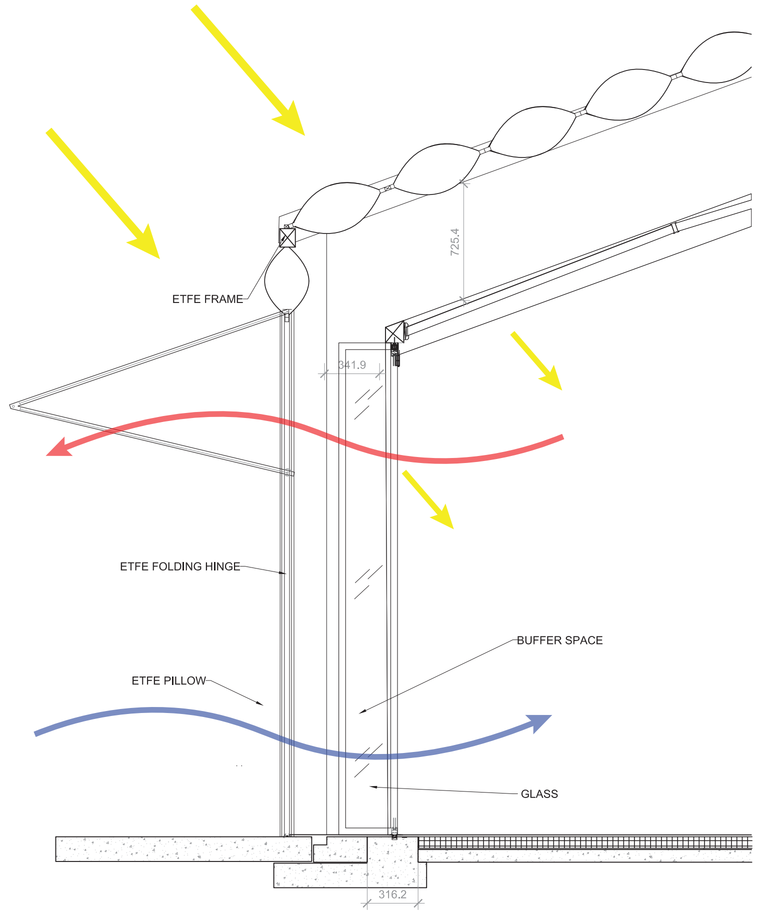
The passive strategies of the solarium are based around preheating the air within the double skin by the sun to be used in the house. This will help to eliminate energy use from the heating pump throughout the year. In the summer, the hot air will be exhausted out by opening of the operable panels. The air inflow will allow for cool air to travel within the double skin systems to promote passive cooling for the building.

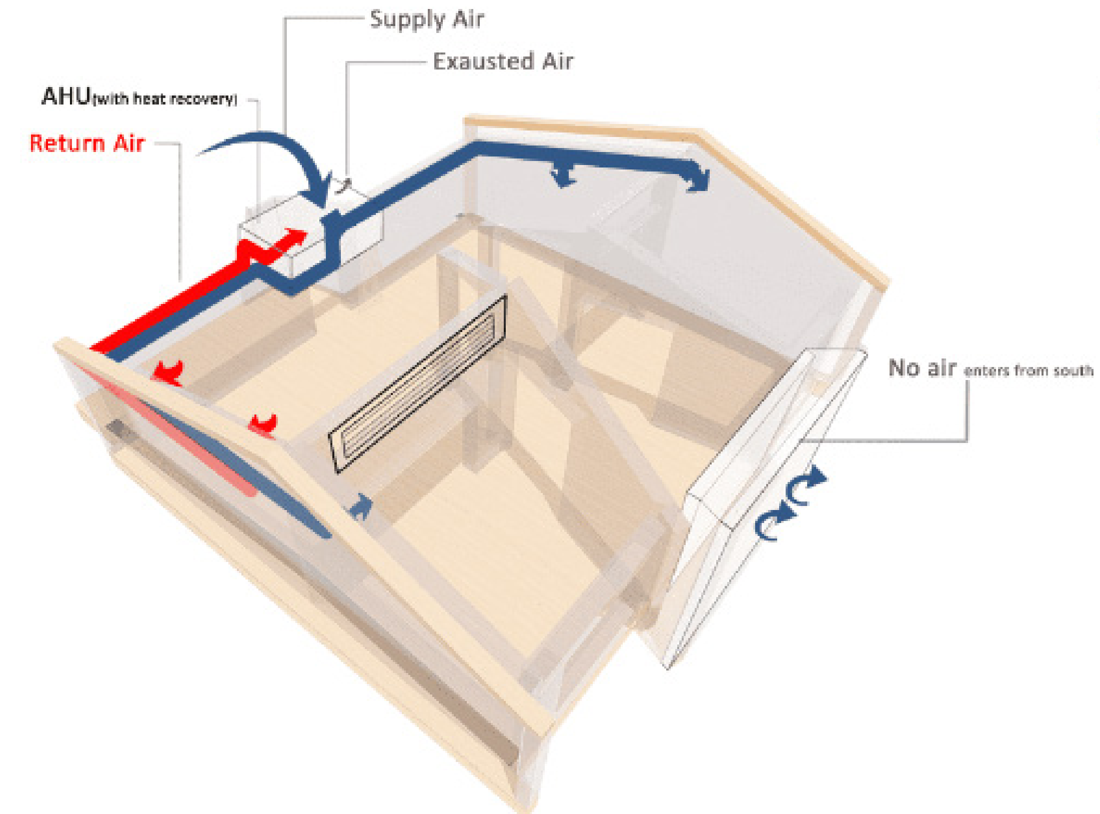


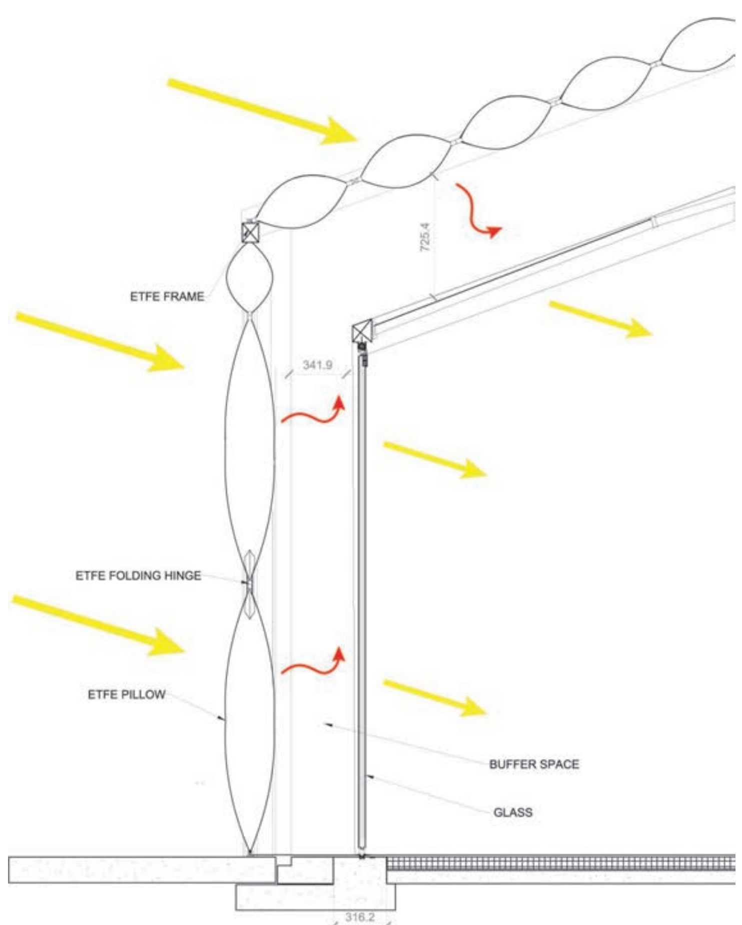
Open Condition (Summer)

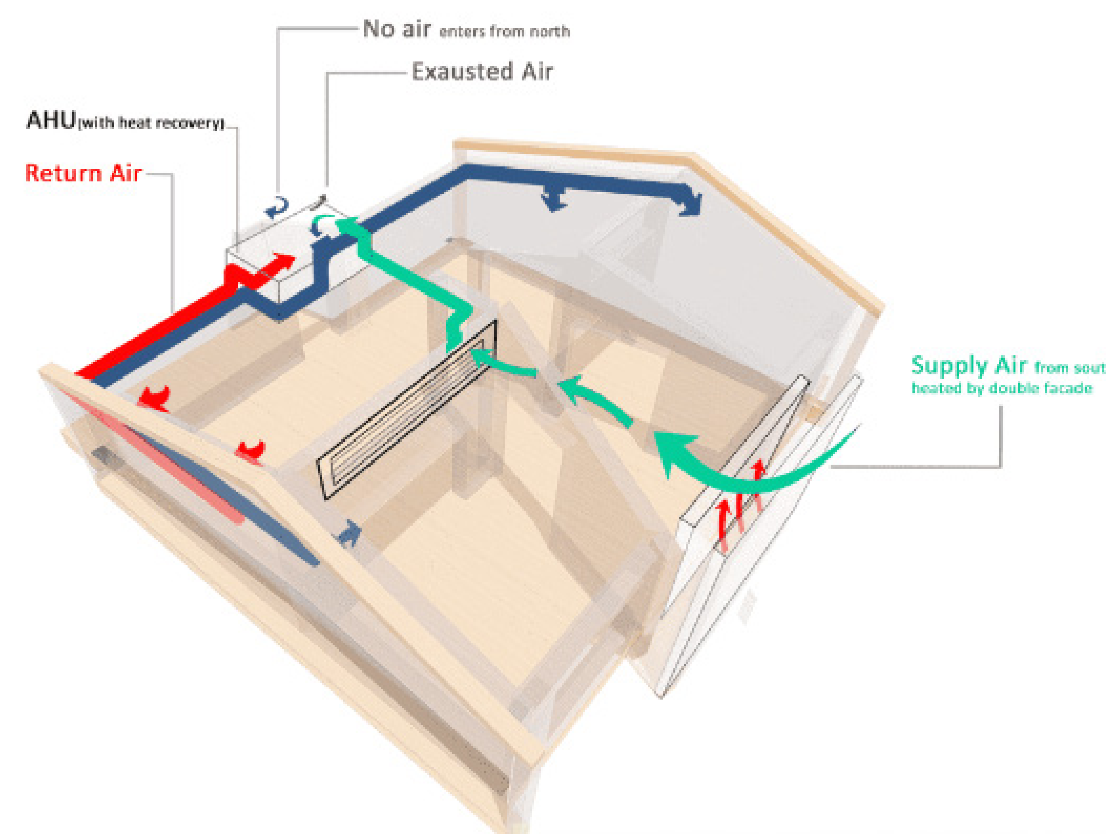


Closed Condition (Winter)









Diagrams by MEP team - SDC Y-Project

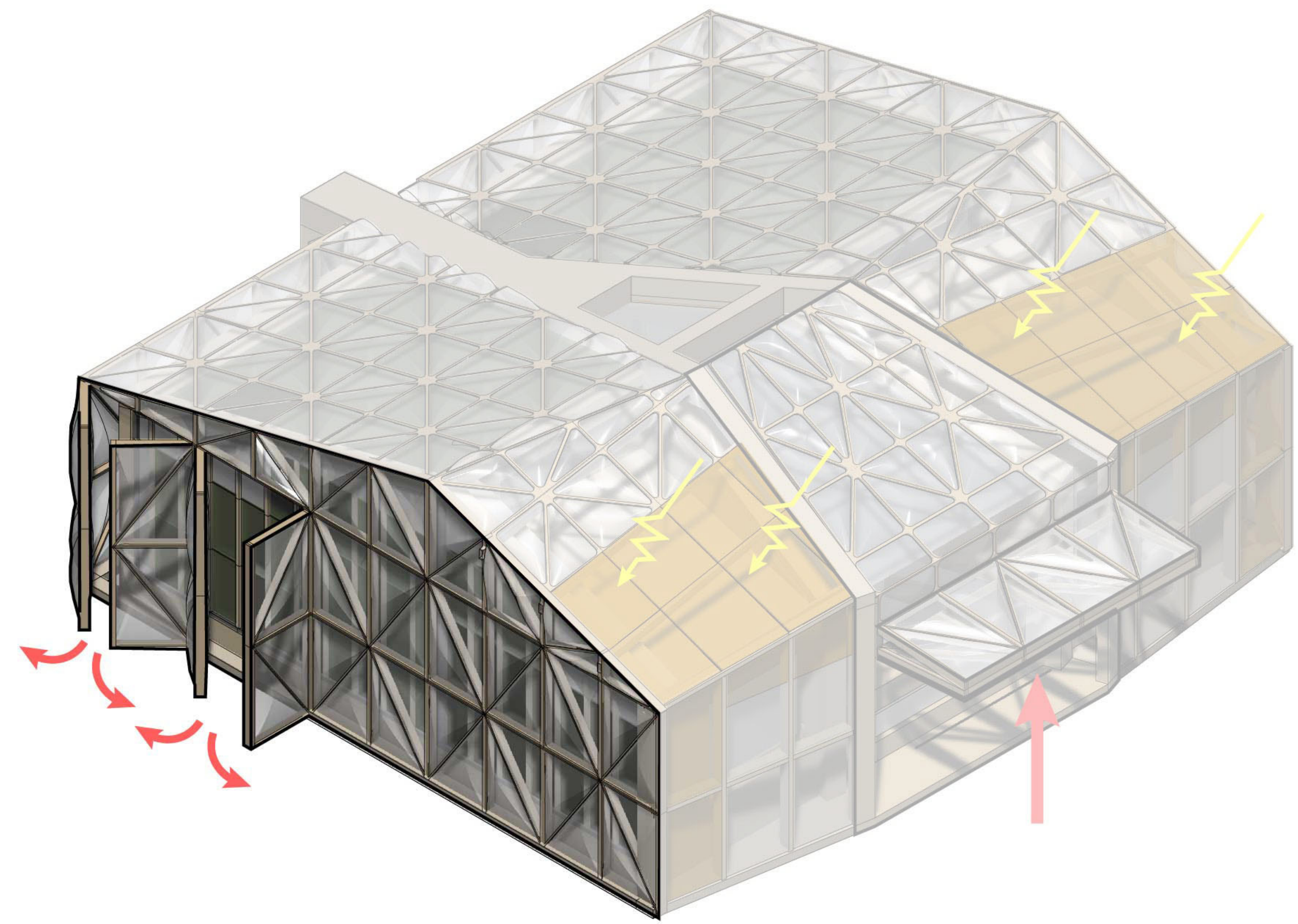
DESIGN DEVELOPMENT

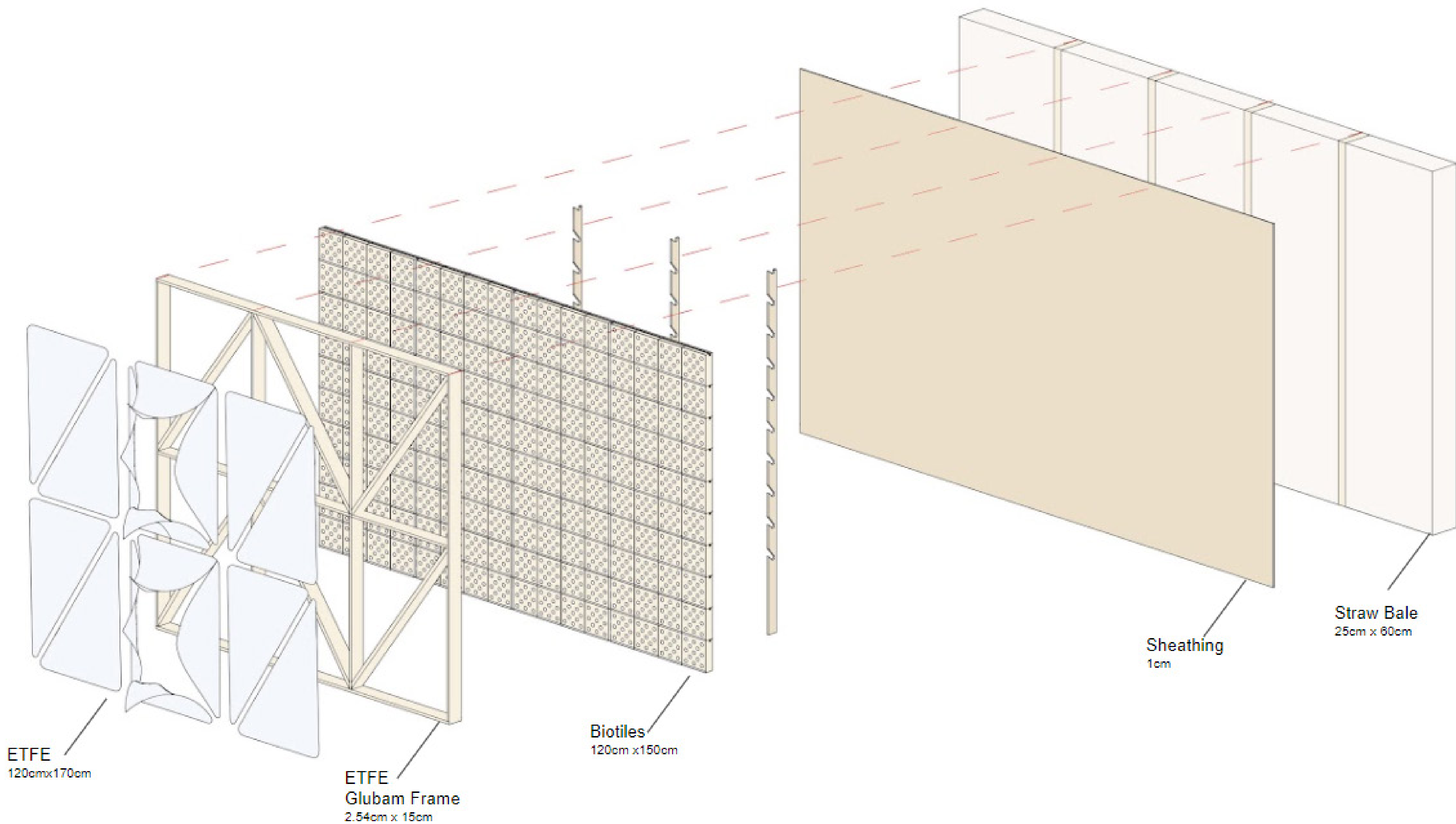
GREEN WALLS

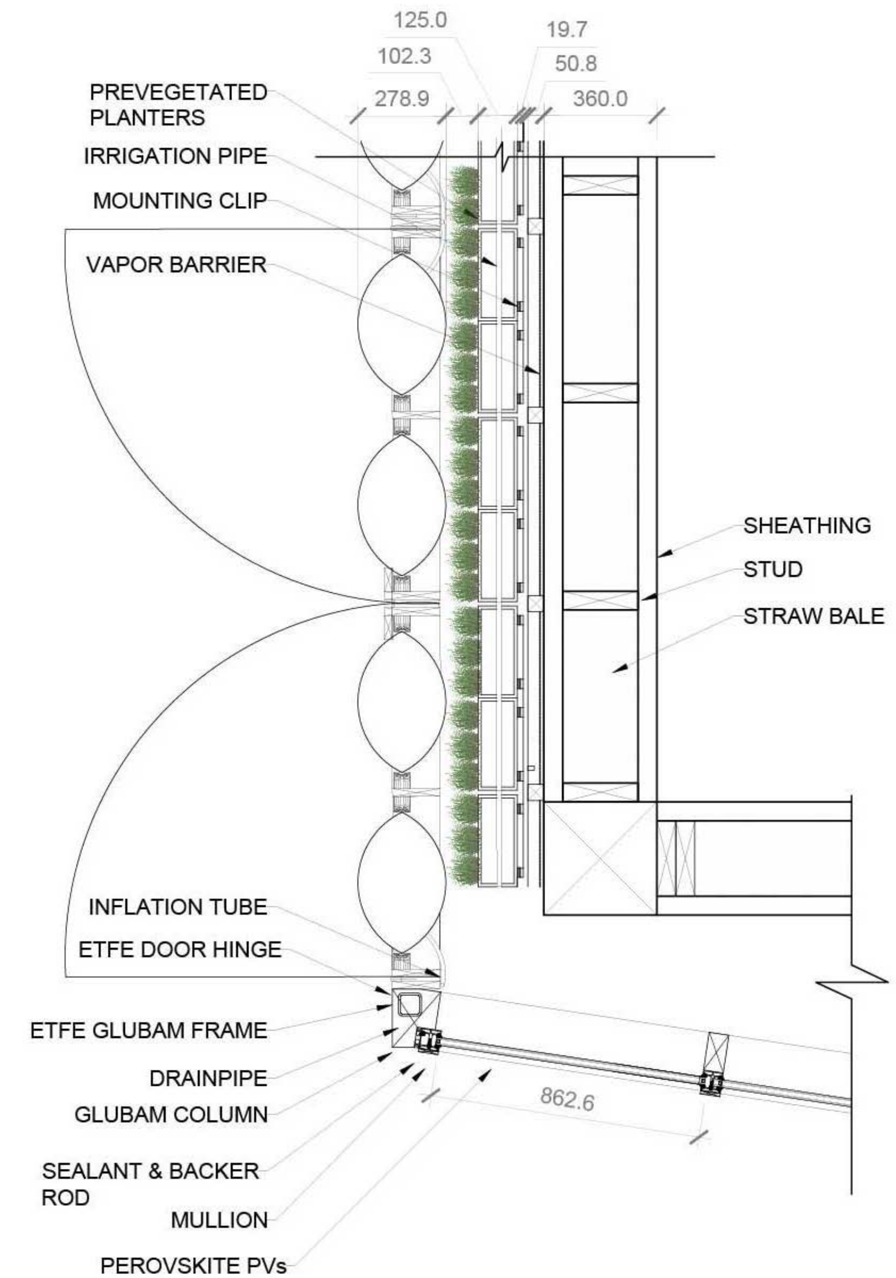
The East and West Walls are designed to have operable doors that would allow for accessibility to the green walls. The operability allows for any maintenance that may need to occur as the plants grow.

The structural frame of the ETFE coordinates with the green wall panels and the struts within the straw bale walls. The alignment of all the members allows for all the loads to be transferred back to the main wall.

The framing for the ETFE consists of Glubam members in order to keep the same material throughout the building. The structure of the green wall also utilizes glubam as well. This composition uses the same structural materials to allow for ease of connecting to each other.




ETFE
120cmx170cm
ETFE
Glubam Frame
2.54cm x 15cm
Biotiles
120cm x150cm
Sheathing
1cm
Straw Bale
25cm x 60cm

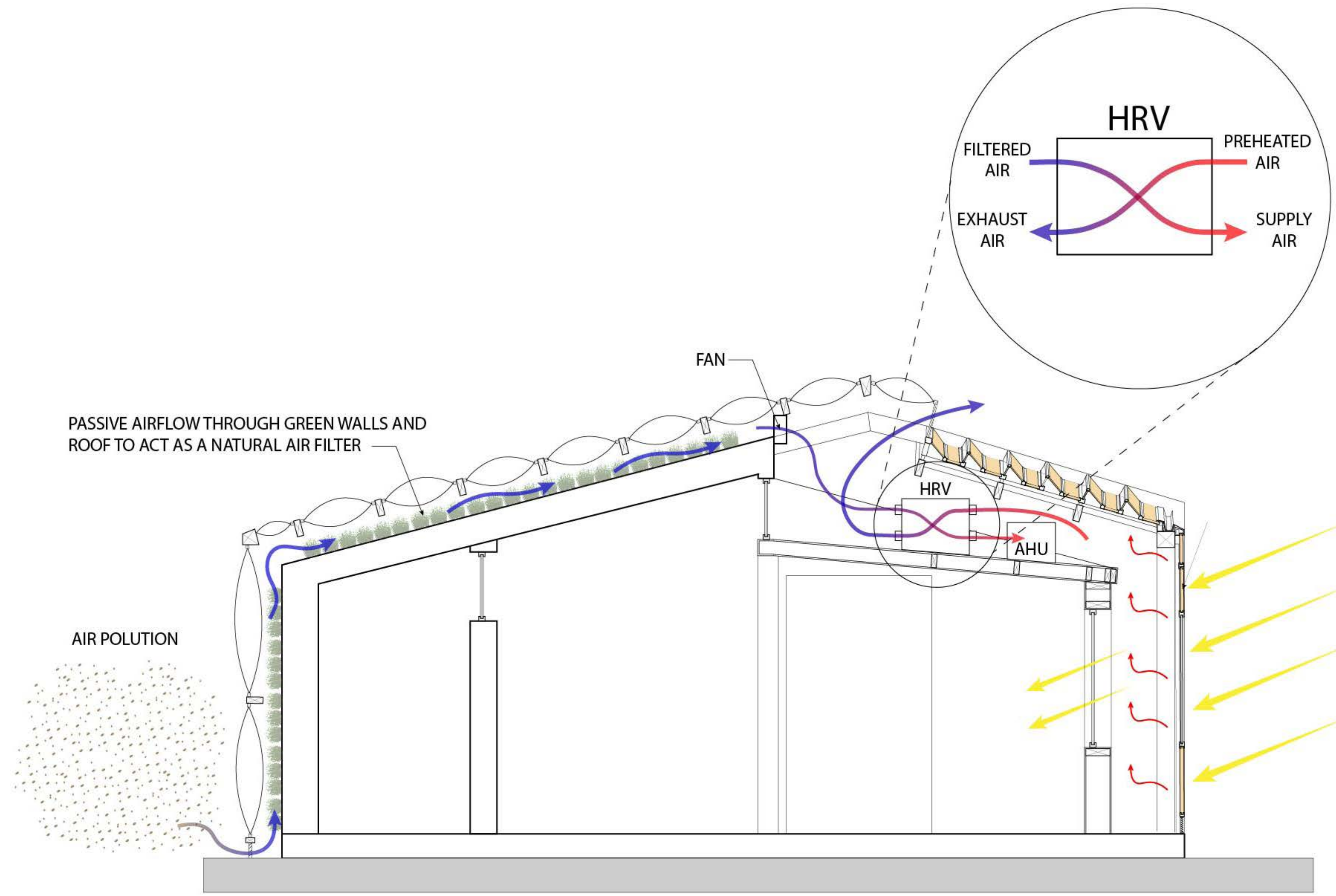

125.0
19.7
102.3
50.8
278.9
360.0
PREVEGETATED PLANTERS
IRRIGATION PIPE
MOUNTING CLIP
VAPOR BARRIER
SHEATHING
STUD
STRAW BALE
INFLATION TUBE
ETFE DOOR HINGE
ETFE GLUBAM FRAME
DRAINPIPE
GLUBAM COLUMN
862.6
SEALANT & BACKER ROD
MULLION
PEROVSKITE PVs

DESIGN DEVELOPMENT

PASSIVE STRATEGIES & GREEN WALL ANALYSIS

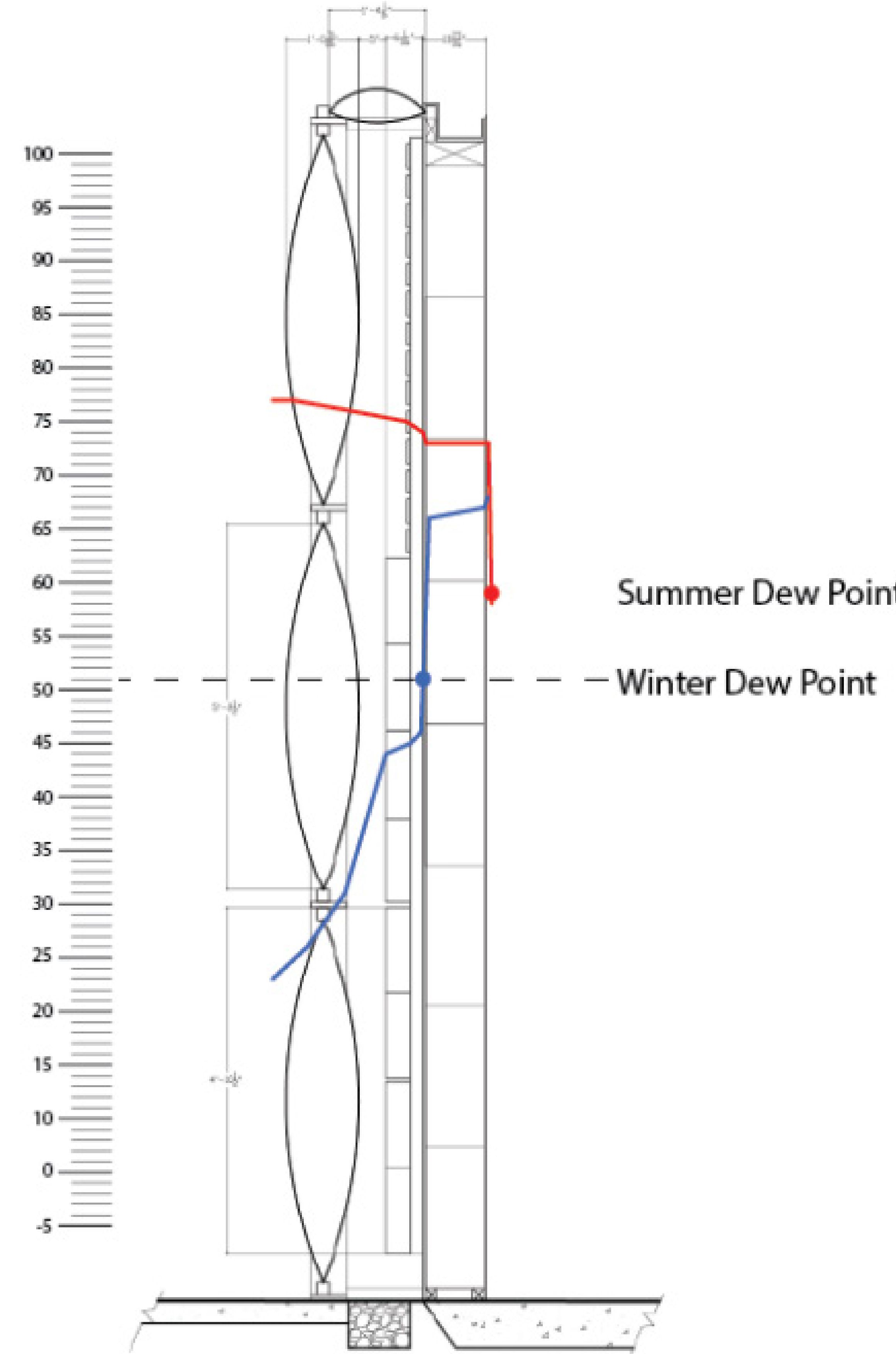
In order to design an efficient wall system we looked into finding where the dew point fell within the wall. The location of the dew point helped determine where the water barrier would be placed within the three layer facade.

In order to implement passive cooling strategies into the design of the facade the walls were raised off the ground in order to allow air to enter the bottom and rise through the roof in order to be circulated out. This was implemented in order to prevent overheating between the ETFE and the green walls and to filter the polluted air from the outside.



Passive Strategy - Winter Condition

	Dew Point Calc	DB T	RH	Dew Point T			
A	Winter Outside Air	23	42	5			
B	Summer Outside Air	77	57	57			
C	Winter Inside Air	68	55	51			
D	Summer Inside Air	72	65	59			
	Component	**R-Value**	**Cumulative R-Value**	**ΔT Winter**	**Winter T**	**ΔT Summer**	**Summer T**
	Outside Temperature						
A	Outside Air Film	0.17	0.17	0.284	23.284	0.0316	77
B	1' ETFE	2.00	2.17	3.6	26.6	0.4032	77
C	6" (15cm) Air Gap	2.40	4.57	7.6421	31	0.8491	76
D	4" (10cm) Biotile	8.00	12.57	21.02	44	2.3356	75
E	Air Gap	0.80	13.37	22.358	45	2.4842	75
F	Sheathing	0.63	14.00	23.411	46	2.6013	74
G	10" Straw Bale	11.60	25.60	42.809	66	4.7566	72
H	Sheathing	0.63	26.23	43.863	67	4.8737	72
I	Interior Air Film	0.68	26.91	45	68	5	72
	Inside Temperature						
	Total R-Value	26.91					

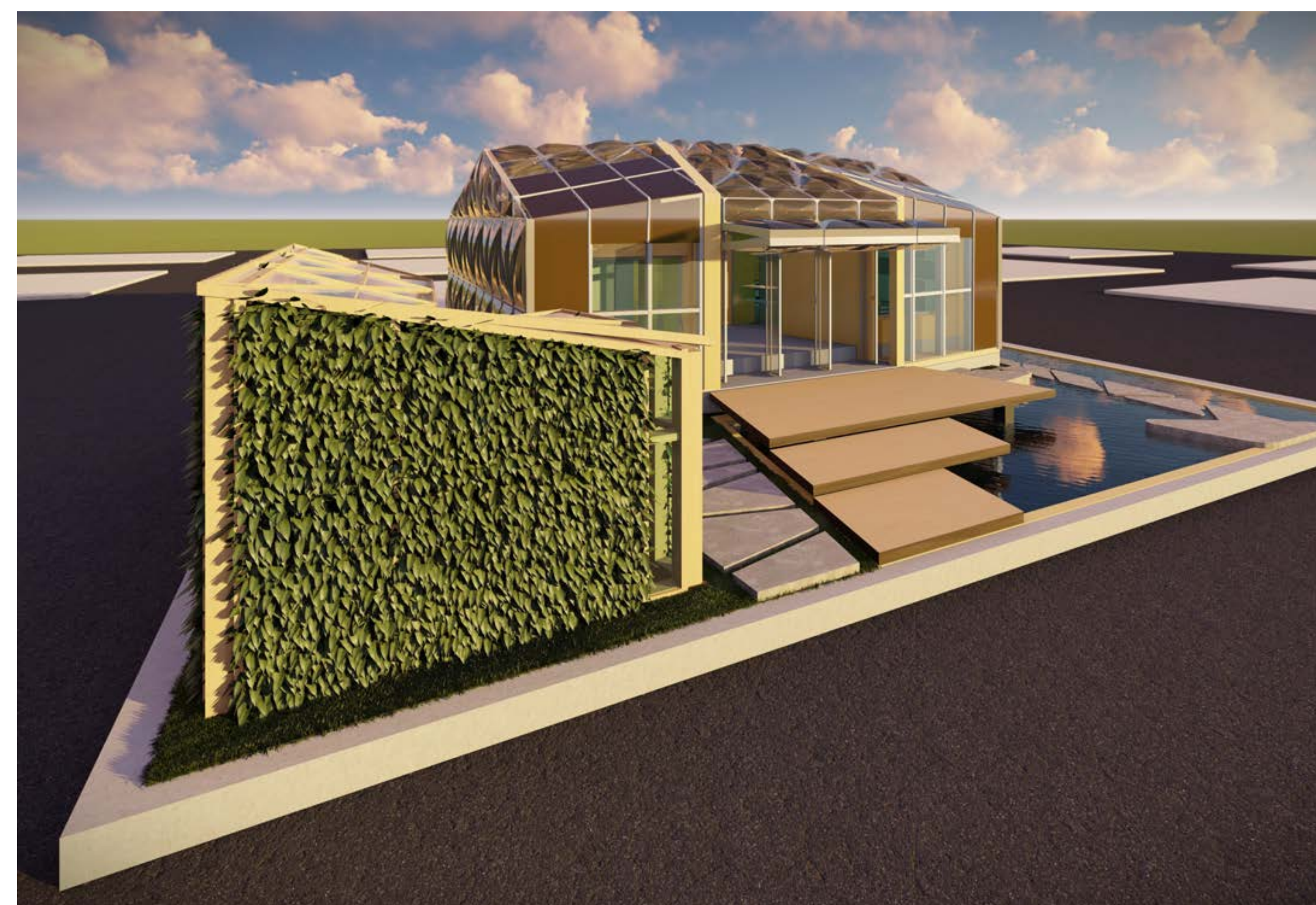


Drawn by Norm Engel

DESIGN DEVELOPMENT

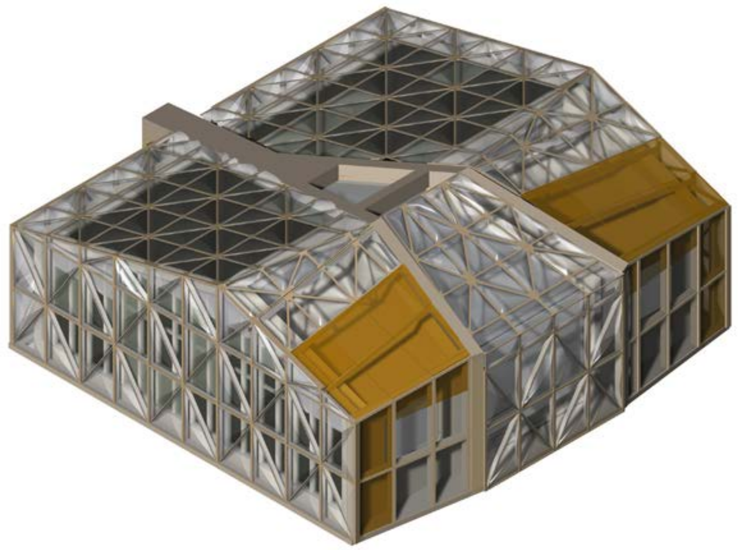
SUMMARY

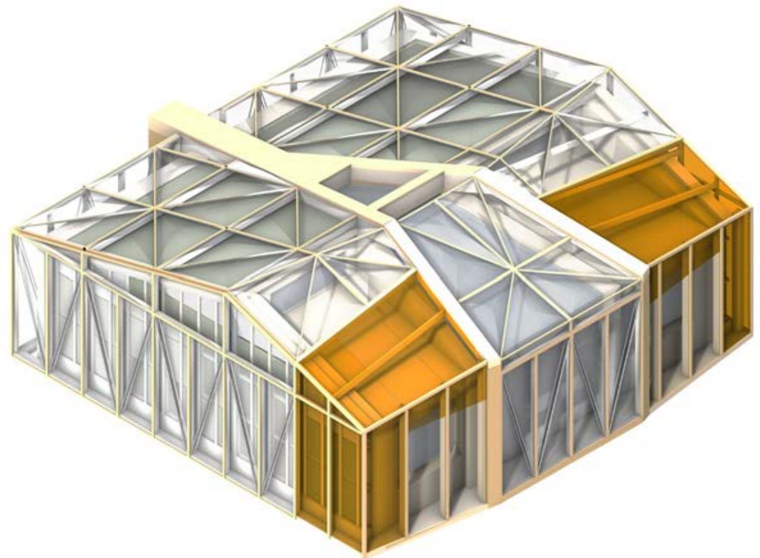
The design development submission focuses on advancing the themes of the design intent while beginning to implement structural and mechanical systems to enhance the facade's concept. Major development was made with the perovskite PVs. Several analyses and coordination with the other teams helped the development of the orientation and aesthetic. The concept of the buffer-space was enhanced with the MEP team to develop an integrated system in which the preheated air would be used within the HVAC systems; reducing heating loads. Experimentation and prototyping of the inflatable facade begins to express a method for creating a working solution. Details drawings create understanding of how assemblies come together. Overall, the vertical greenhouse concept and the use of ETFE pillows resonated well with jurors and begins to define a language for the house.

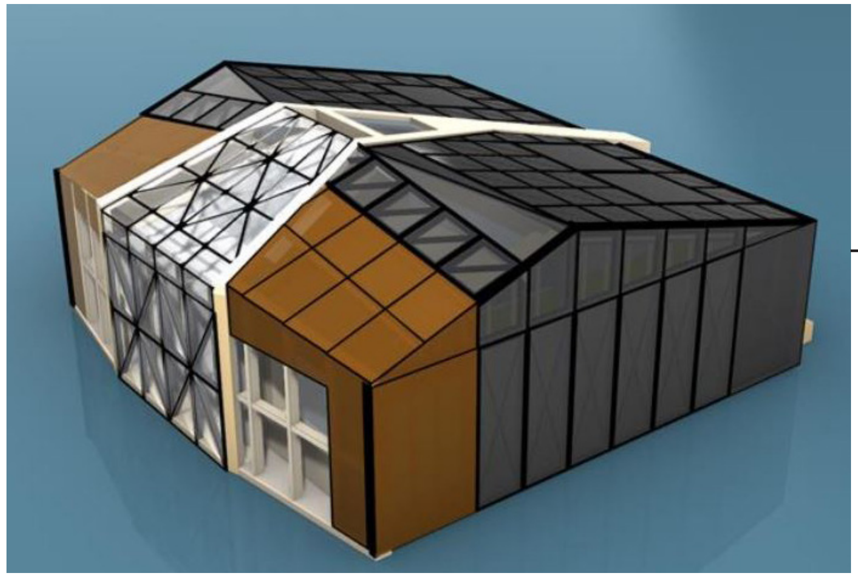


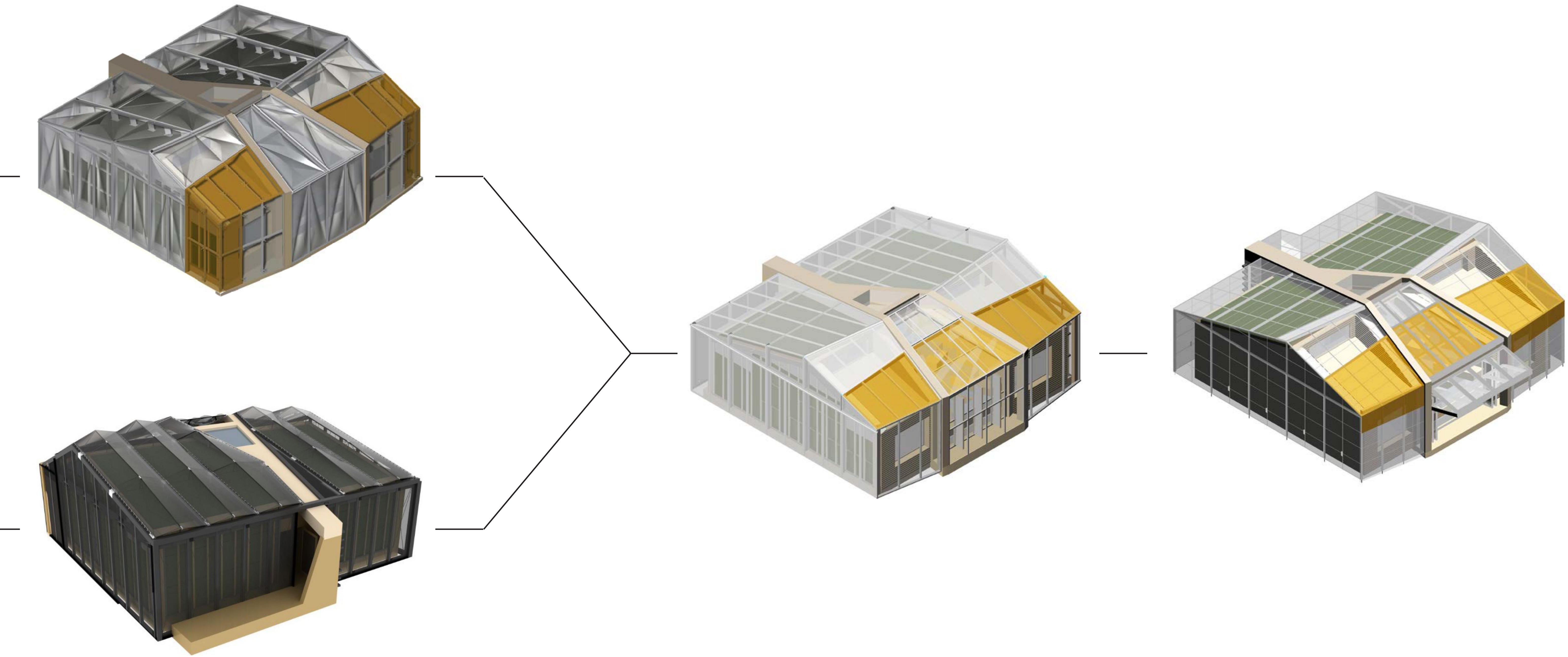
Renderings by Jack Whalen

CONSTRUCTION DOCUMENTATION







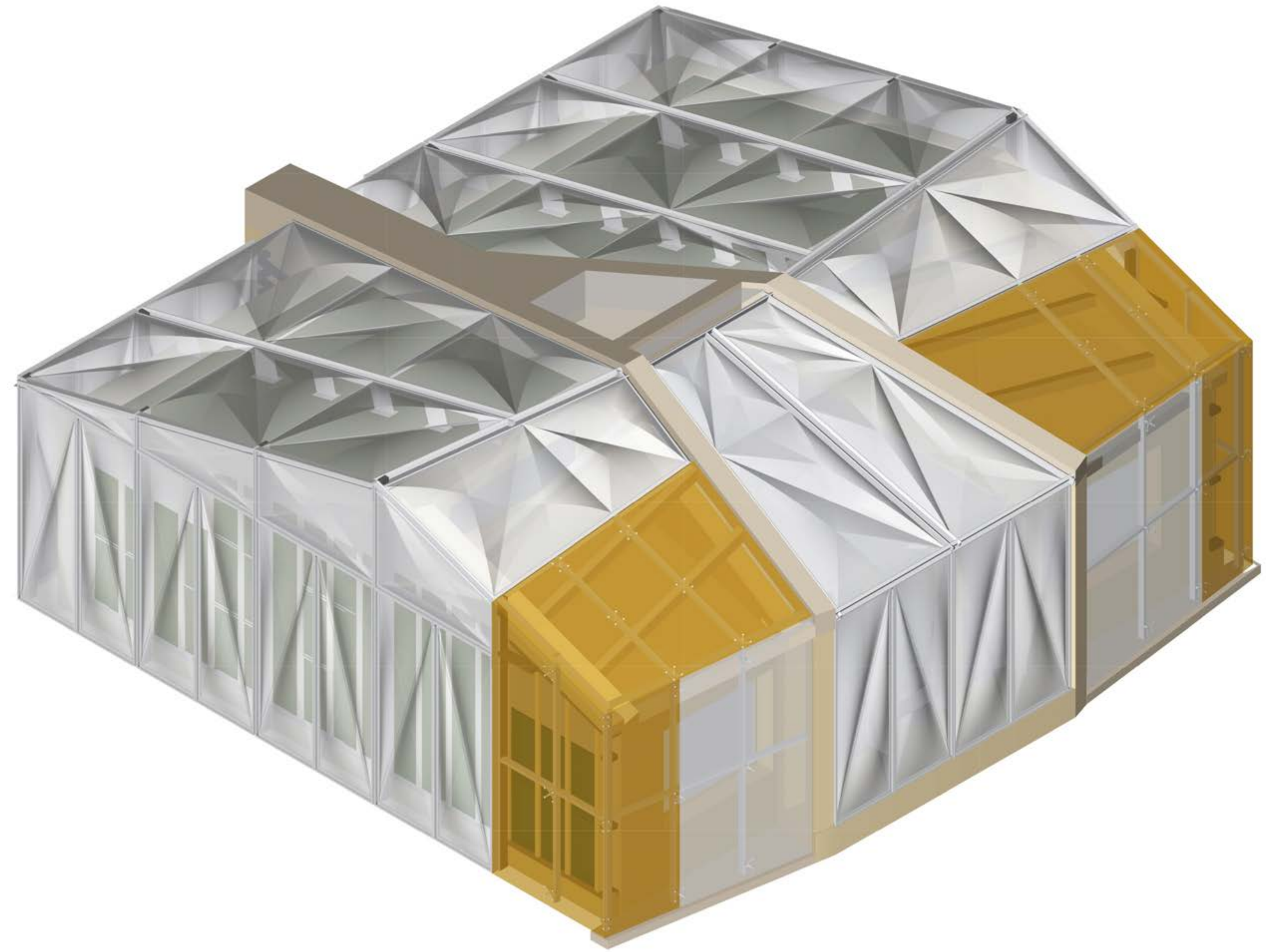


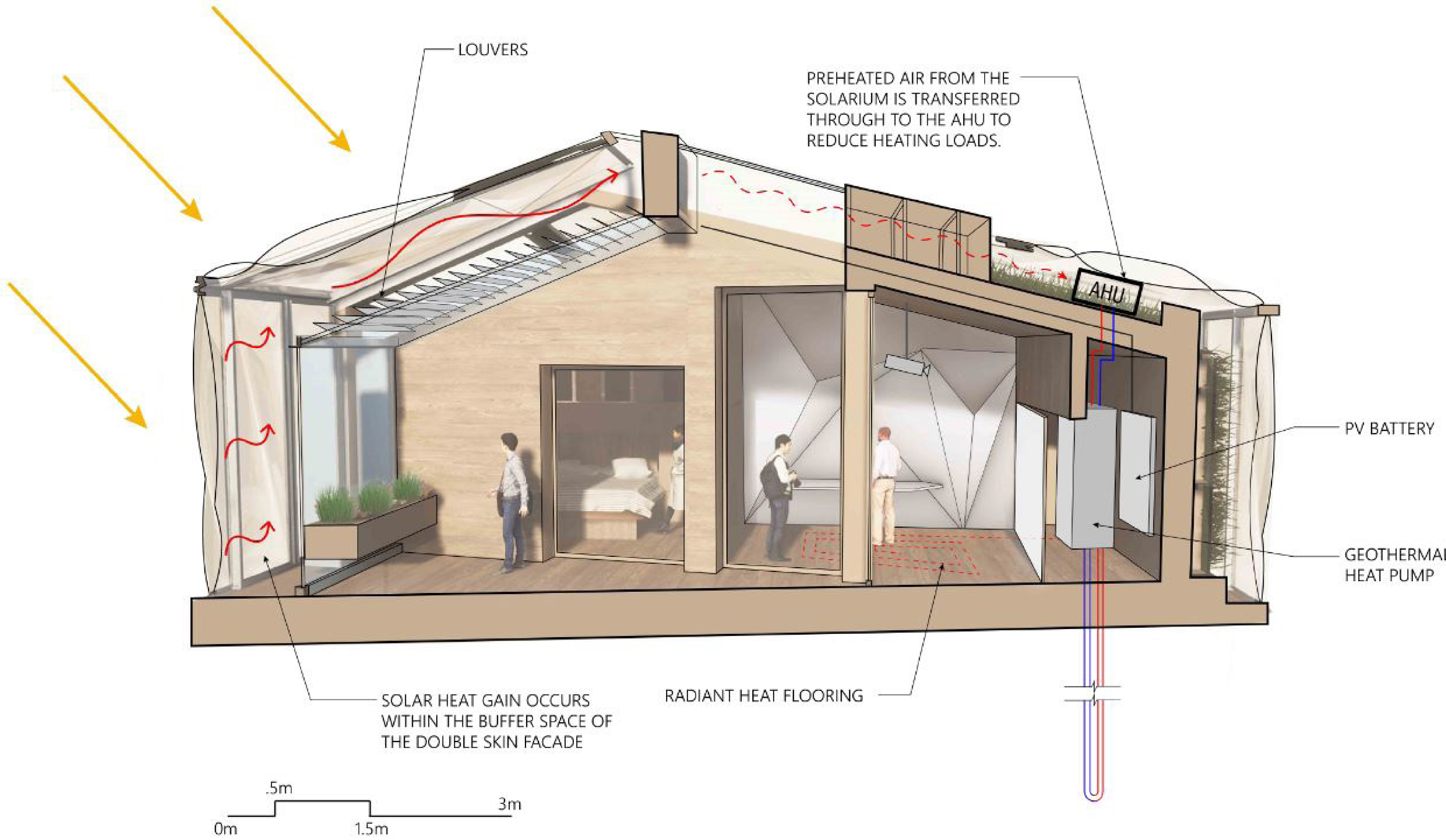
CONSTRUCTION DOCUMENTATION

INFLATED SYSTEM

Starting the construction documentation phase, the team recognized the potential for the inflated ETFE proposal to not meet budget requirements without having obtained a sponsor. Because of this, the team split in two. Team 1 continued pursuing the inflated system while potential sponsors were being contacted. Team 2 pursued a tensioned system to create a cheaper alternative.

This system shown to the right is a continuation of the inflated system design. Construction documentation focused on refining inflated ETFE in both modules and detailing. The section perspective portrays the integration of the passive facade strategies and building systems.





SECTION PERSPECTIVE

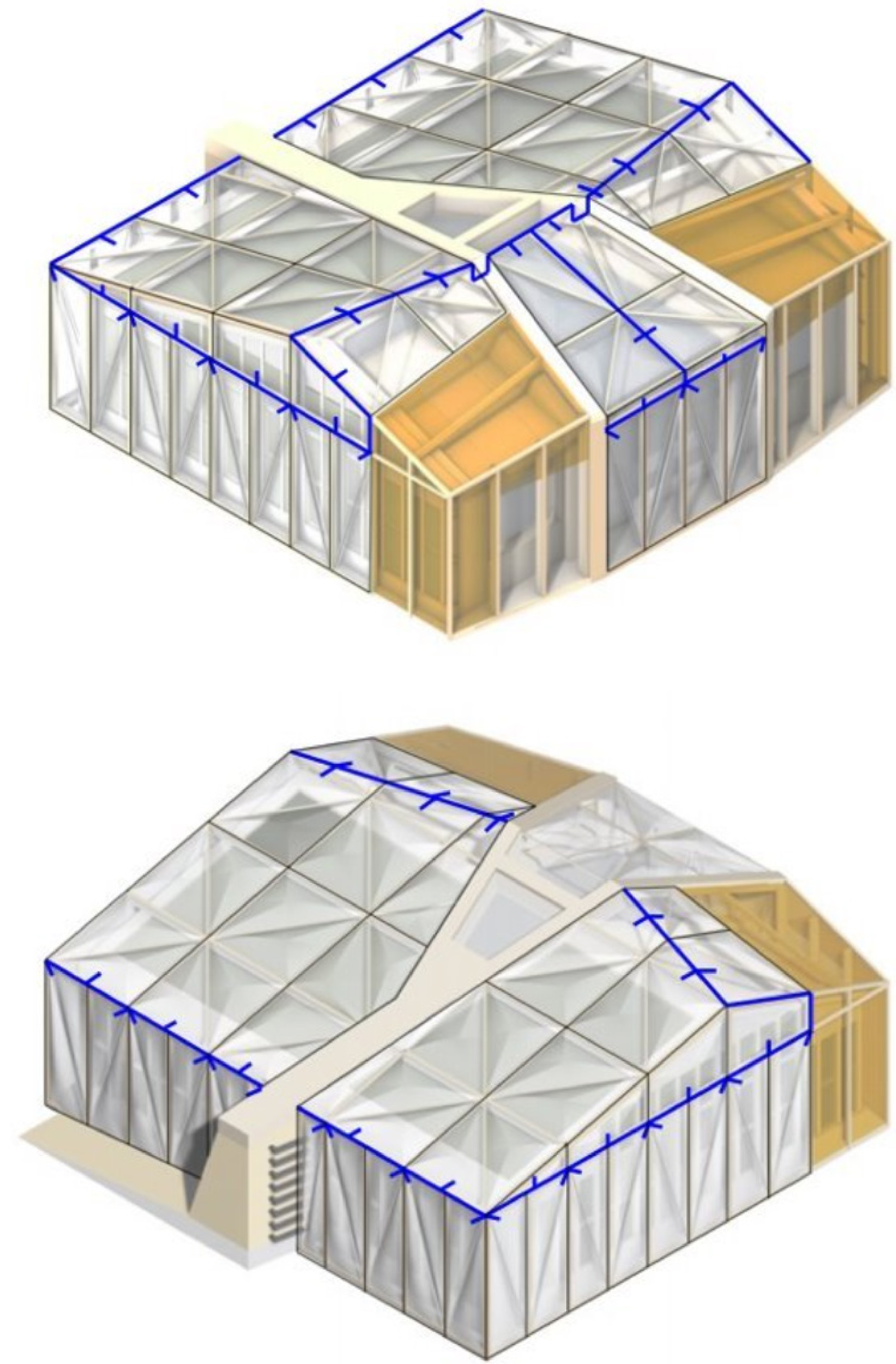
CONSTRUCTION DOCUMENTATION

INFLATED SYSTEM

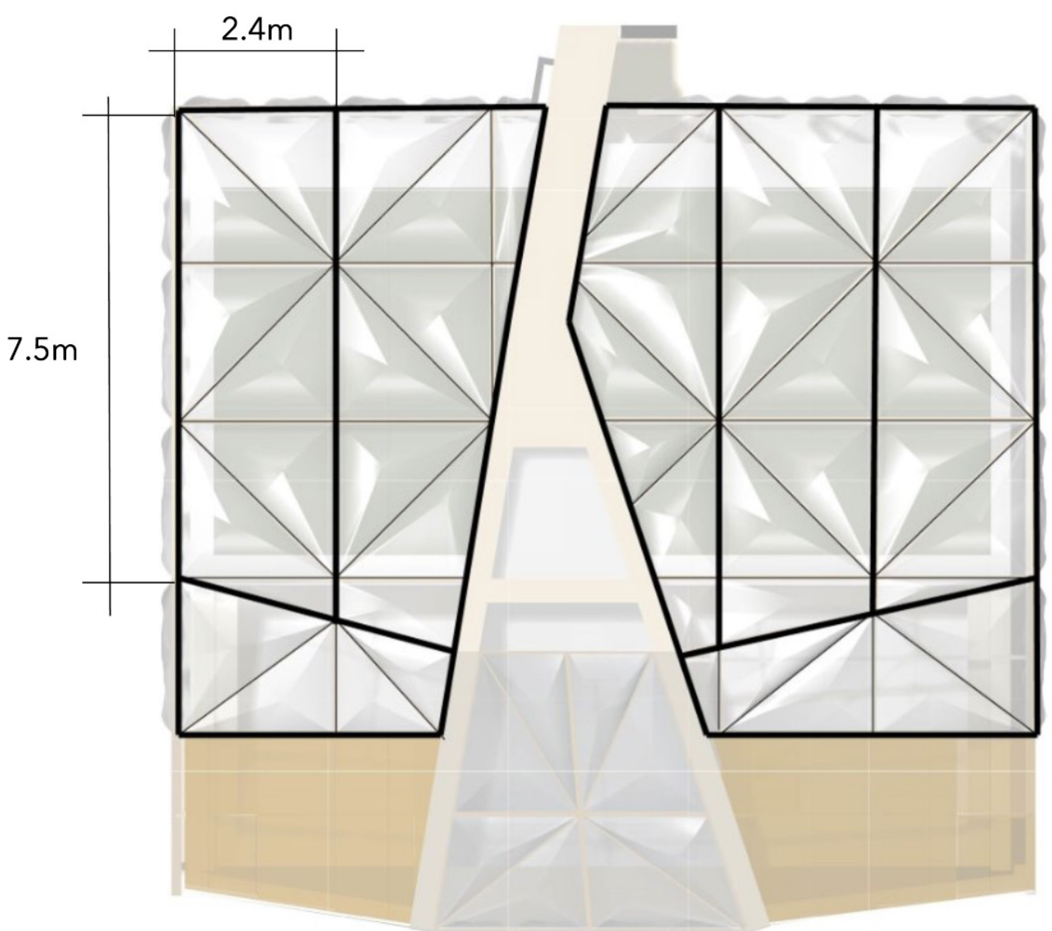
To inflate the ETFE we planned out where the inflation tubing would be placed in order to reach all of the panels. The main tubing would branch off into each of the panels in order to inflate all of them.

In order to simplify the construction and amount of components that need to come together on the roof the panels were broken down into larger components. Though in order to keep the triangular pattern cohesive with the facade there are tension and compression members implemented over top of the ETFE pillows in order to create the pattern.

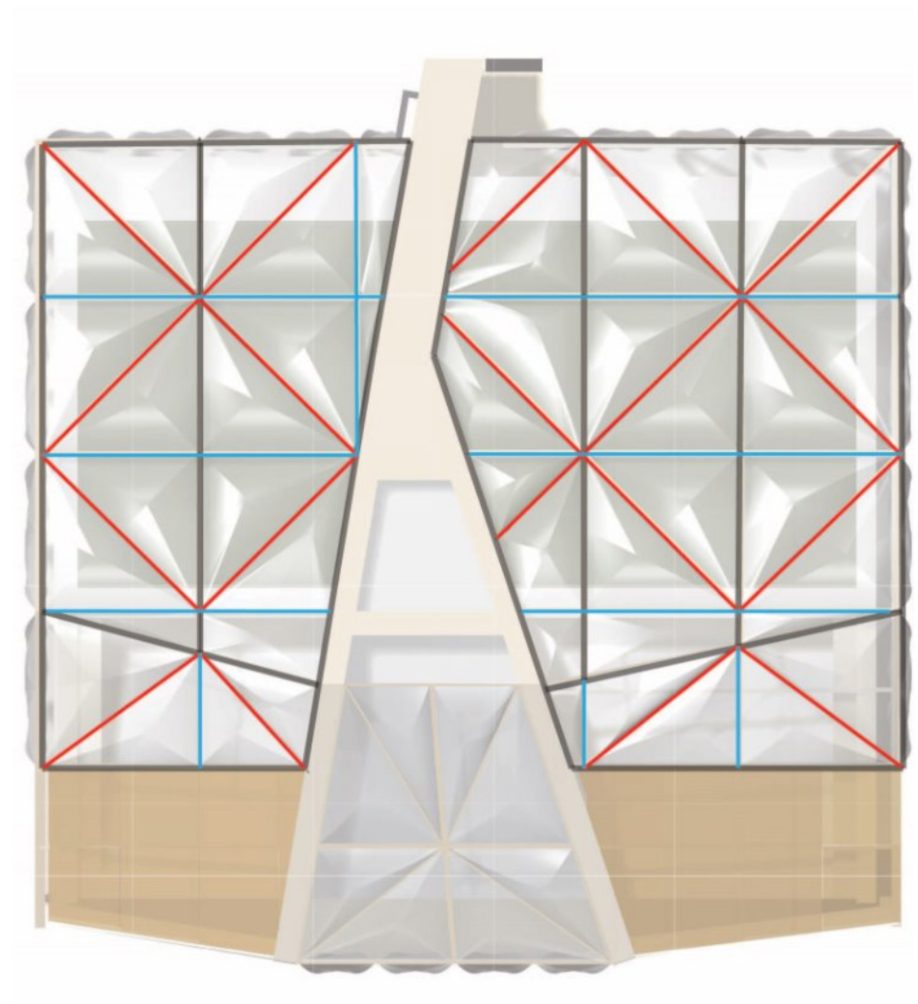
Once the panels were simplified to larger rectangular components we were able to implement a way to allow for water to drain down the roof between the panels.



ETFE INFLATION DUCTS

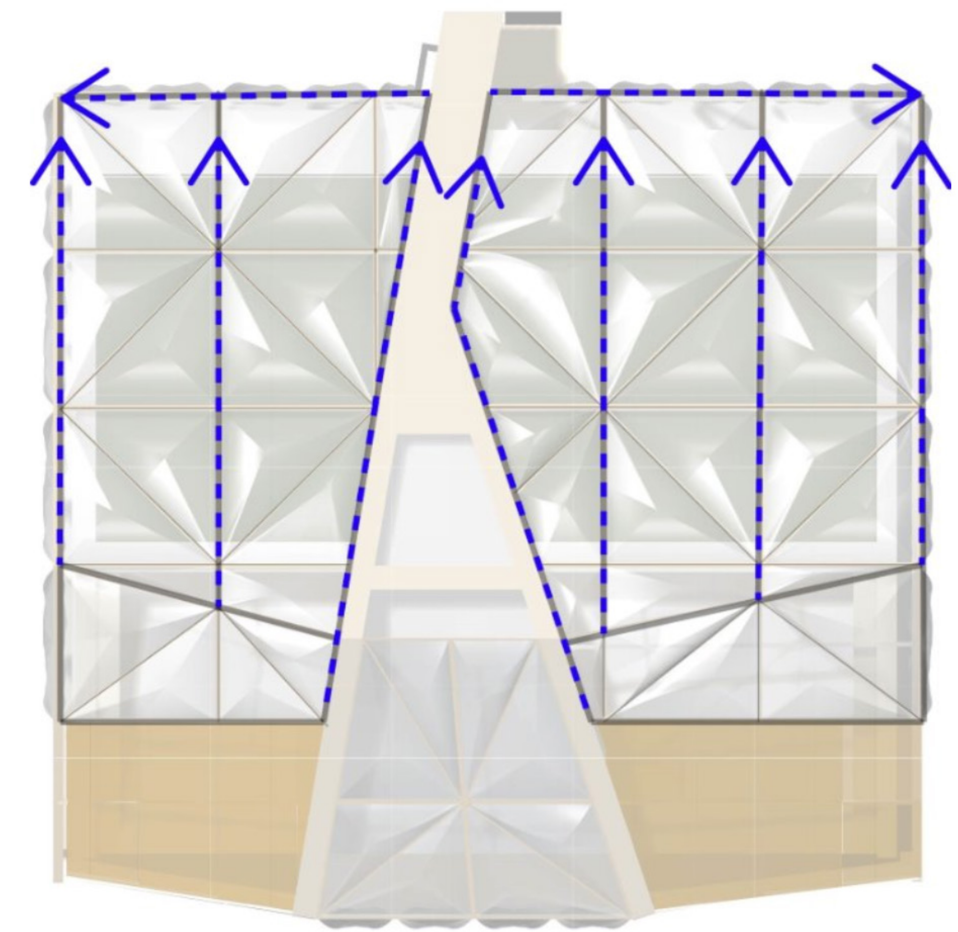


ETFE PILLOW MODULES



COMPRESSION AND TENSION MEMBERS

COMPRESSION
TENSION

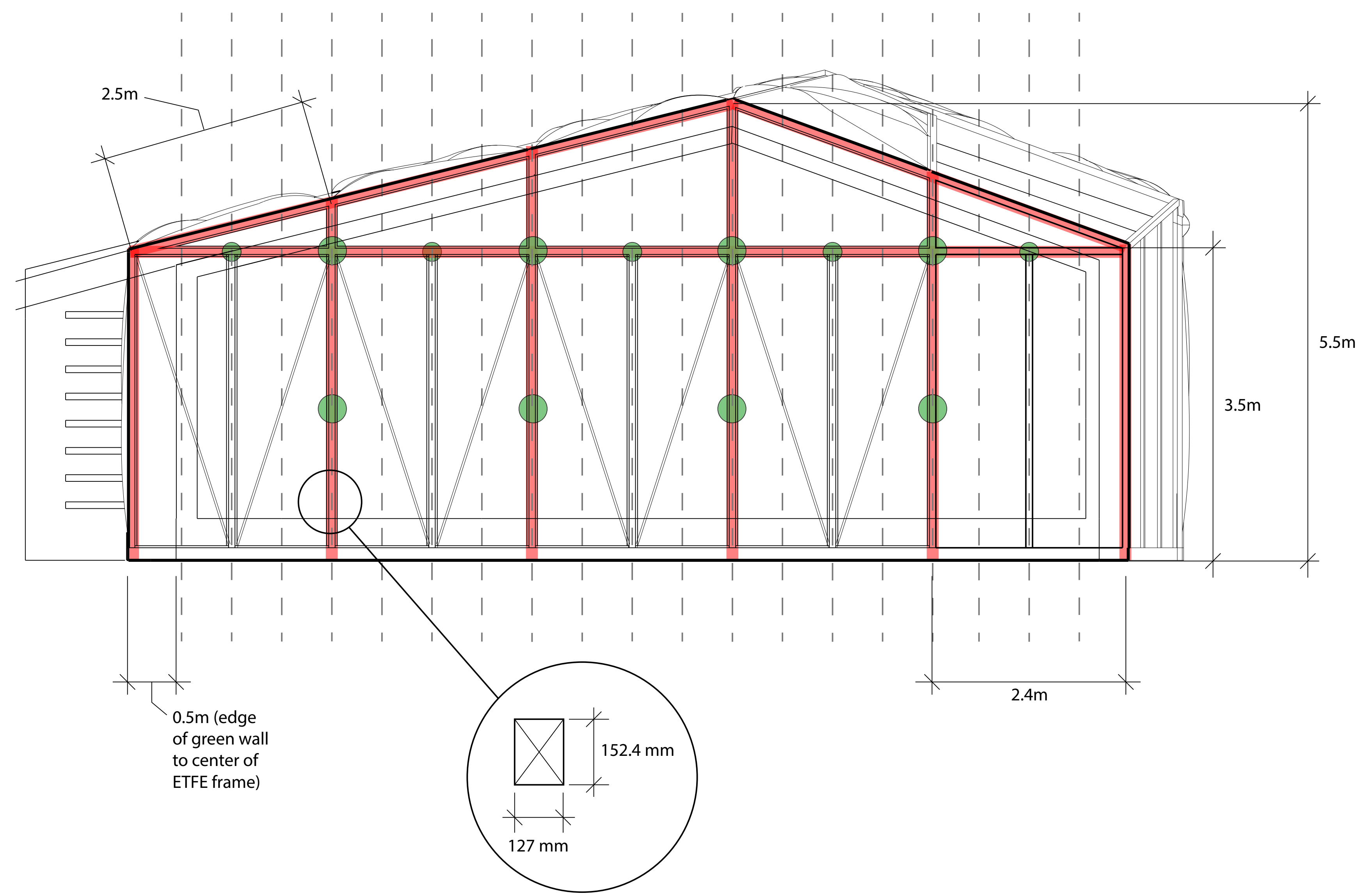


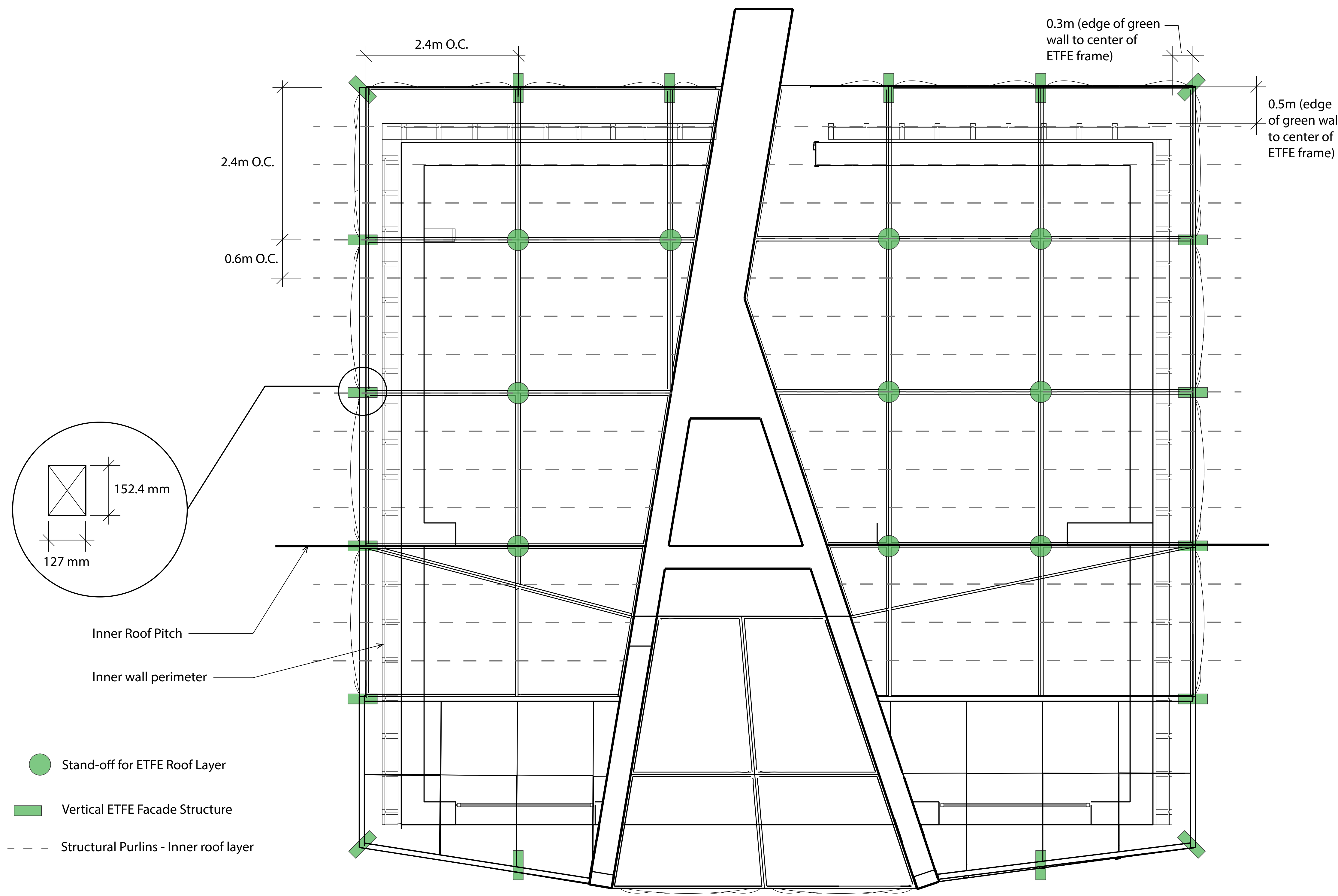
WATER DRAINAGE

CONSTRUCTION DOCUMENTATION

INFLATED SYSTEM - STRUCTURE

In developing detailing, the synthesizing the structural layout of the facade and interior walls was critical. The structural diagrams to the right show the locations of the vertical and horizontal members represented in red. The green points show the locations of tie backs and stand-offs on the roof and walls.





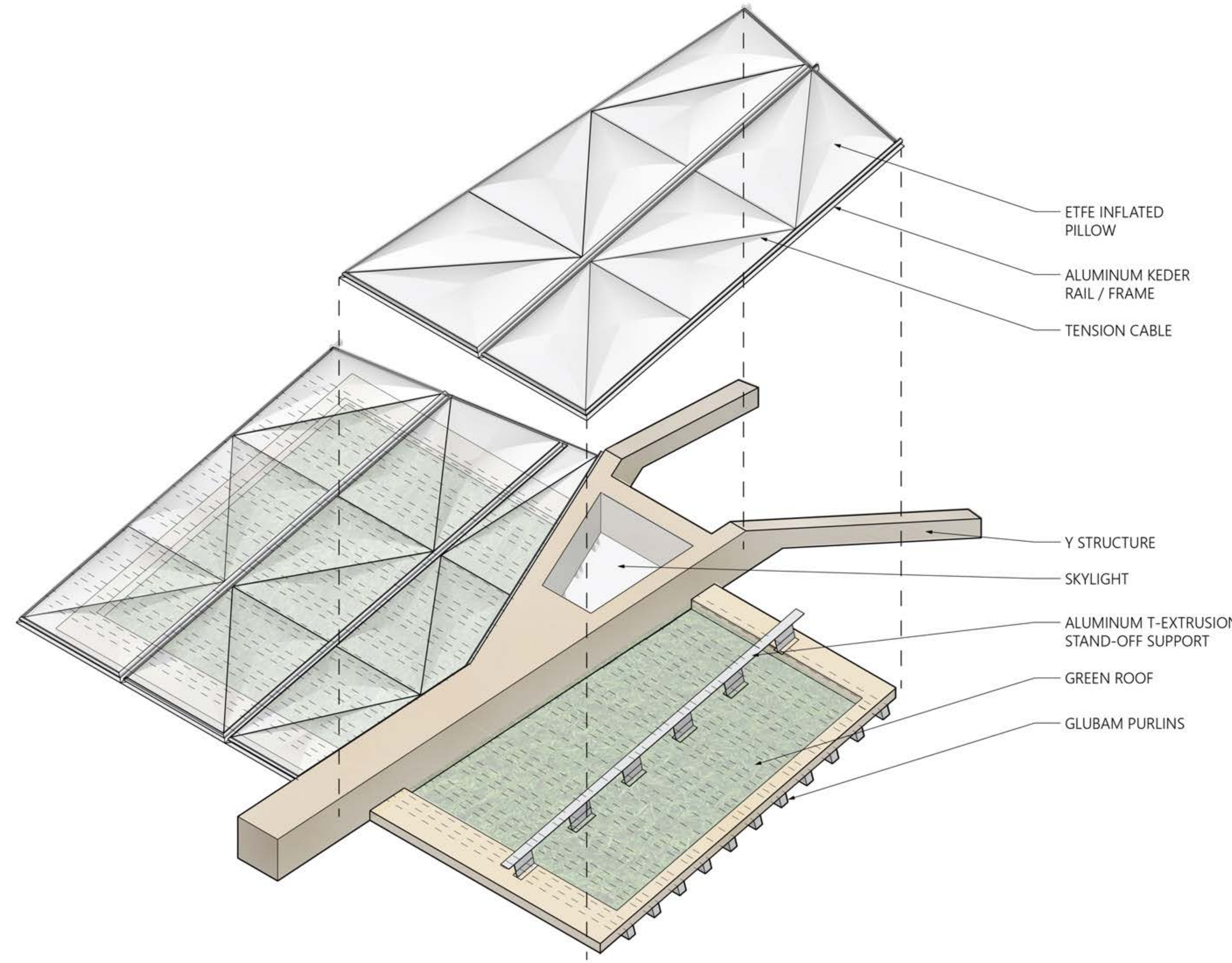
2.4m O.C.
0.3m (edge of green wall to center of ETFE frame)
0.5m (edge of green wall to center of ETFE frame)
2.4m O.C.
0.6m O.C.
152.4 mm
127 mm
Inner Roof Pitch
Inner wall perimeter
Stand-off for ETFE Roof Layer
Vertical ETFE Facade Structure
Structural Purlins - Inner roof layer

CONSTRUCTION DOCUMENTATION

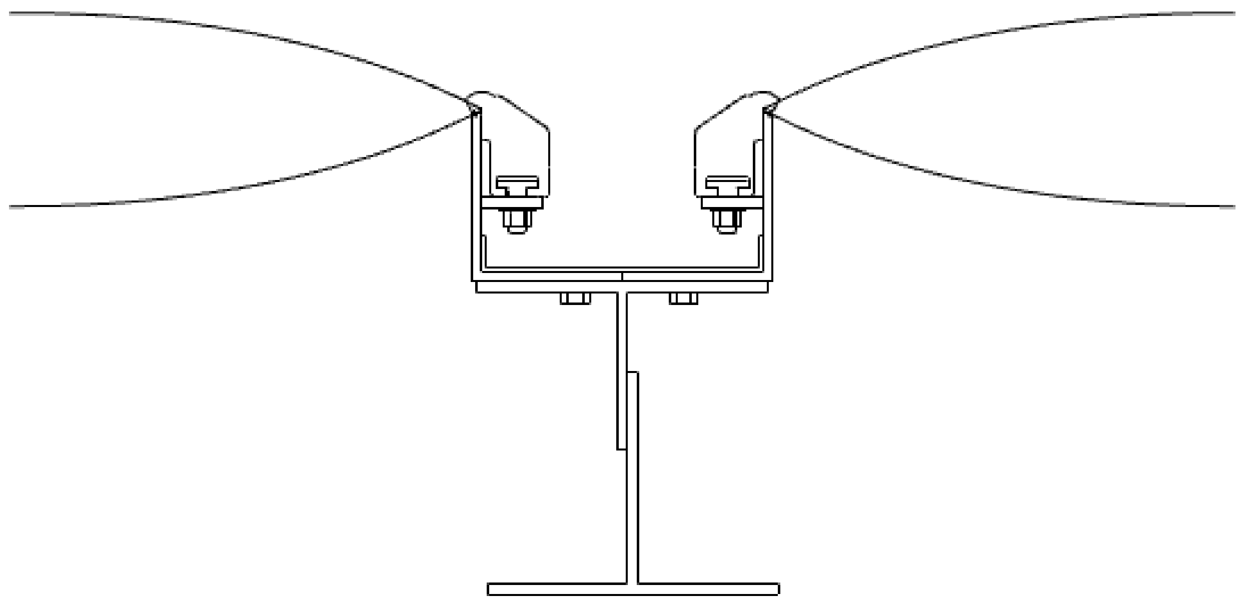
INFLATED SYSTEM - ROOF DETAILING

Continuing forward as we tested multiple schemes, we focused detailing our façade using standard products for ETFE pneumatic structures. After the general layout of panels was determined, the constructibility of the panels was considered. The team investigated the realities of how an ETFE panel is created. The material is wrapped around this tube called a “keder” and heat welded to itself. The keder is then fed into an aluminum extrusion that holds it in place.

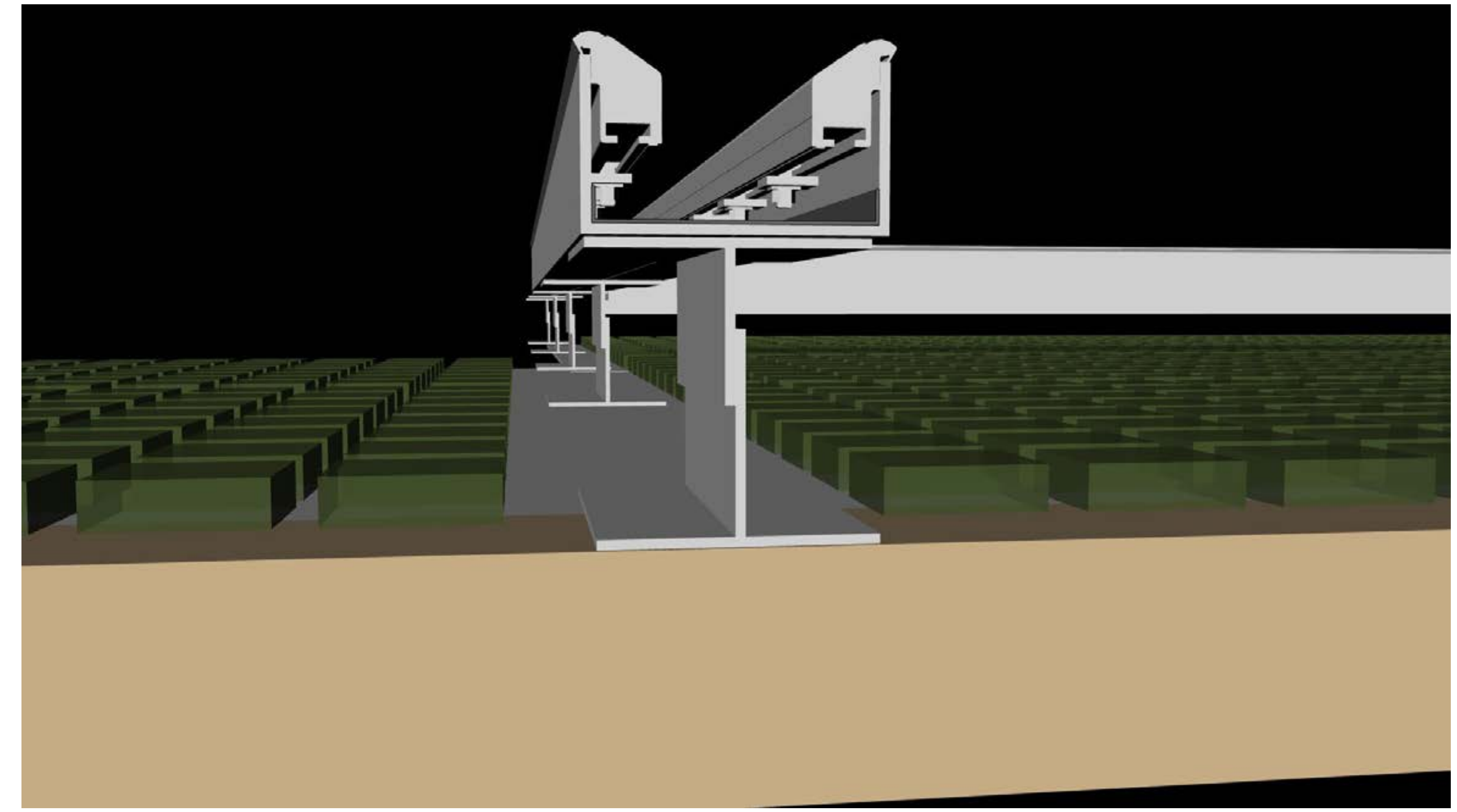
The details of the roof connection systems underwent many changes at this period as a result of consultations from multiple professionals that work closely with the materials involved in the project. One of the challenges of fully realizing the roof was having all of the parts come together within the constraints of height, connections to structure, and finding compatible parts for the design intent.

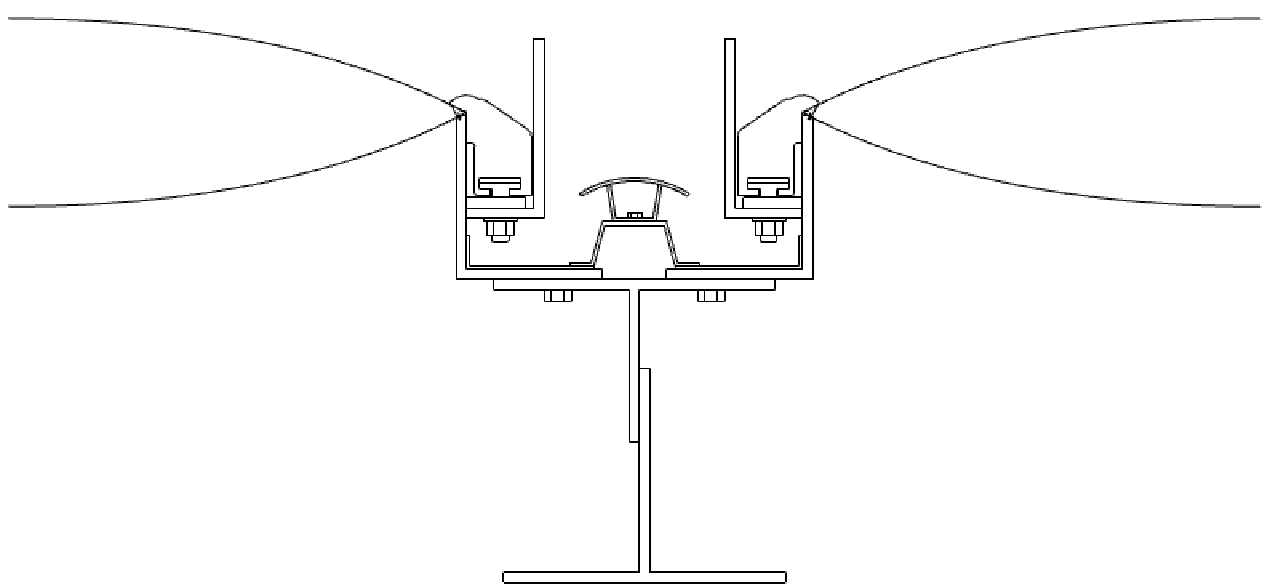


EXPLODED ROOF CONSTRUCTION

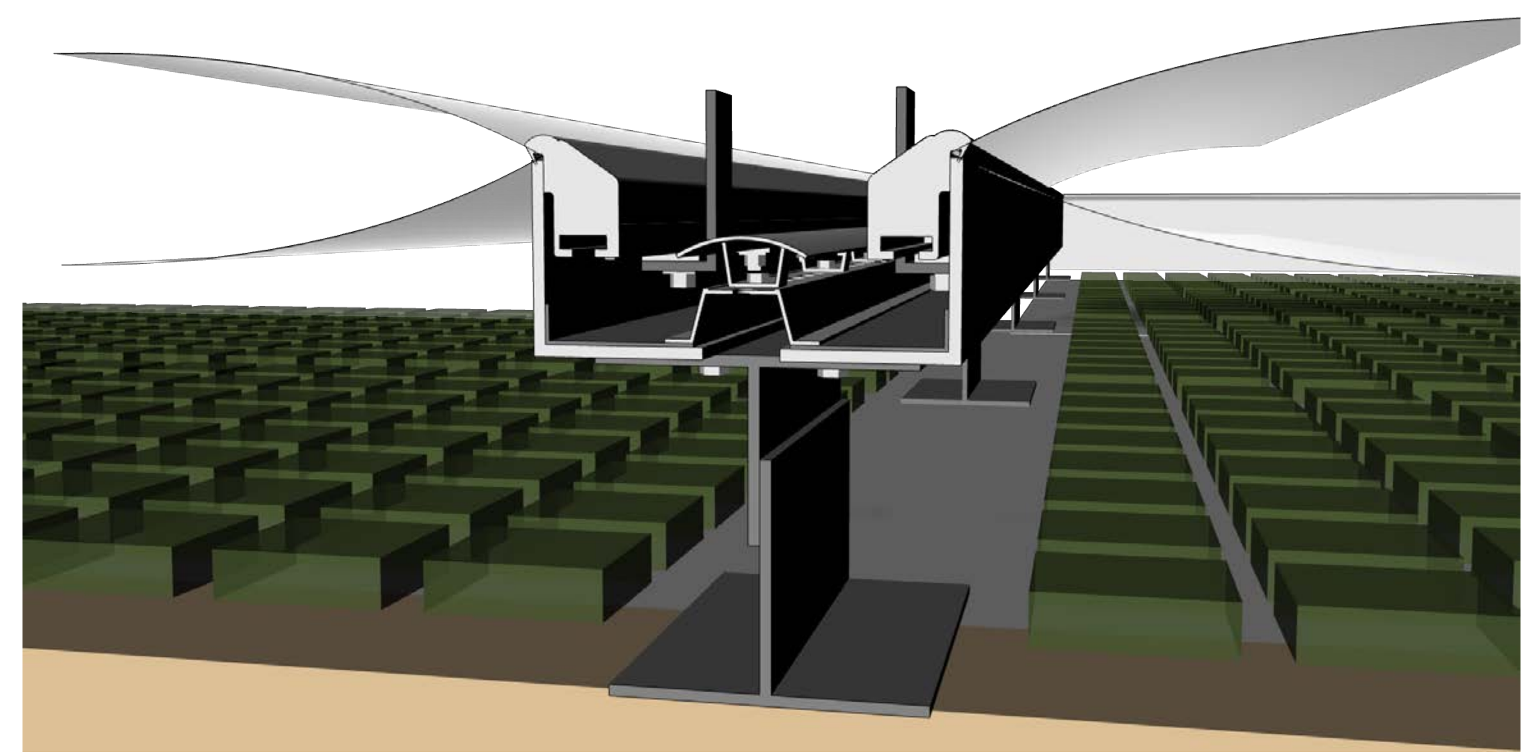


ROOF DETAIL - ITERATION 1





ROOF DETAIL - ITERATION 2



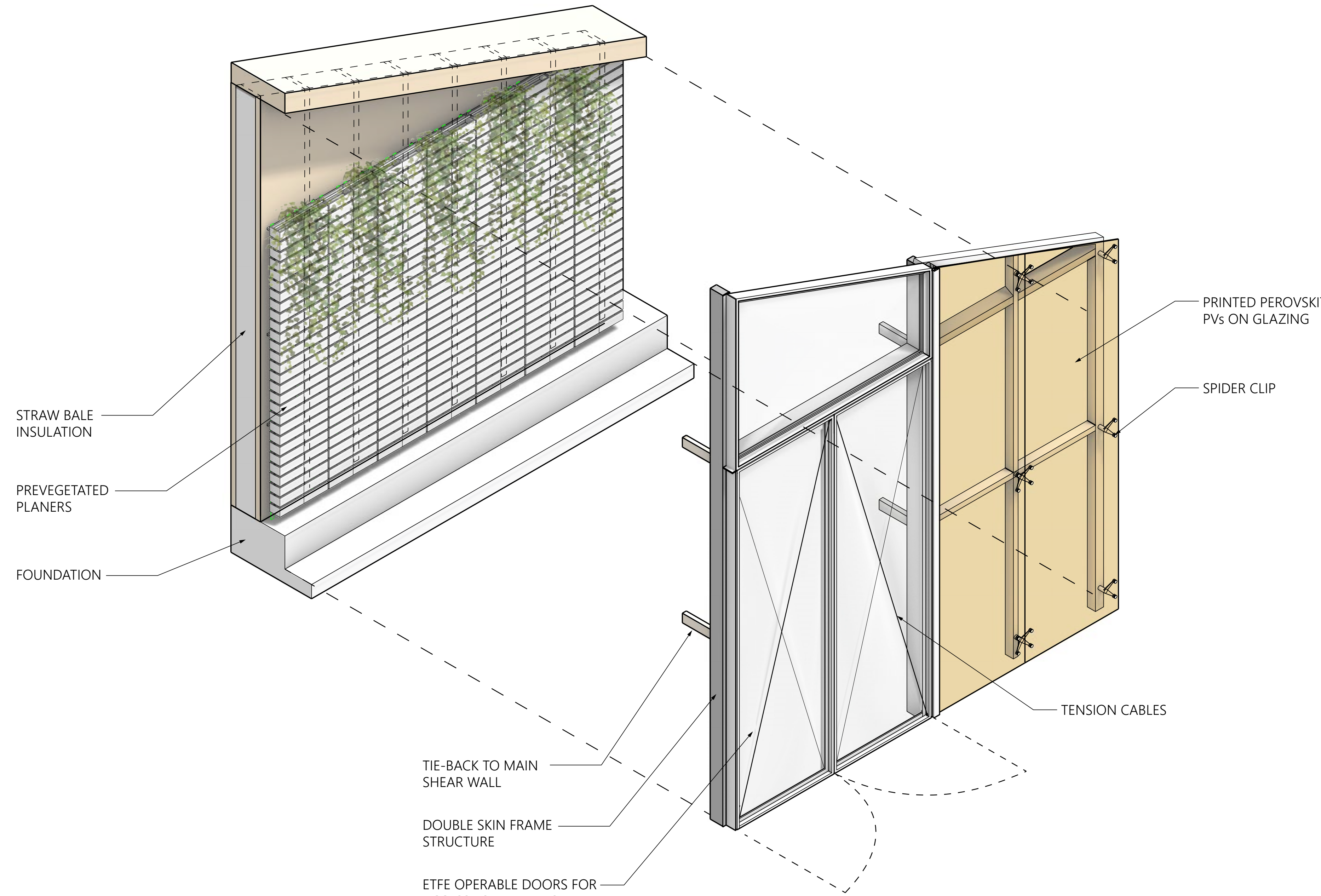
CONSTRUCTION DOCUMENTATION

INFLATED SYSTEM - WALL DETAILING

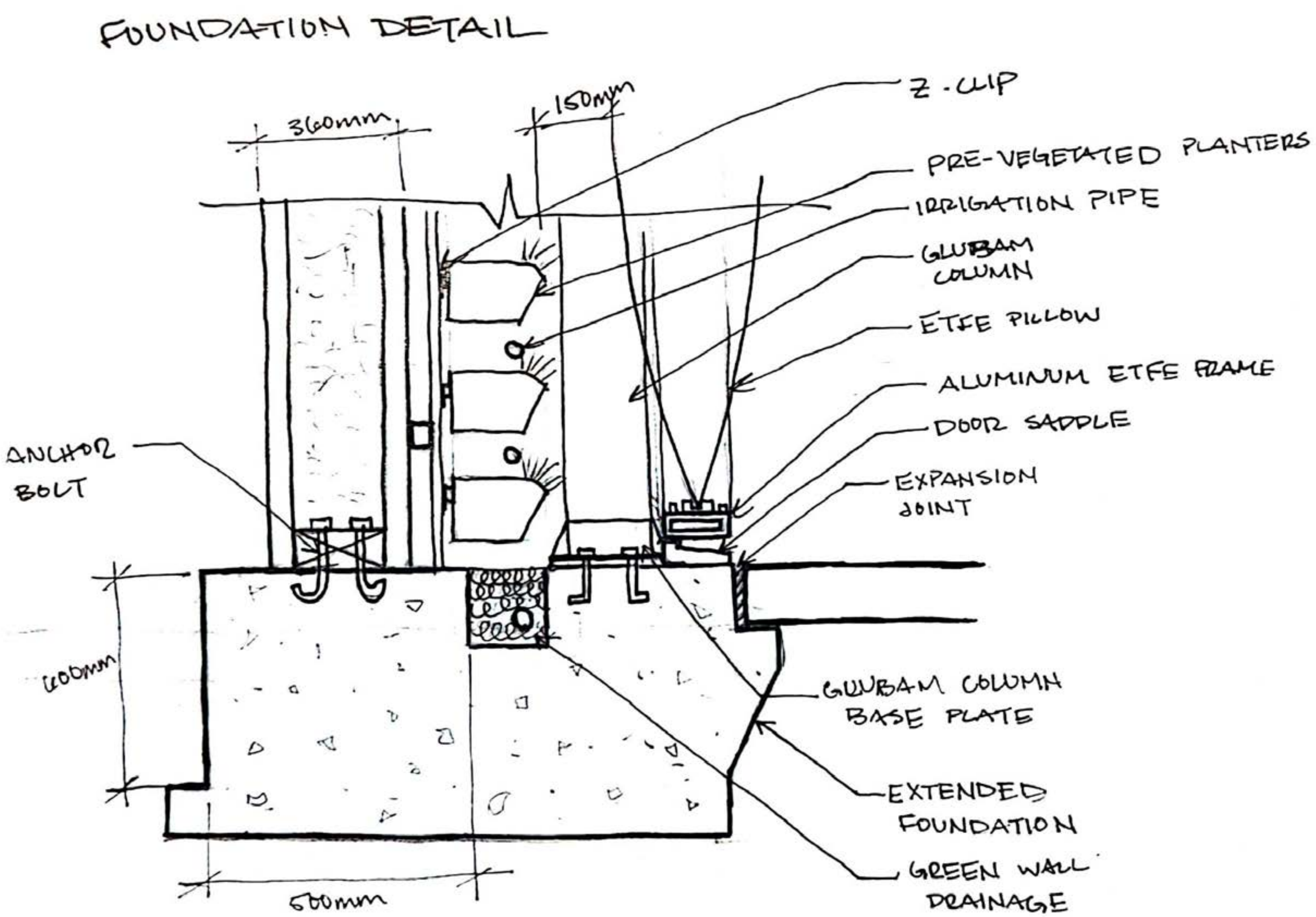
The East and West Walls include part of the PV panels wrapping around from the South Facade.

The ETFE frame and the frame for the PV panels are connected by an aluminum "T" that is connected back to a Glubam structure. The connection of these systems gets tied back to the main straw bale wall.

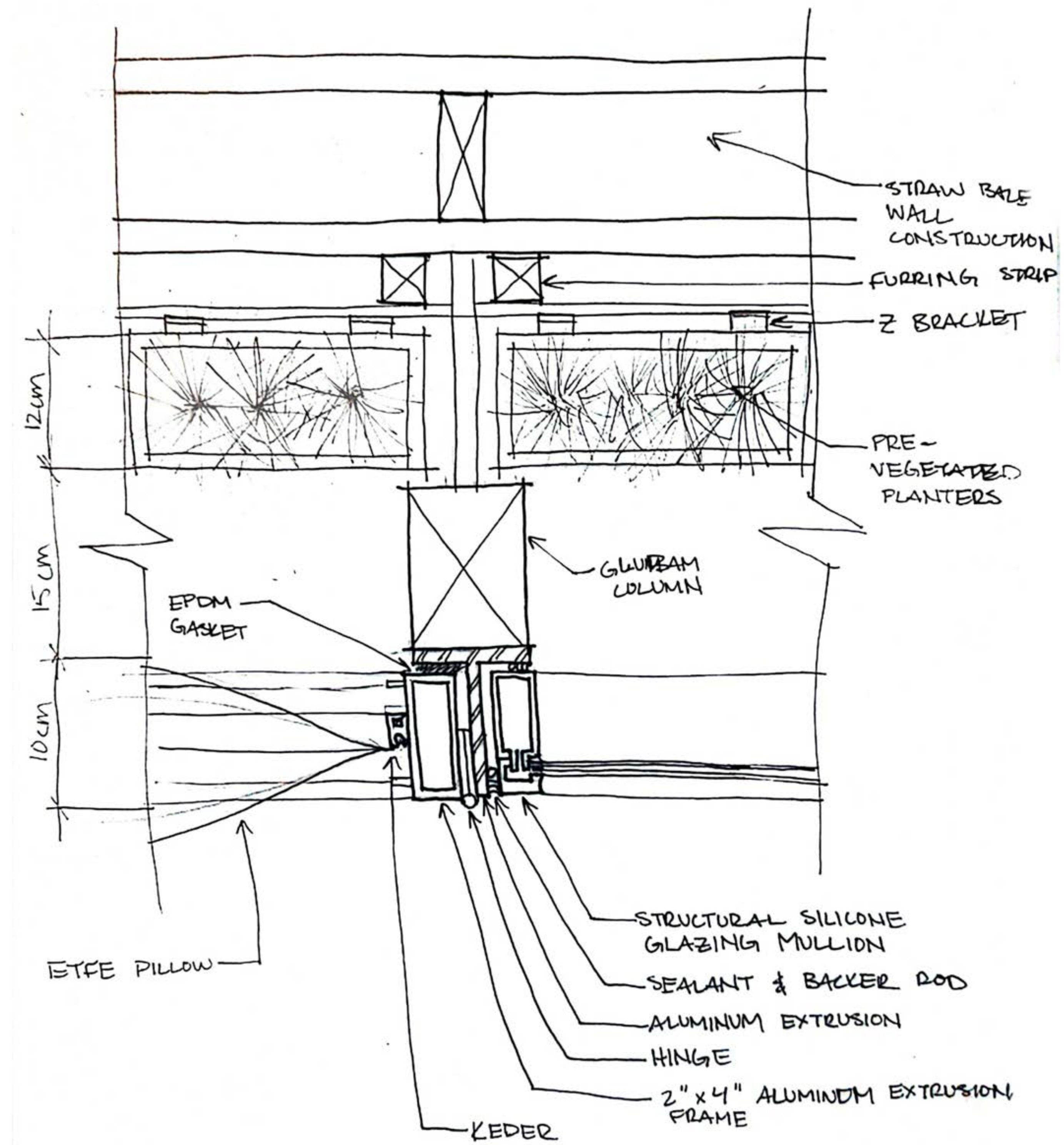
The Foundation of this system consists of the glubam column directly sitting on the concrete to help support the ETFE wall. The column allows for enough space between the ETFE and the plants. The frame of the ETFE sits above the ground enough to allow the doors to swing open.



EXPLODED WALL CONSTRUCTION



FOUNDATION DETAIL

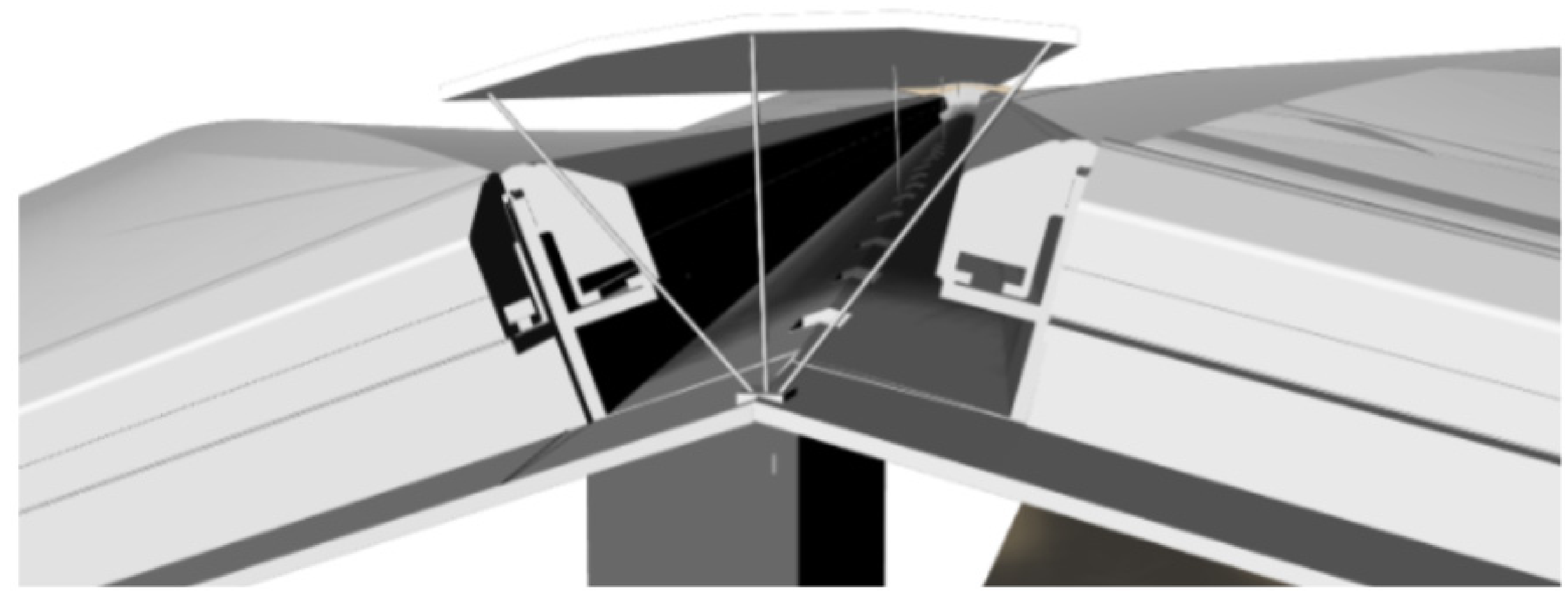


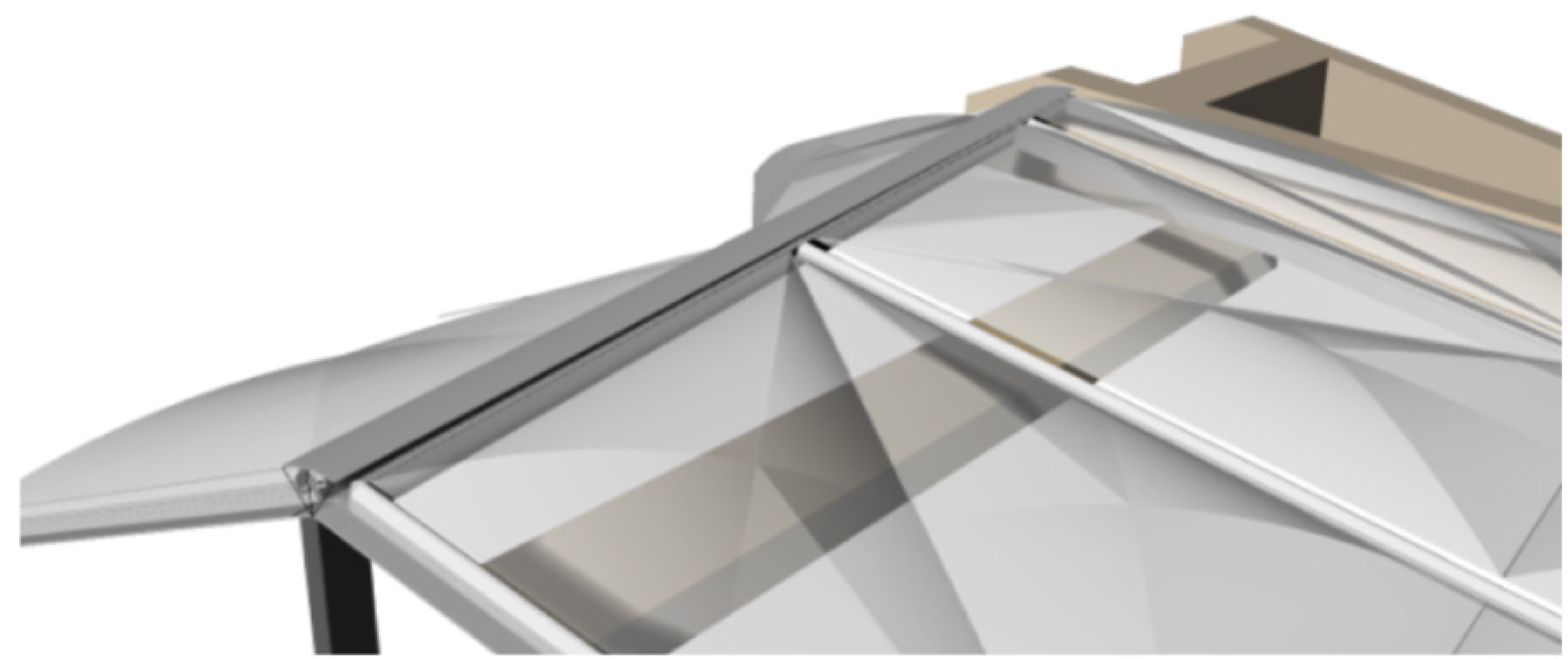
ETFE TO GLASS PLAN DETAIL

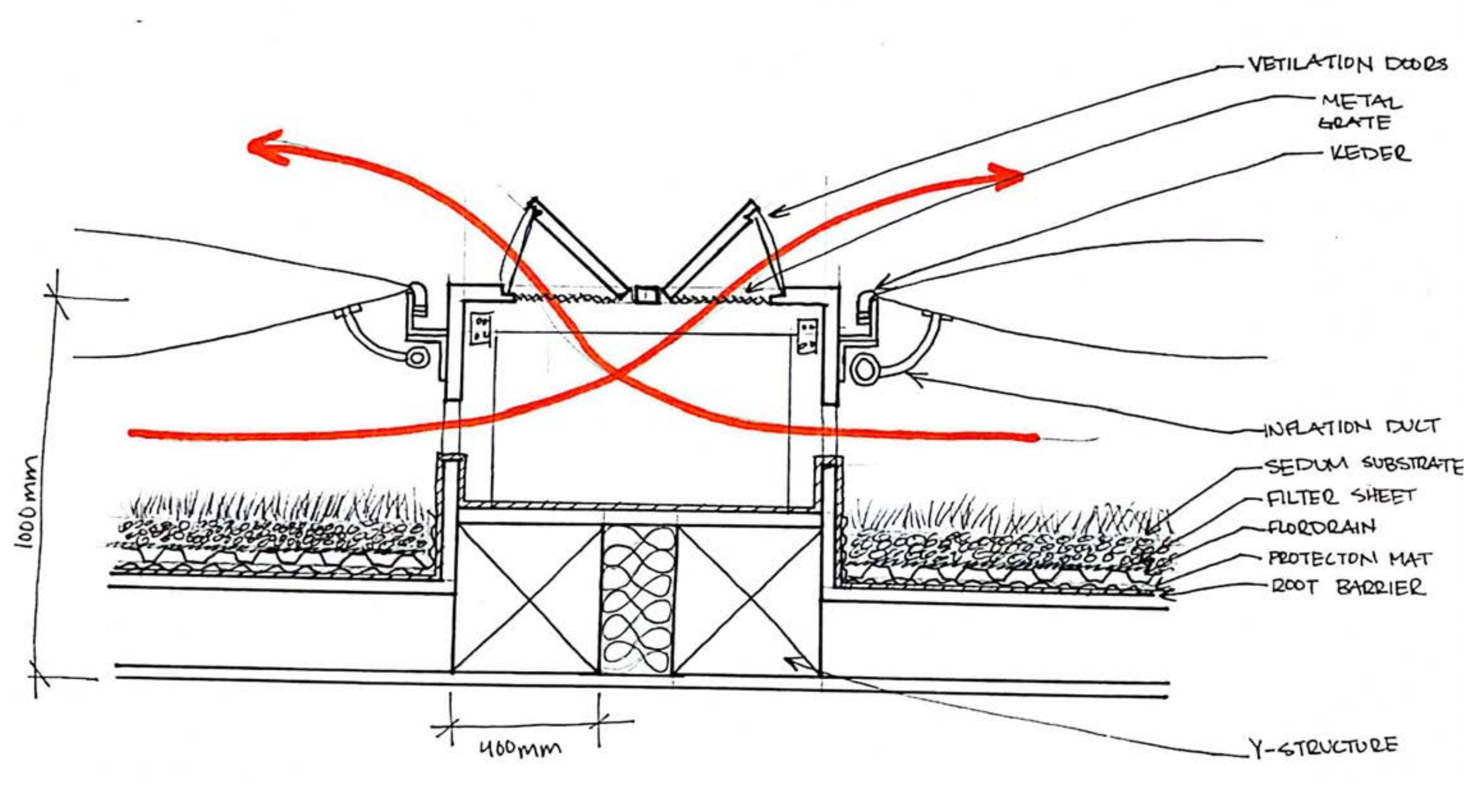
CONSTRUCTION DOCUMENTATION

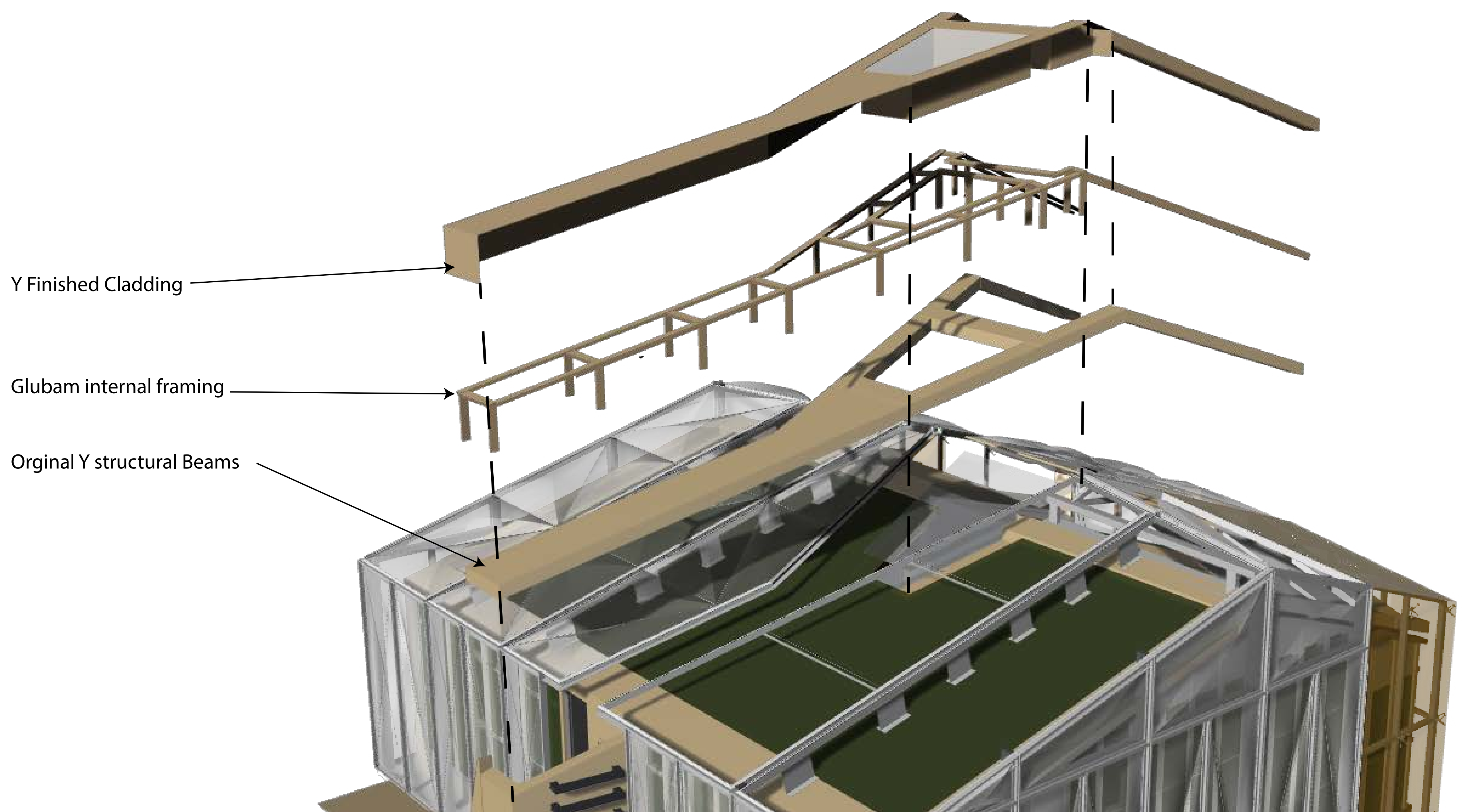
INFLATED SYSTEM - VENTILATION

During design development, the project began to develop the logistics of ventilation into the double skin façade out of necessity for the plants and energy efficiency. We designed and modeled multiple vent systems for the façade including co-opting the Y-structure as an outlet for air and multiple ridge vents at the peak of the building before deciding on a rotating vent on the northern tip of the roof. Through negative and positive pressure, the proposed system intakes cold air from the ground and releases the air by letting it out at the operable upper ridge, controlling the heat of the "greenhouse" effect taking place.





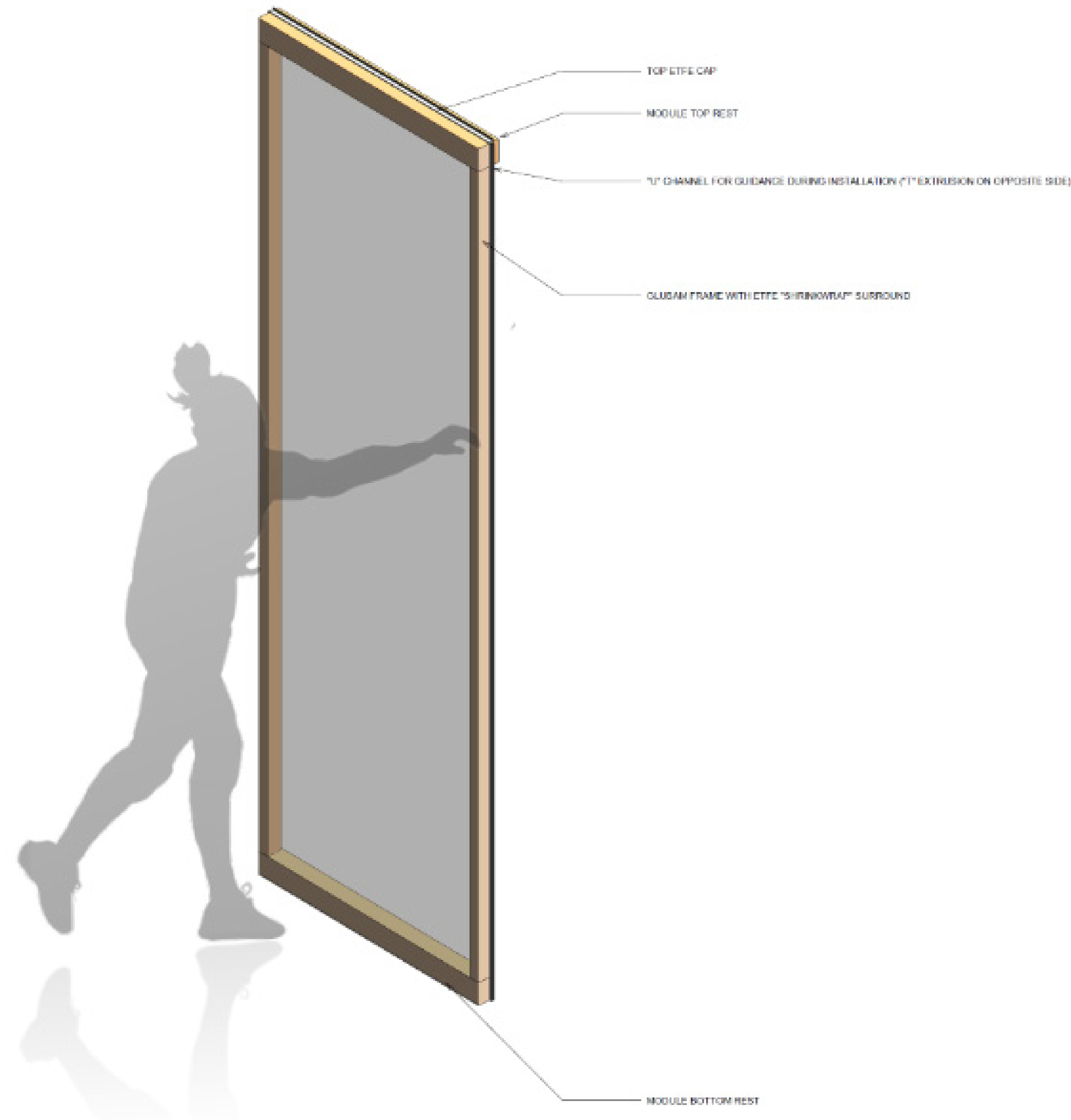

VETILATION DOORS
METAL GRATE
KEDER
INFLATION DUCT
SEDUM SUBSTRATE
FILTER SHEET
FLORDRAIN
PROTECTON MAT
ROOT BARRIER
Y-STRUCTURE
1000mm
400mm


Y Finished Cladding
Glubam internal framing
Orginal Y structural Beams

CONSTRUCTION DOCUMENTATION

TENSIONED SYSTEM

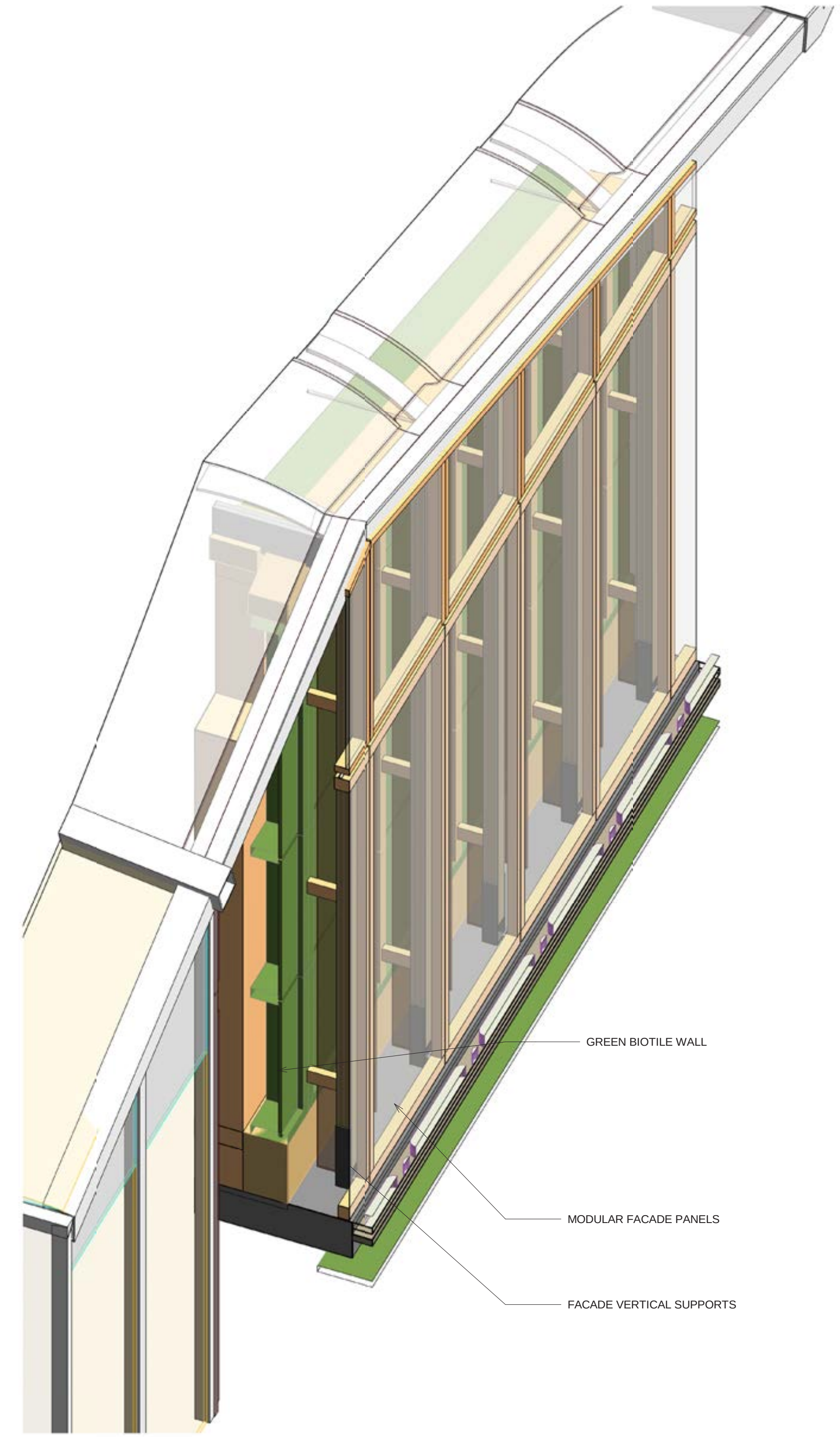
The tensioned façade proposal is comprised of two primary components, the wall and roof panels. Each system utilizes different strategies in order to solve their design requirements, with both collectively accomplishing the project's primary goals of accessibility to the Bio-tile system, affordability, thermal performance, maintenance, redundancy, and construction tolerance. For the wall panel system on the East, West, and Northern faces of the building, the panels utilize tensioned ETFE via an enclosed keder rail system. By enclosing the tensioned system within the frame, greater thermal performance is achieved, in addition to significant greater simplicity in construction onsite.

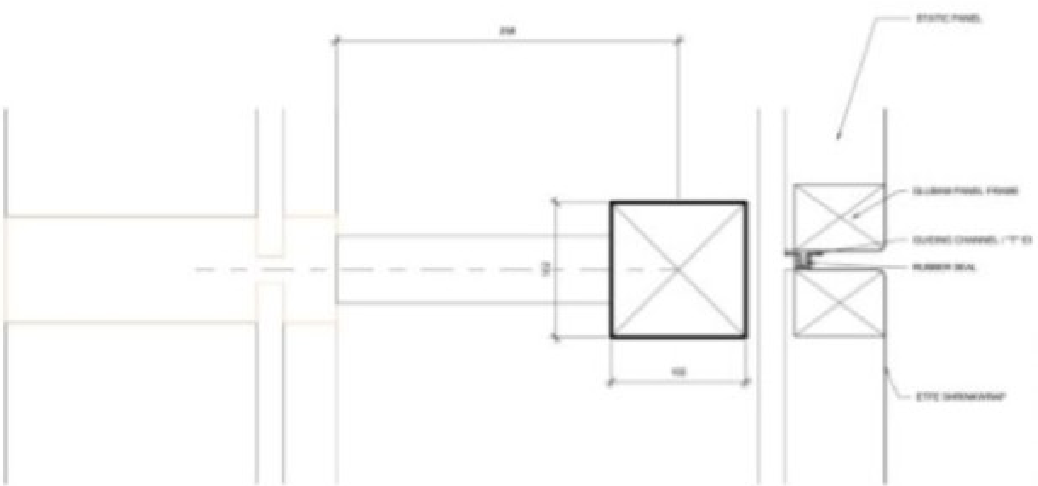


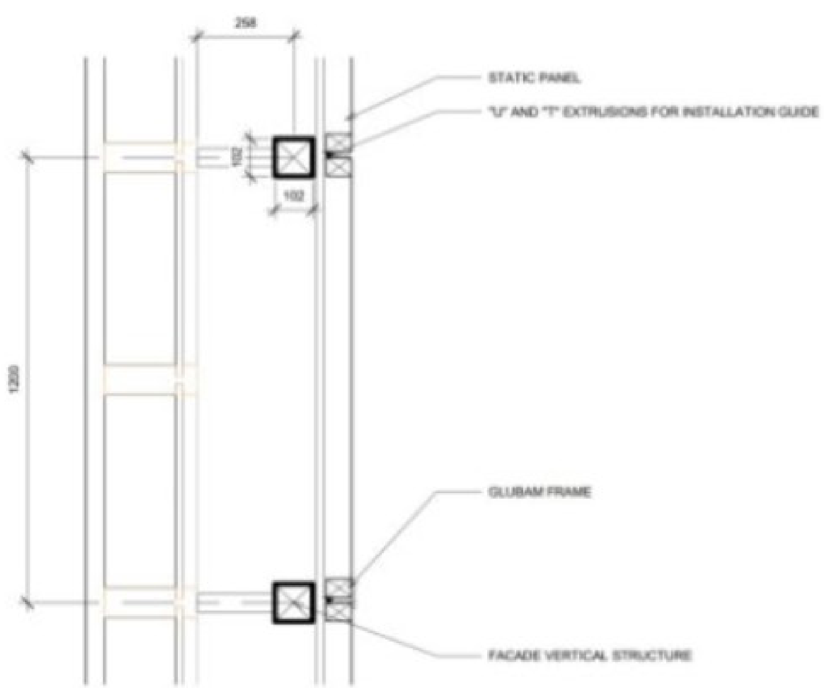
CONSTRUCTION DOCUMENTATION

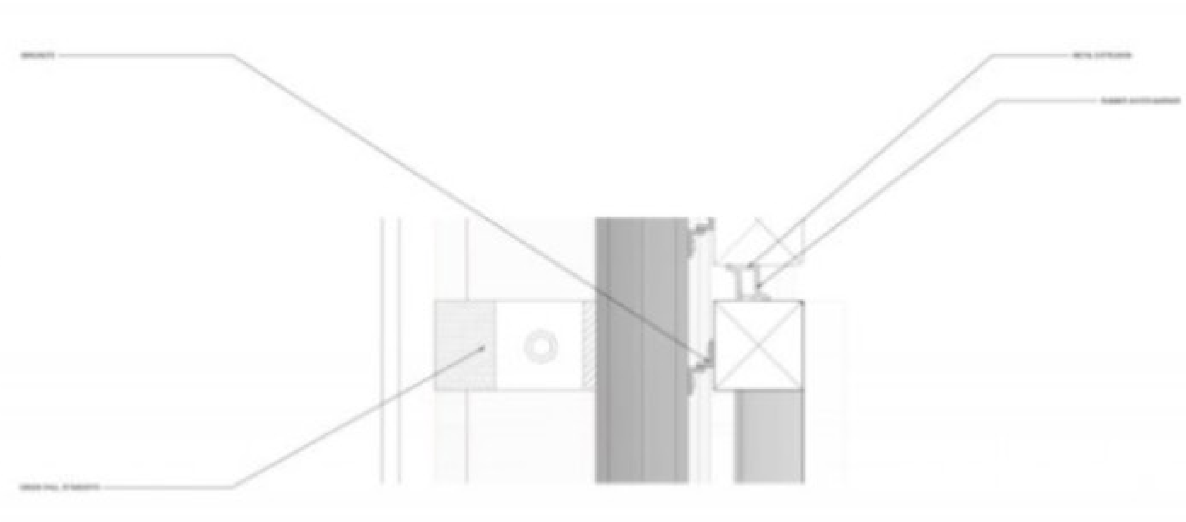
TENSIONED SYSTEM

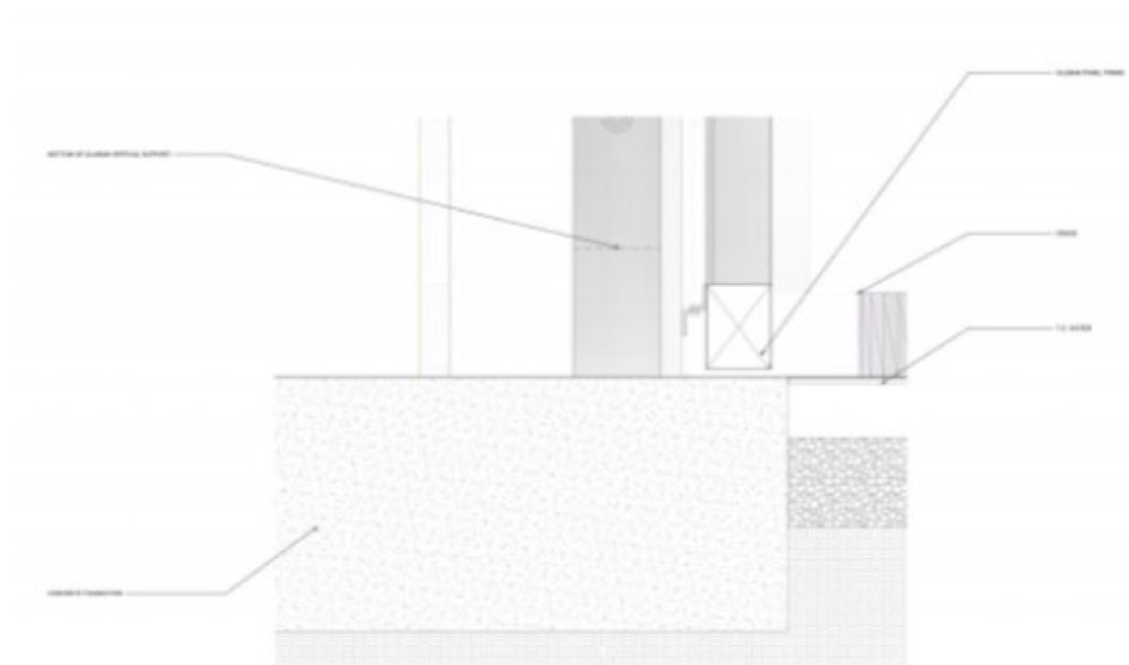
The proposal began a discussion of how we wanted our façade to perform. Such as if the facade functions as a rain-screen or a water and airtight enclosure. The details to the right suggest a system in which panels are individually fastened and unfastened to gain access to the bio-tiles behind.

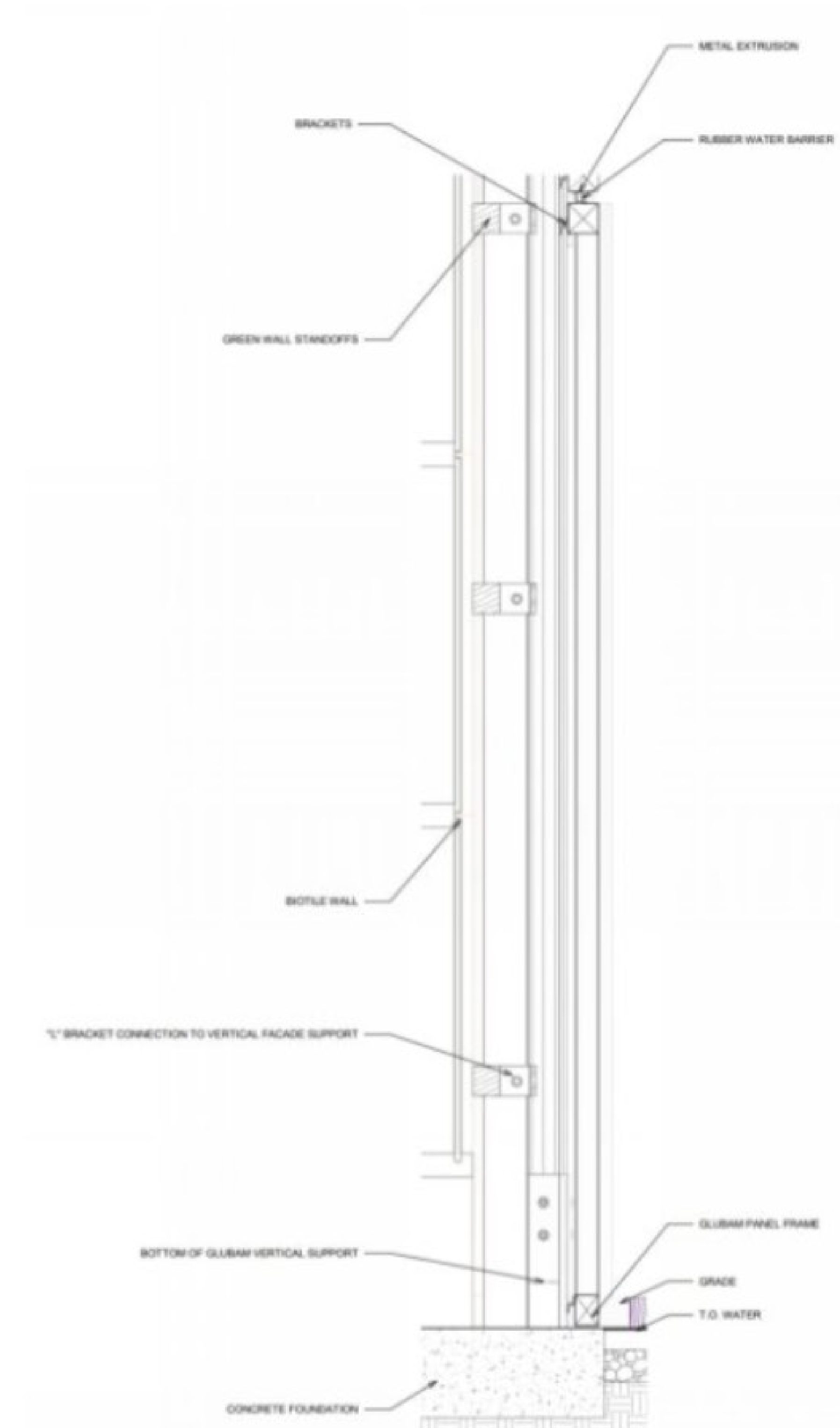





258
STATIC PANEL
"U" AND "T" EXTRUSIONS FOR INSTALLATION GUIDE
102
102
1200
GLUBAM FRAME
FACADE VERTICAL STRUCTURE





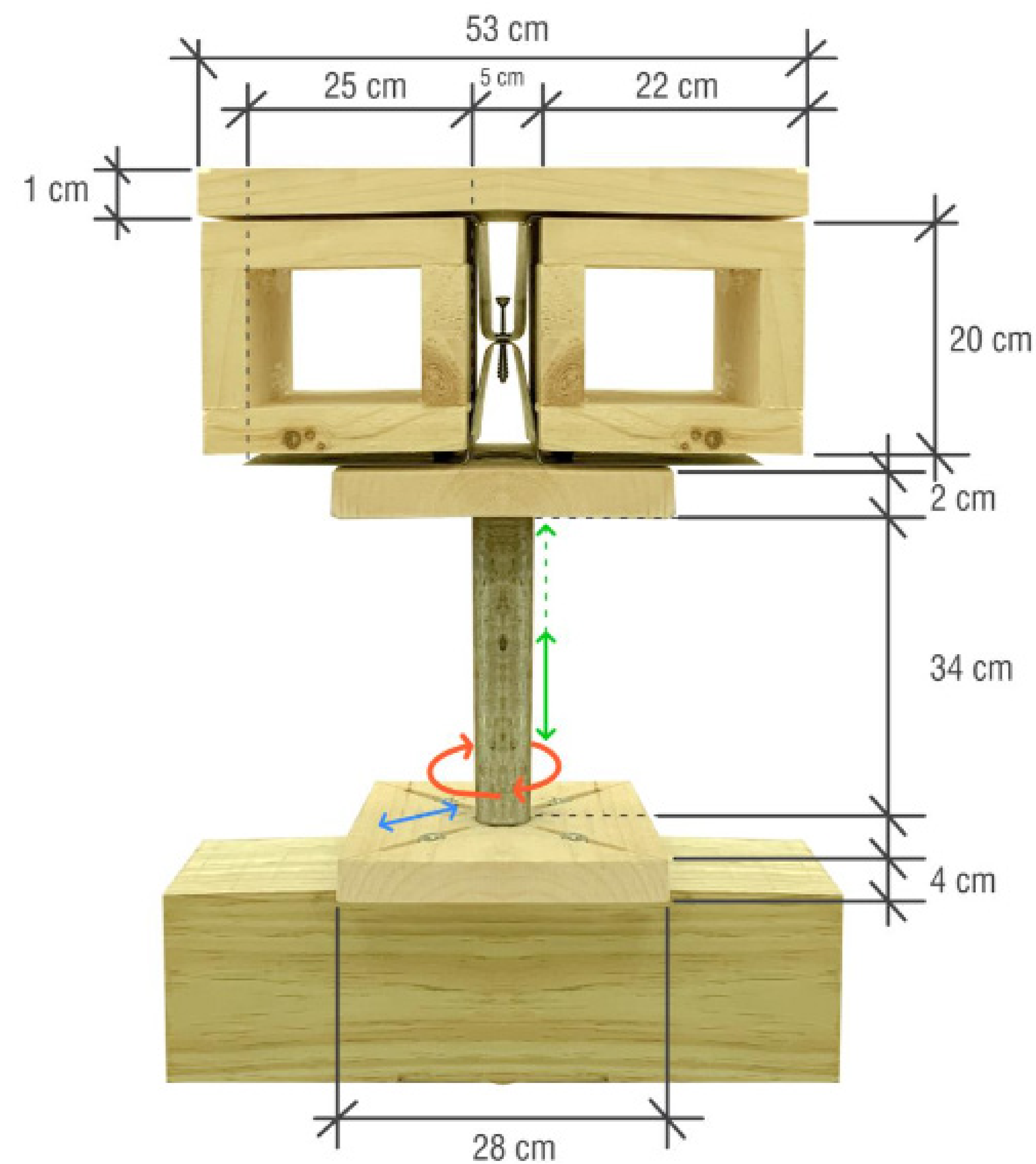

METAL EXTRUSION
BRACKETS
RUBBER WATER BARRIER
GREEN WALL STANDOFFS
BIOTILE WALL
"L" BRACKET CONNECTION TO VERTICAL FACADE SUPPORT
GLUBAM PANEL FRAME
BOTTOM OF GLUBAM VERTICAL SUPPORT
GRADE
T.O. WATER
CONCRETE FOUNDATION

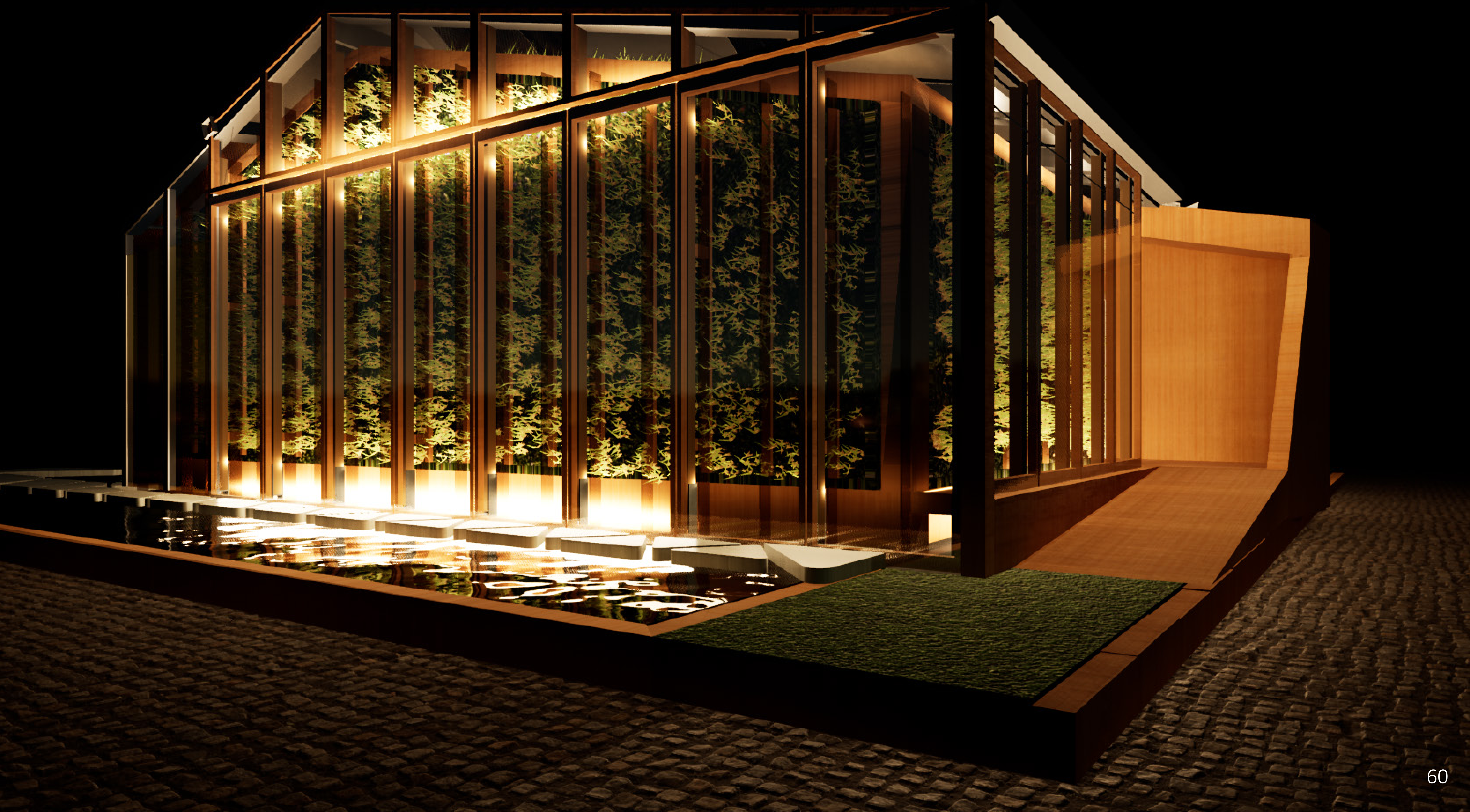
CONSTRUCTION DOCUMENTATION

TENSIONED SYSTEM

For the roof structure, the assembly uses an overlapping ETFE sheet system that is fastened down via snap ties, connecting to the roof assembly's standoff modules and framing. The pitch of the framing redirects water into valleys that flow down the pitch, being collected by a cistern for greywater usage on site. The simple sheet construction and high tolerance roof standoff modules, the assembly can handle a wide variety of scenarios and application, all while remaining modular and affordable.

The simple and clean aesthetic generated by this scheme was attractive to the team and influenced future design changes and proposals.





CONSTRUCTION DOCUMENTATION

COST ESTIMATION

The team received cost estimates from Covertex, an ETFE manufacturer and installer. As expected, team one's proposal was more expensive due to the required inflation system. However, both proposals were above budget.

Upon speaking with Bjoern Beckert, an advisor from Fabritechture, it was brought to the team's attention that the estimates were roughly marked up by 1.5x. This is assumed to be because both proposals were still in early stages of development. Additionally, due to the fact that the company has larger scale projects at the Olympics there was no incentive for the company to provide sponsorship.

As a result of the information provided the facade team had to quickly evaluate alternative materials and strategies that would perform similarly, but at an effective cost.

Budget Base Line Estimation **Y-Project- Team 1** 2021-3-17

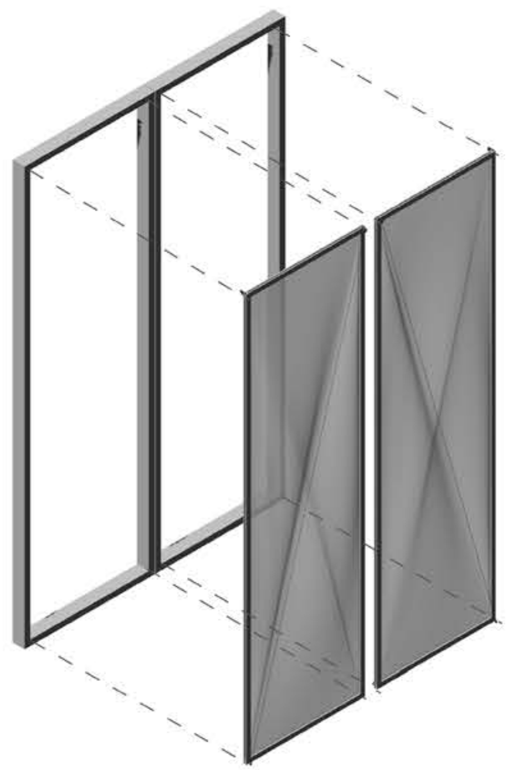
Pos.	scope, service, product	amount	unit	price per unit [USD]	price [USD]
1	ETFE cushion （250um dots printing+250um clear）membrane purchase & fabrication	266	sqm	110	29,260
2	Accessories （Al profiles, EPDM） for fix on the secondary strcuture	266	sqm	50	13,300
3	Air supply system（Machine, sensor, controller, wire, air duct /pipes）	1	sets	34,000	34,000
4	Engineering for detail discussion, deepen design & work shop drawings	60	days	800	48,000
5	logistics, packing	1		2,000	2,000
6	PM 1 people	25	days	500	12,500
7	Installation labors	25	days	800	20,000
8	PM & installation team travel flights and accomendation	25	days	2,000	50,000
9	Storaging and safty measurement	2	Months	5,000	10,000
	cost sum				219,060
	margine			0%	0
	Advanced payment		87,624	40%	
	Total sum				**219,060**
	price per sqm	**266**	**sqm**		**824**

Budget Base Line Estimation **Y-Project- Team 2** 2021-3-17

Pos.	scope, service, product	amount	unit	price per unit [USD]	price [USD]
1	ETFE 2 layers（60um+100um）membrane purchase & fabrication	266	sqm	80	21,280
2	Accessories （Al profiles, EPDM） for fix on the secondary strcuture	266	sqm	20	5,320
3	Engineering for detail discussion, deepen design & work shop drawings	60	days	800	48,000
4	logistics, packing	1		2,000	2,000
5	PM 1 people	20	days	500	10,000
6	Installation labors	20	days	800	16,000
7	PM & installation team travel flights and accomendation	20	days	2,000	40,000
8	Storaging and safty measurement	2	Months	5,000	10,000
	cost sum				152,600
	margine			0%	0
	Advanced payment		61,040	40%	
	Total sum				**152,600**
	price per sqm	**266**	**sqm**		**574**

Cost Estimates Provided by Covertex

ETFE



1. R-Value for double membrane: 2.0

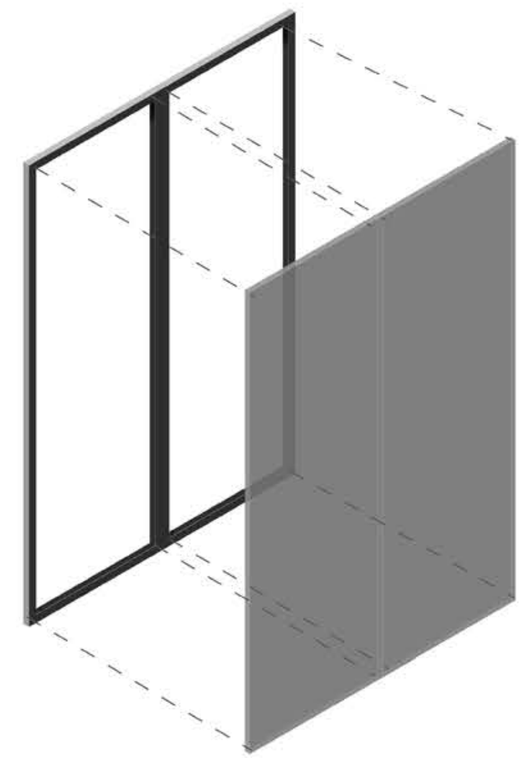
2. R-Value for single membrane: 1.0

3. Cost Double membrane: $824 sq meters

4. Cost Single Membrane: $574 sq meters

*includes cost of engineering

POLYCARBONATE

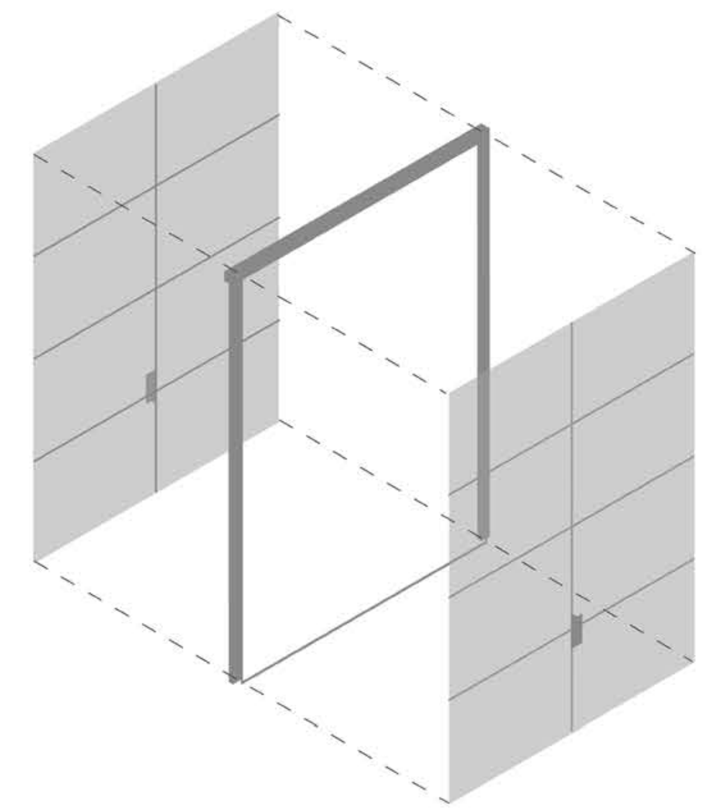


1. R-Value for double wall: 1.5-2.0

2. Cost Double membrane: $32 per sq meter

3. Poorer design aesthetics

ACRYLIC



1. R-Value for double wall: 2.0

2. Cost Double membrane: $54 per sq meter

3. Design Versatility

CONSTRUCTION DOCUMENTATION

THERMAL TEST CHAMBER

With the cost estimates considered, the team still needed to evaluate the tensioned ETFE system to understand how a single versus double membrane would perform. The concern was that a single membrane system would not be insulative enough. The test chamber was set up with box of expanded polystyrene foam that “sandwiched” a layer of ETFE foil on the inside. On the outside, an additional layer of ETFE foil was held in place by spray foam. Between each chamber, thermo couples were placed and connected to a data logger. Unfortunately, due to limited knowledge about the software, the data collection was not comprehensible. As an alternative, a thermometer was placed in the first chamber layer to measure temperature fluctuations.

Given the test results of a period of roughly 36 hours, it was assumed that a single layer of ETFE membrane would not perform well enough for the needs of the facade. The low R-value and transparency of the material allowed immense solar heat gain to occur. However, overnight the heat was not retained.

Single Membrane ETFE Test
March 21, 2021

Outside temperature:
4:23pm: 70F

Inside temperature (Direct Sunlight):
4:30pm: 84F
4:40: 93F

Inside temperature (Indirect Sunlight):
5:03pm: 82F

Highest Temperature: 156F
Lowest Temperature: 27F

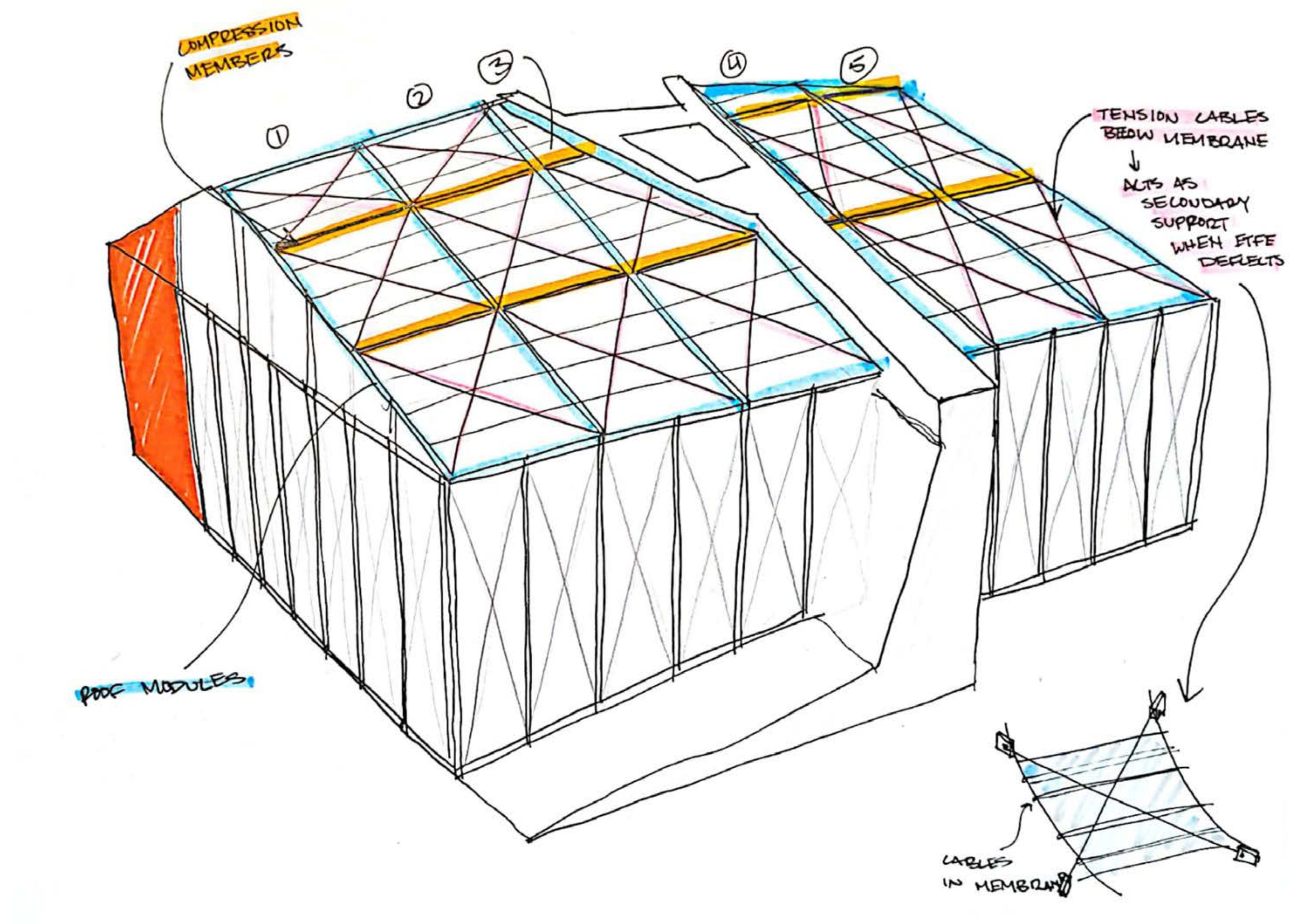
CONSTRUCTION DOCUMENTATION

ACRYLIC FACADE

While re-evaluating the use of inflated ETFE as a secondary building skin, an alternative single membrane skin was developed using integrated tension cables that would help support snow and wind loads across the facade.

While this ETFE proposal was not used, it established an industrial aesthetic that was appealing to the team and the vernacular of greenhouses. This was carried through to the acrylic facade by maintaining the horizontal bands that run across the entirety of the facade.

Additionally, the acrylic material was decided upon because of its R-value and design versatility that brought potential for new opportunities in design.

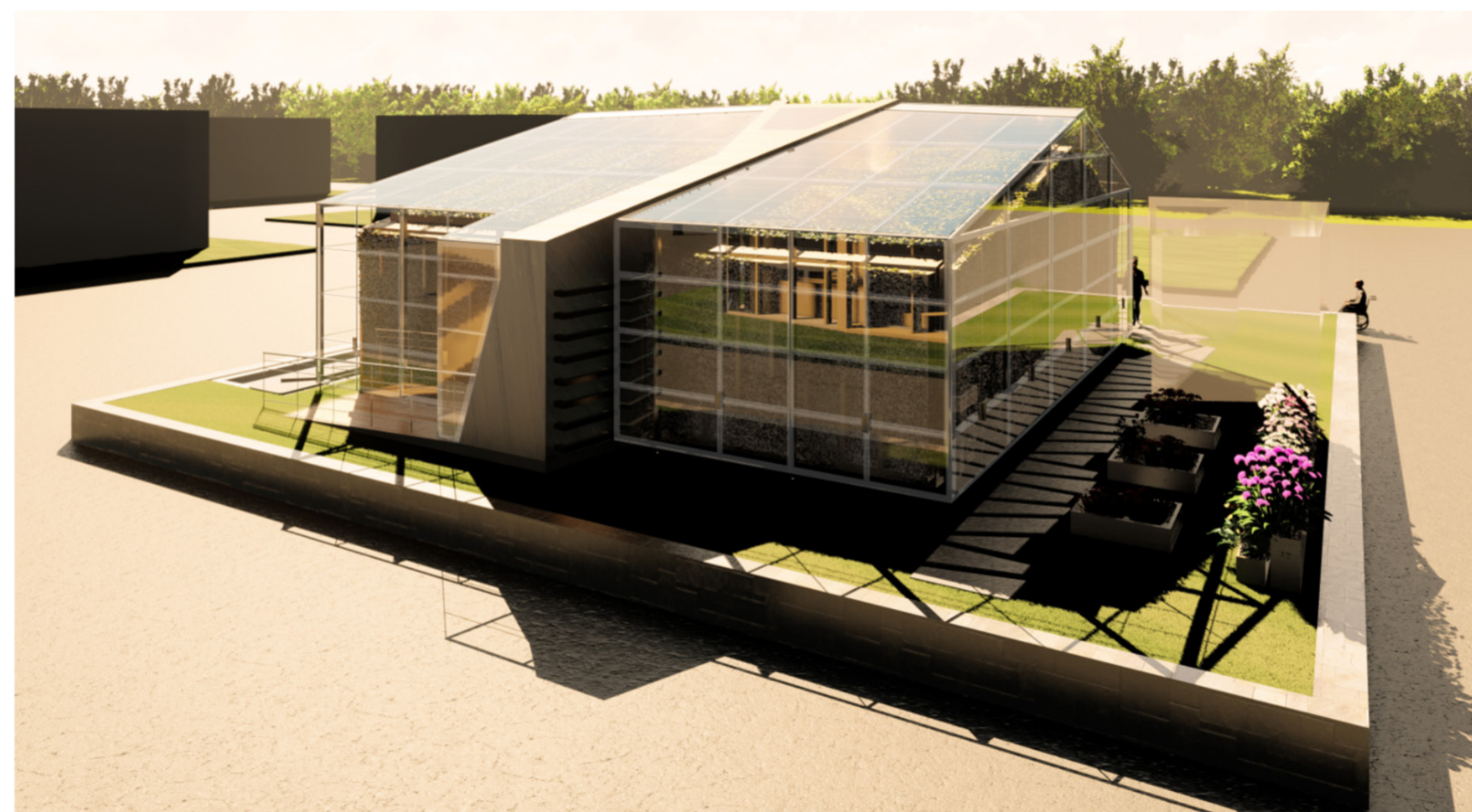


CONSTRUCTION DOCUMENTATION

ACRYLIC FACADE

The use of acrylic was also important because of its visual clarity to the vegetation behind which play a major role in the aesthetics and design language of the Y-Project.

At night the facade will be illuminated by LED lights that run parallel to the facade's structure. This turns the house into a lantern at night that draws attention to the innovative features of the house.



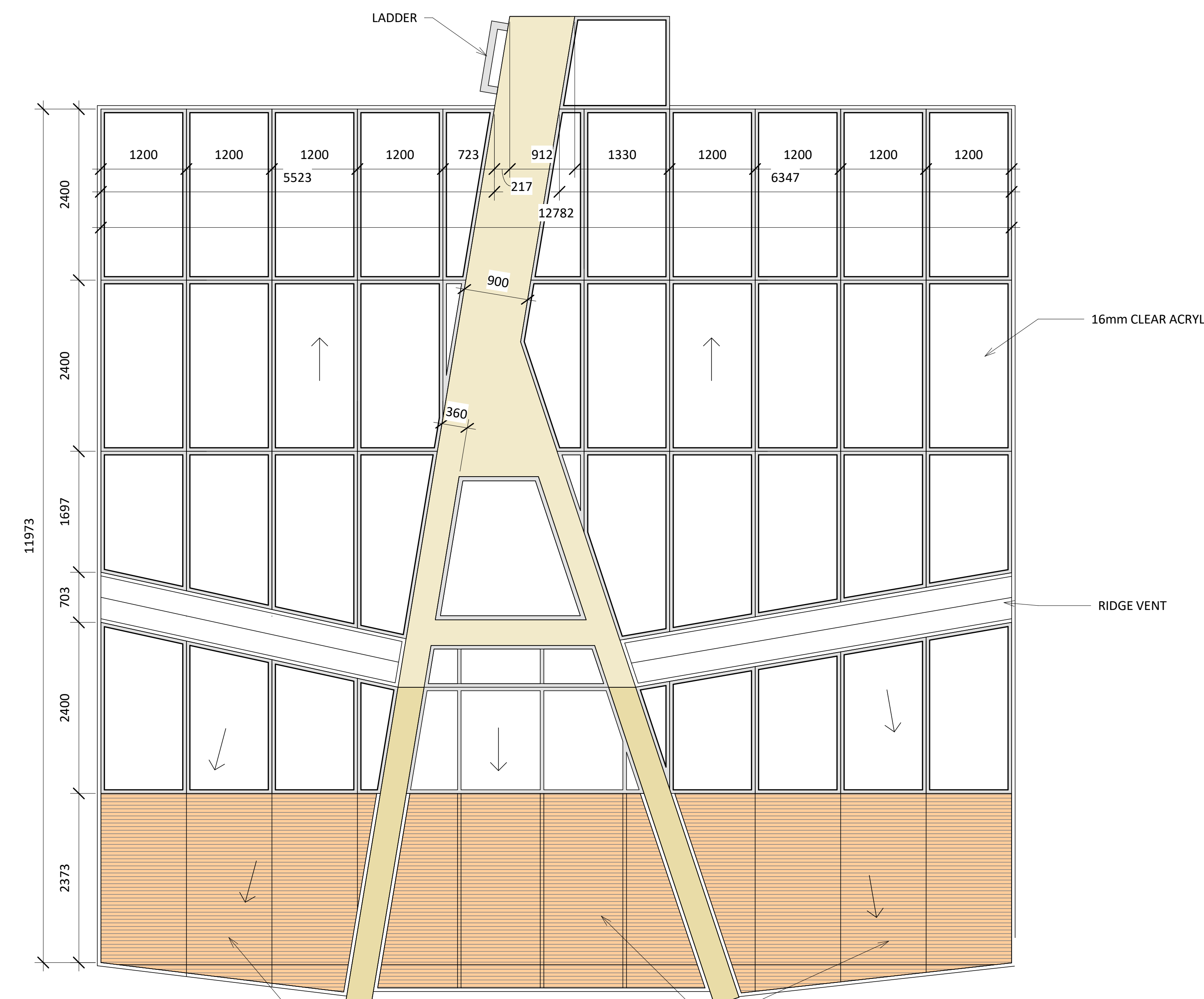
CONSTRUCTION DOCUMENTATION

ACRYLIC FACADE

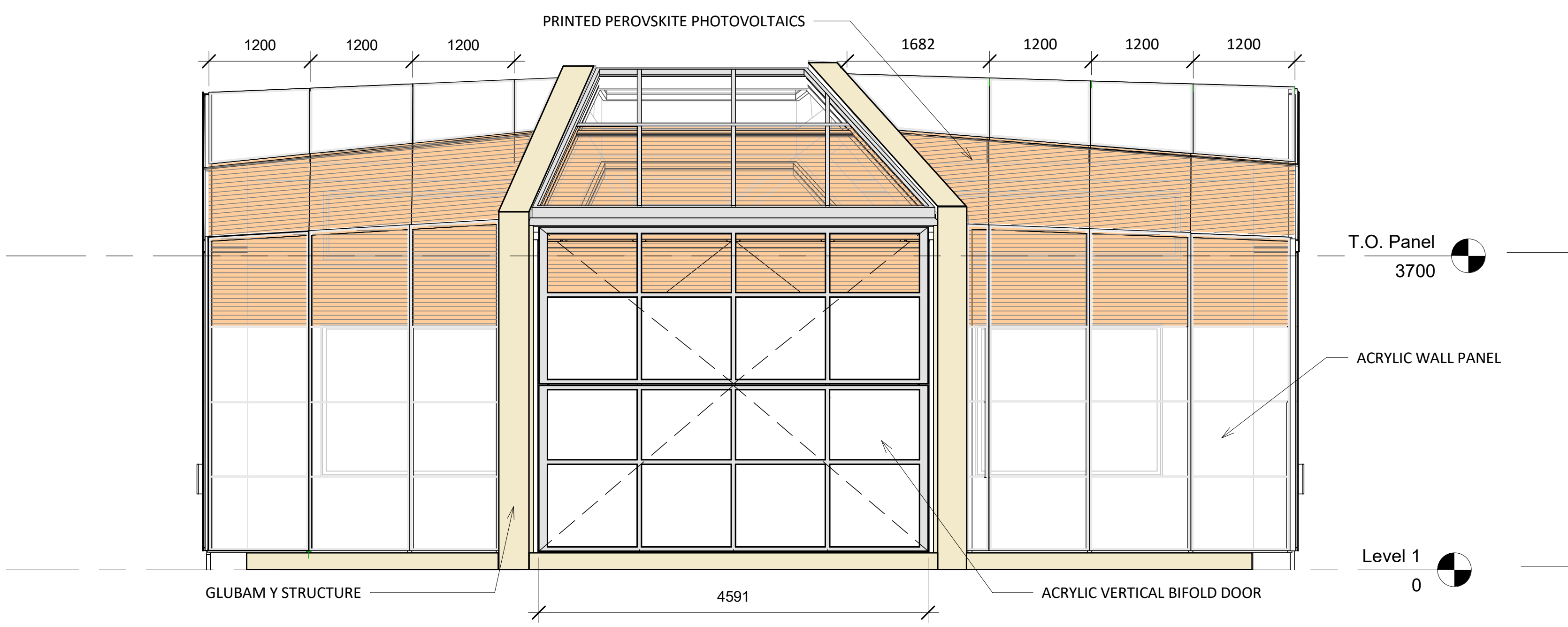
The acrylic facade is made up of modular panels that would be pre-fabricated to reduce construction time during the competition period.

The roof is made up of modules of 1.2m by roughly 2.4m. Around the east, west, and north facades, the walls are made up of operable door panels that are 1.2m wide by 3.5m tall. In future development, an alternative assembly for the walls will need to be considered due to the size limitations of acrylic.

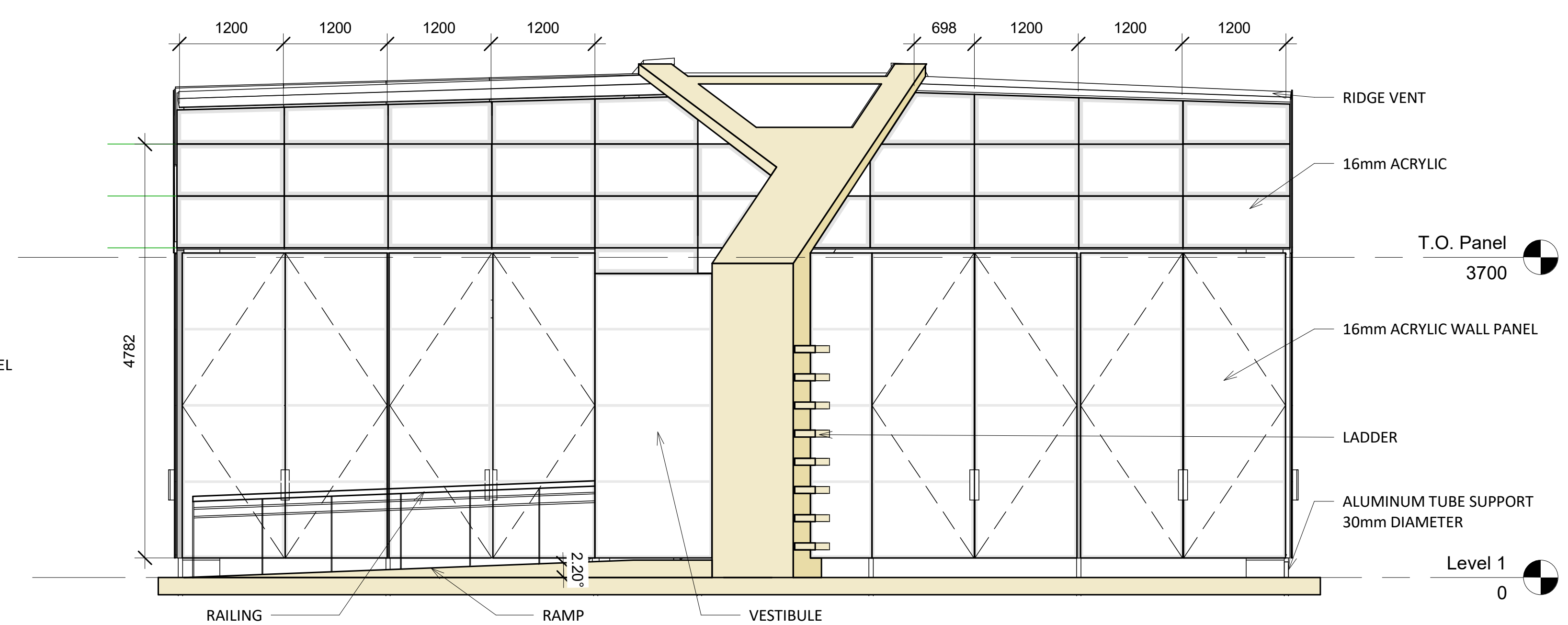
Acrylic will also be used in areas where PVs are located based upon the assumption that the perovskite can be printed on acrylic as well as glass.



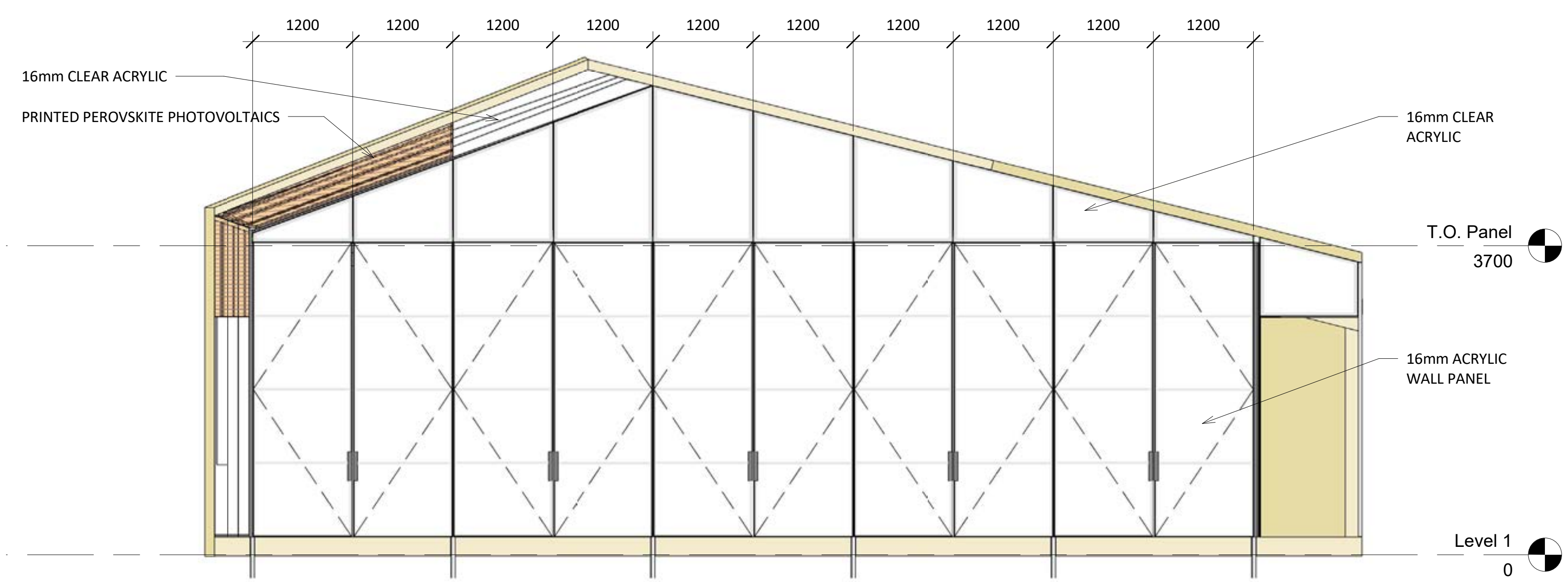
1 Roof Plan
1 : 50



1 South Elevation 1 : 50



1 North Elevation 1 : 50



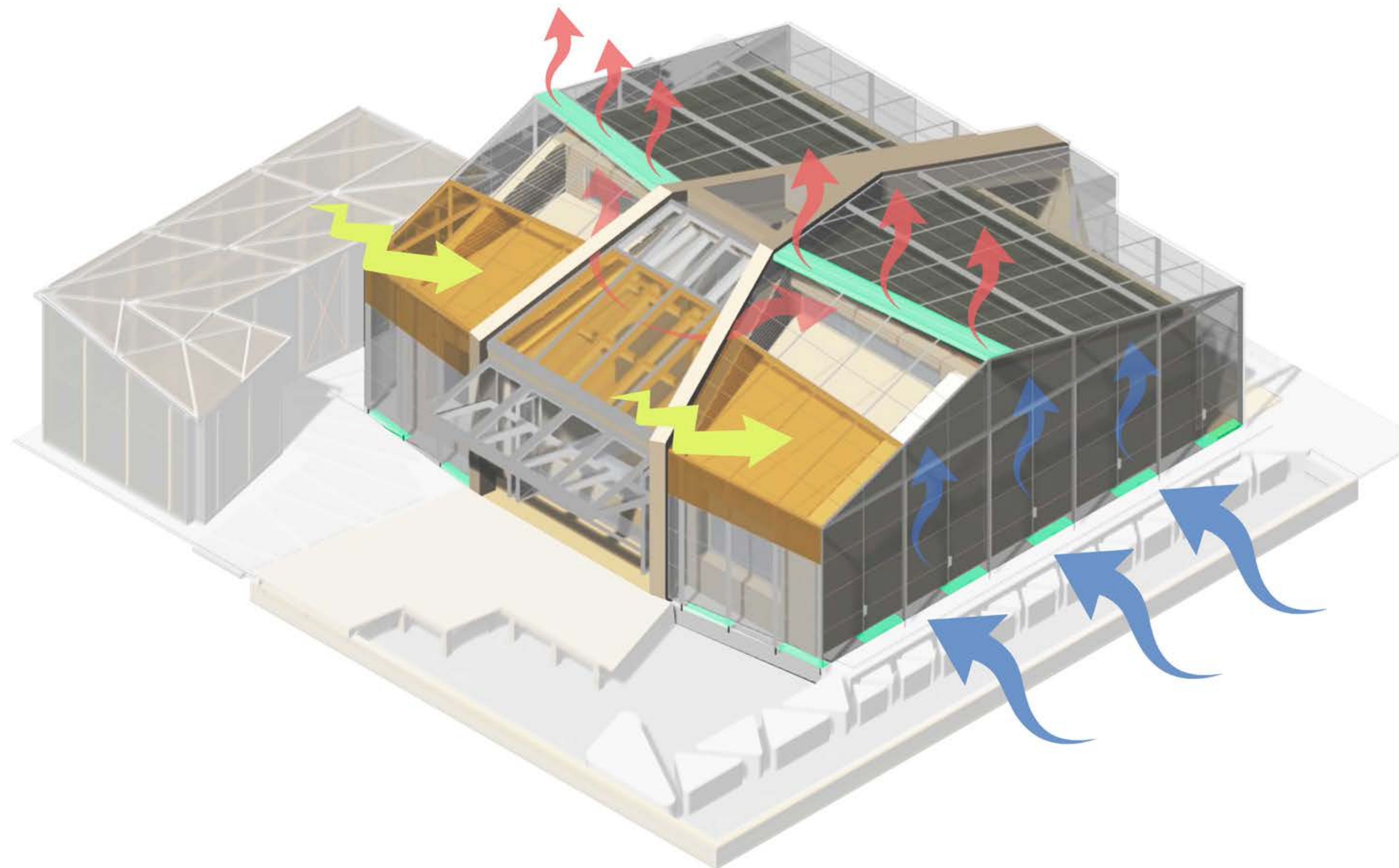
1 East Elevation 1 : 50

WEST ELEVATION SIMILAR ON OPPOSITE

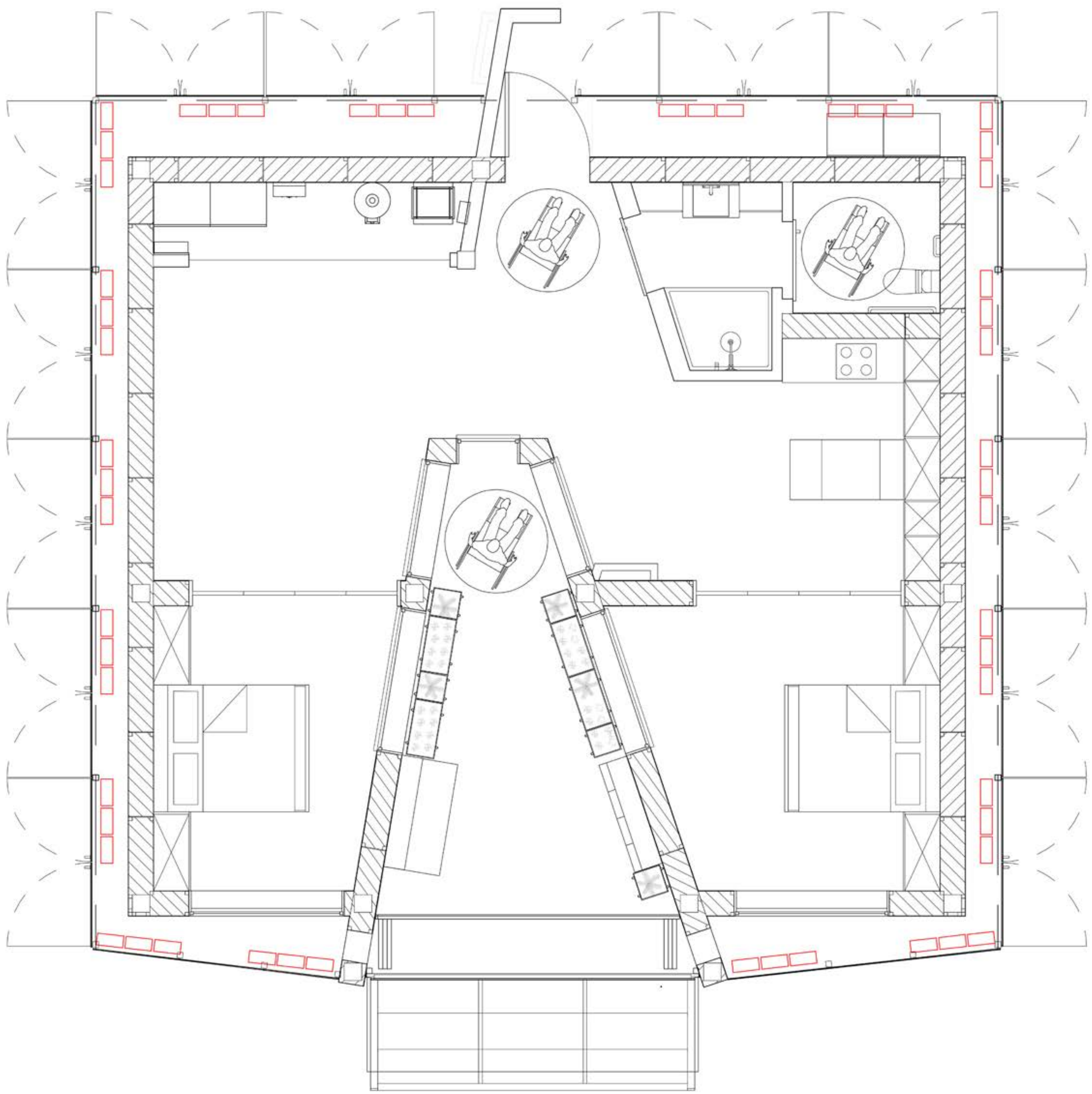
CONSTRUCTION DOCUMENTATION

VENTILATION

This Diagram describes the overall façade performances, starting the negative pressure vent flap which allowed cool air into the double skin system. Moving on the roof, the ridge vent system located on both sides of the building regulates the internal air temperature by letting hot air out of the double skin system. There's also an Internal HRV vent system, which pulls hot air out of the double skin system to heat the house. Finally, the Perovskite Photovoltaics, located on the southern façade which absorbs the sunlight and transforms it into usable energy.

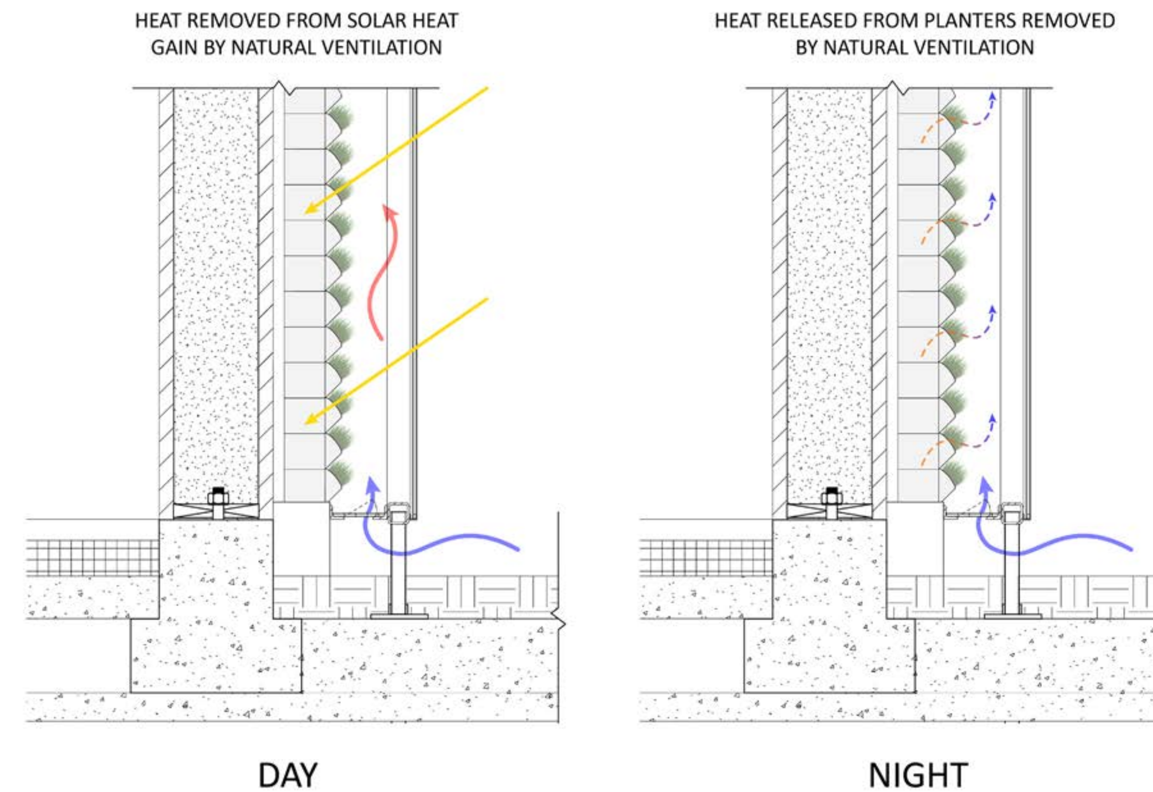


FACADE PERFORMANCE

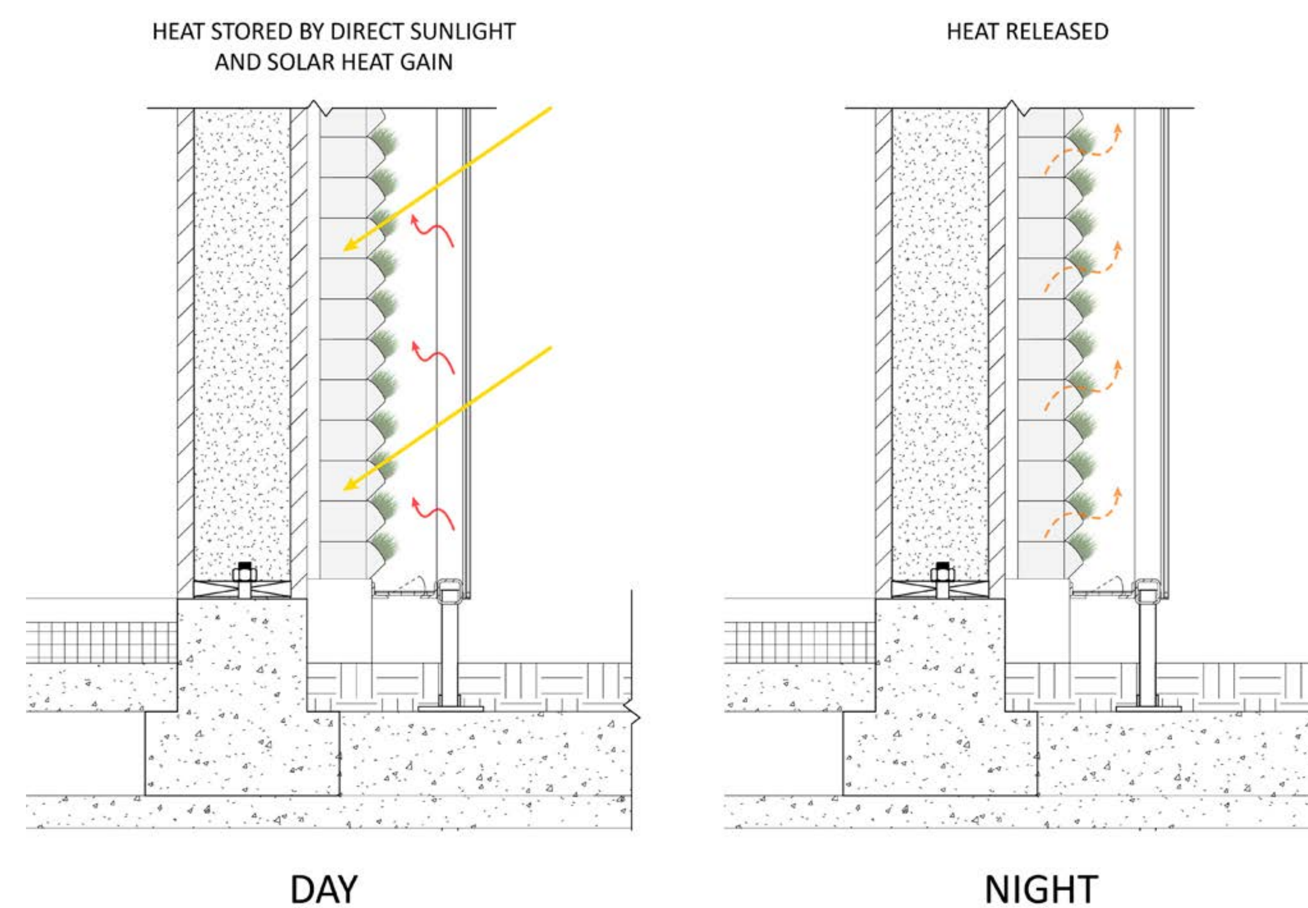


BOTTOM VENT LOCATIONS

SUMMER



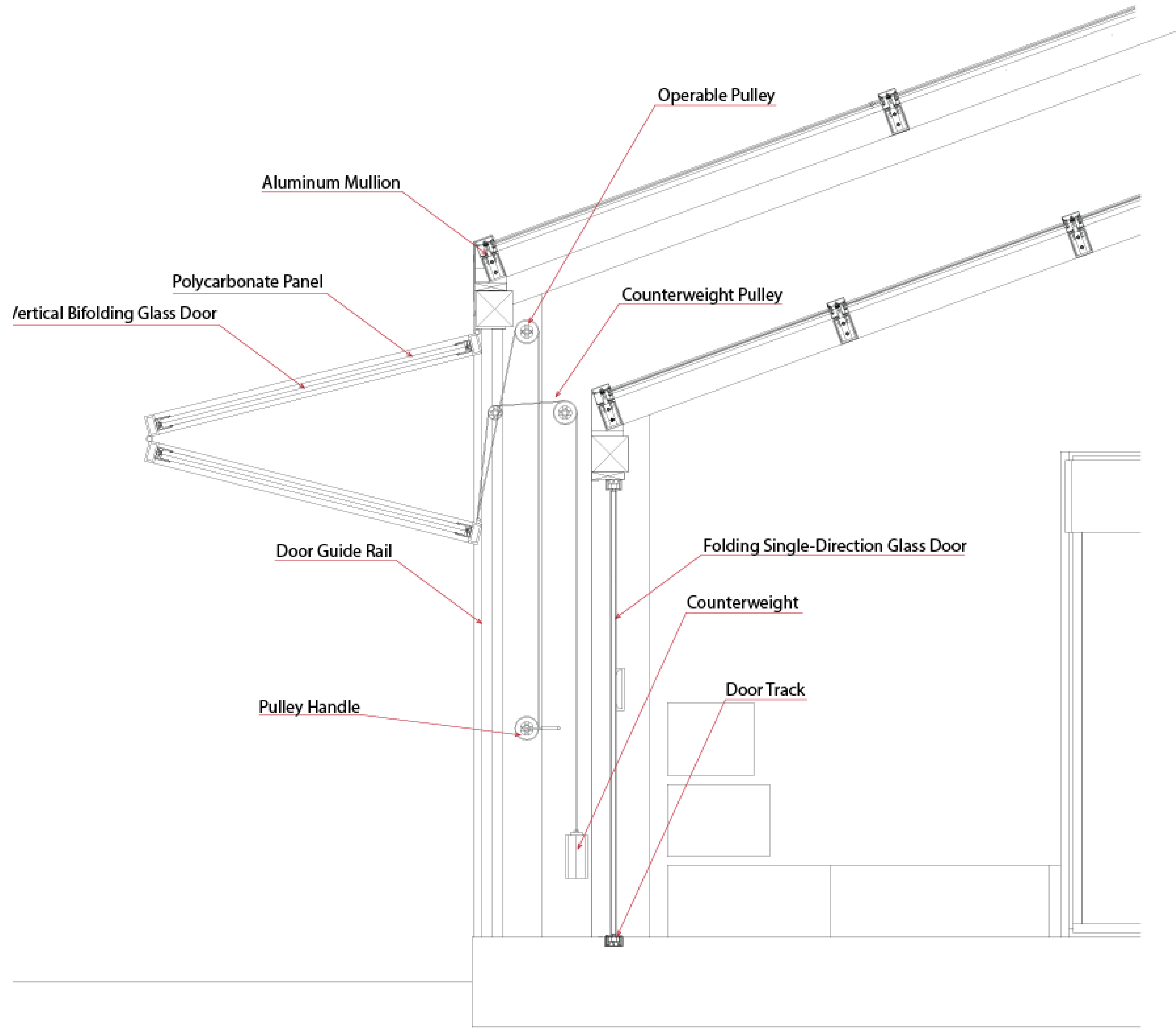
WINTER



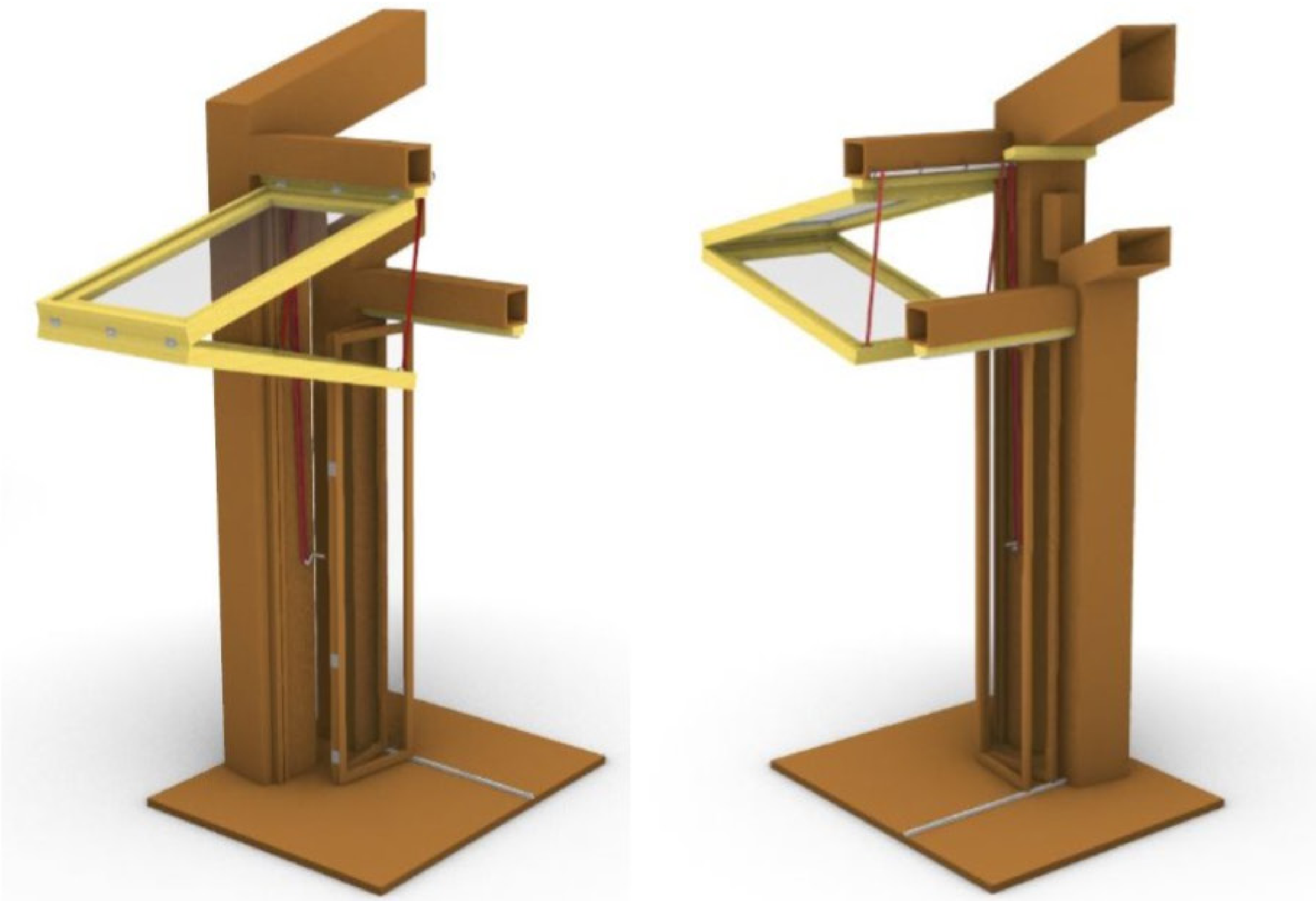
CONSTRUCTION DOCUMENTATION

SOLARIUM BI-FOLDING DOOR

The images pictured are digital models of what the solarium team intended to physically construct. The left model represents one of our earlier designs while the one on the right is our finalized prototype. Due to several practical considerations and the fact that this structure would have to be constructed at full scale, the overall design had to be simplified and modified to operate using an electric motor rather than a manual pulley system.



SOLARIUM WALL SECTION



FULLY DETAILED ASSEMBLY

ASSEMBLY FOR PROTOTYPE

CONSTRUCTION DOCUMENTATION

SOLARIUM BI-FOLDING DOOR PROTOTYPE

This series of photos showcase how the team was able to construct the model, as well as its overall size. The structure is comprised of two 6in x 6in and 12ft long timber beams connected with 2in x 6in studs and 4in x 4in timber. The overall structure was held upright with six 2in by 4in studs.

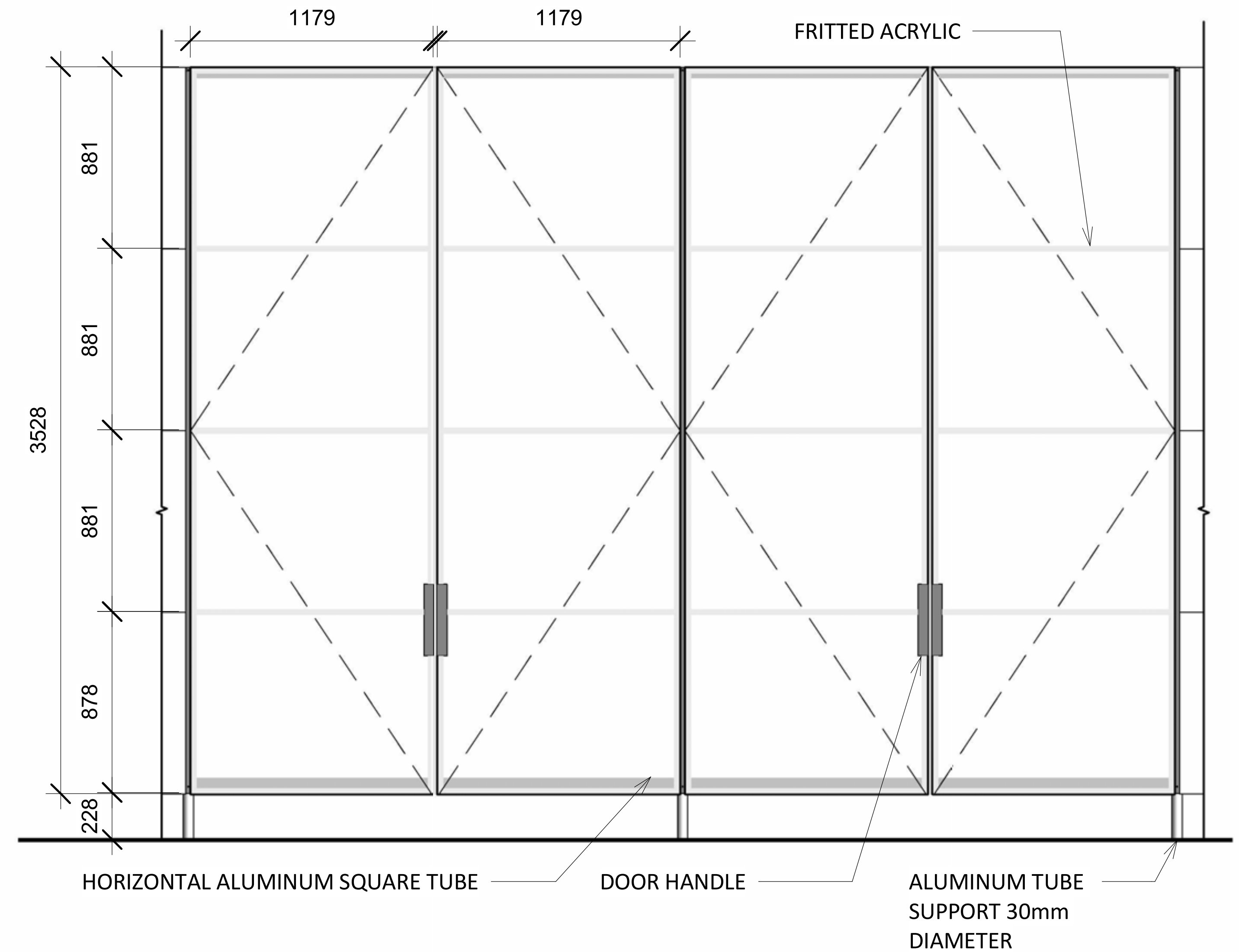
The finalized full scale prototype model is shown here. Operability of the solarium door is made possible via a 2500lb electric towing motor bolted to the header beam. A pulley and winch are connected to a handle that itself is connected to the lower acrylic panel.

CONSTRUCTION DOCUMENTATION

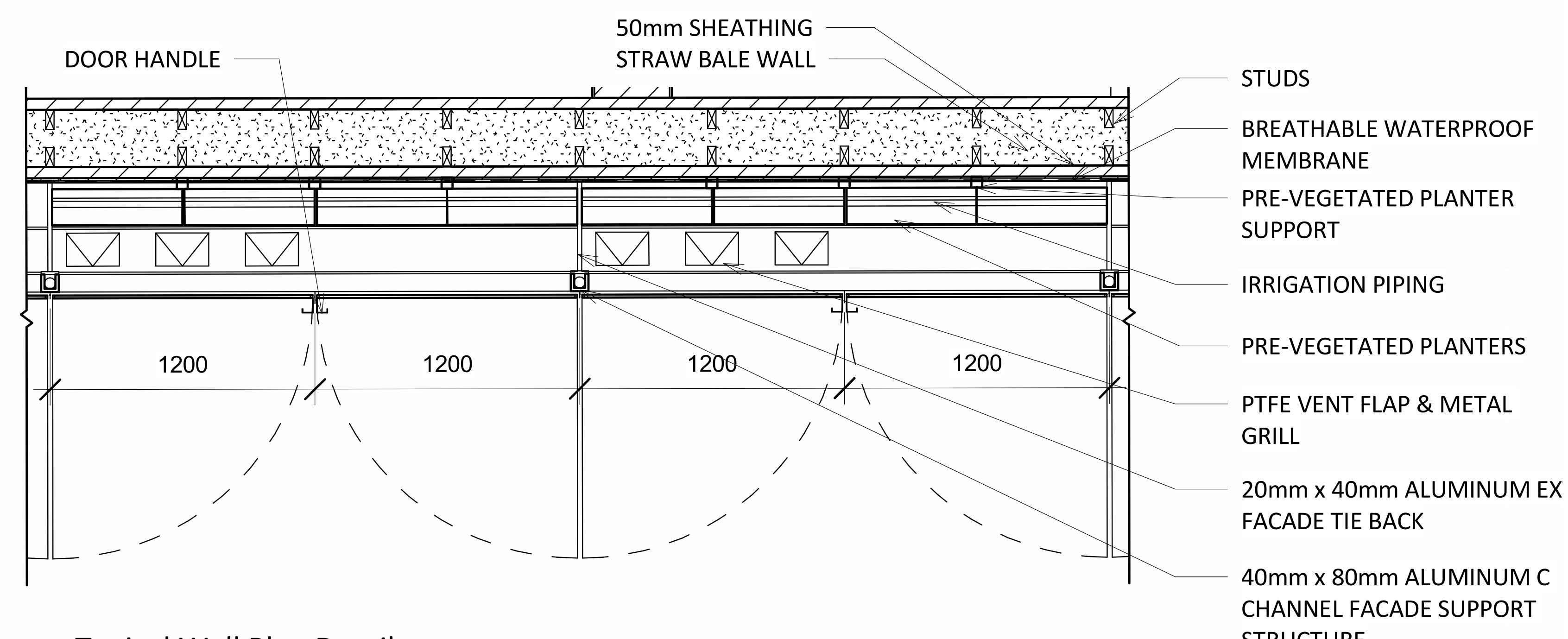
ACRYLIC WALL DETAILS

The construction documentation phase required revised details in coordination with partner teams in China. These details showcase the tectonic relationship of the operable acrylic wall panel and prevegetated planters. The acrylic panels would include a frosted pattern that acts as a means of covering the spacers and seams of the assembly.

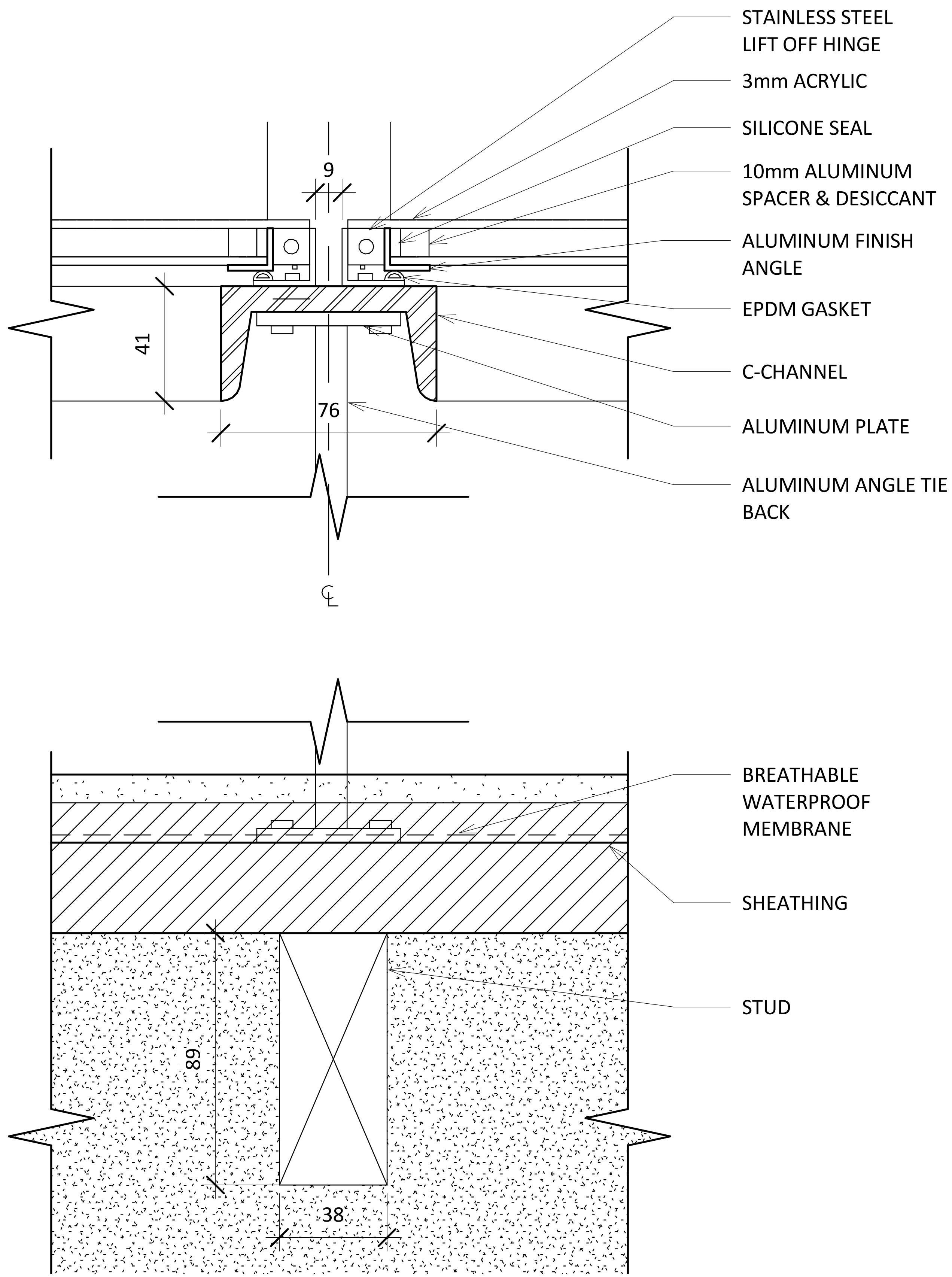
The plan details of the hinge and jamb portray the panel construction and the tectonics of the frame-less aesthetic.



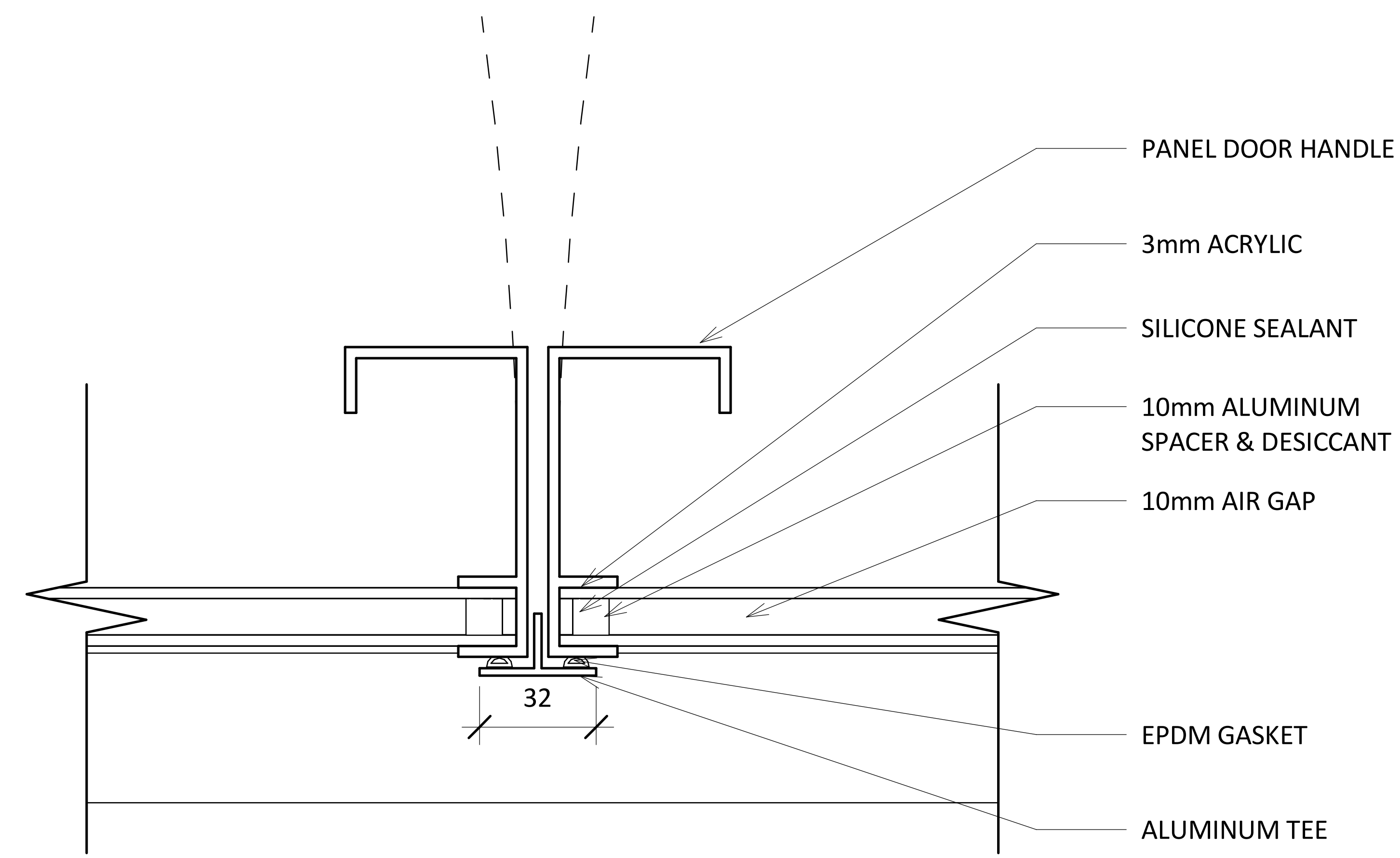
1 Typical Door Panel Elevation
1 : 30



2 Typical Wall Plan Detail
1 : 30



1 Door Hinge Detail
1 : 2



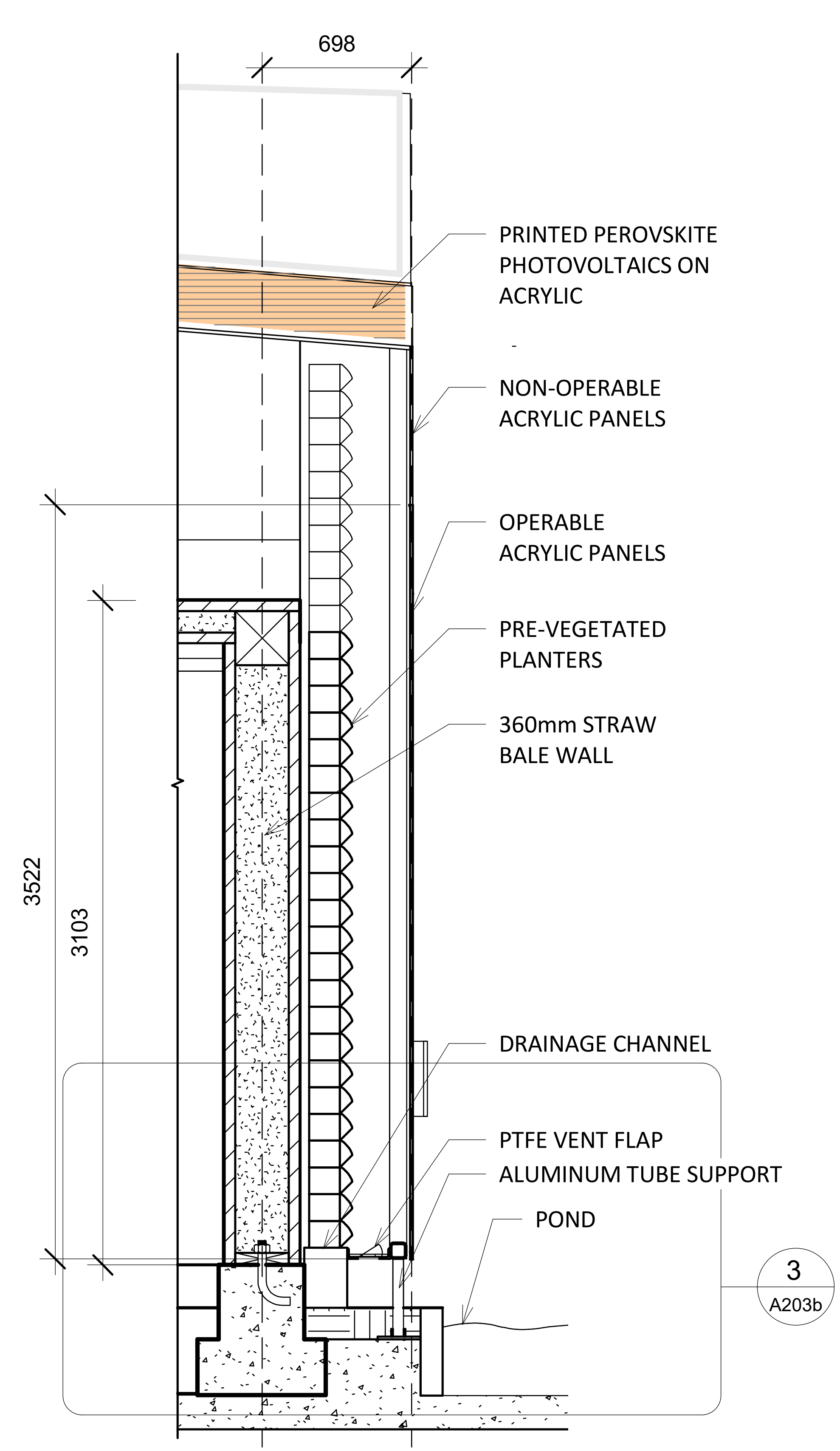
2 Door Jamb Detail
1 : 2

CONSTRUCTION DOCUMENTATION

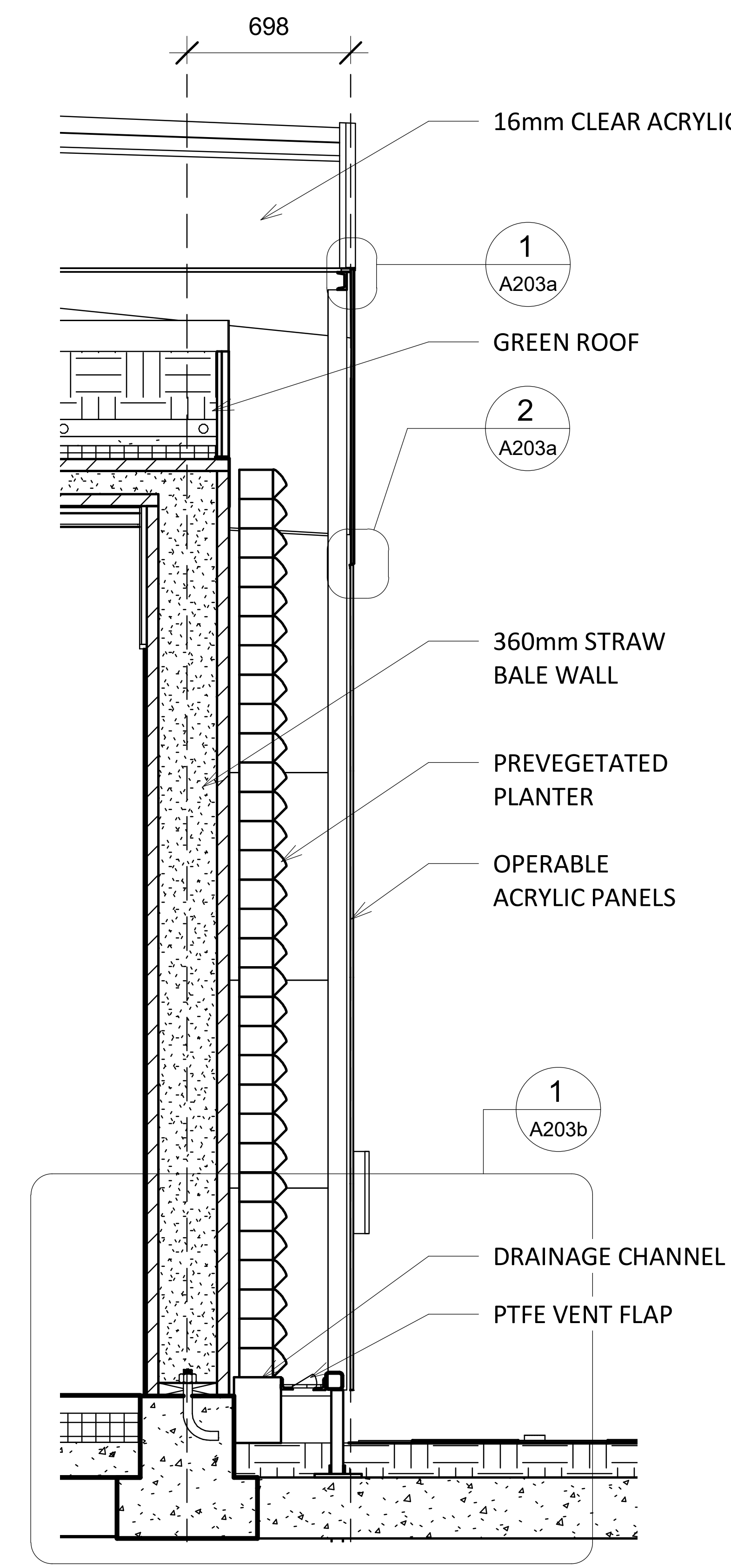
ACRYLIC WALL DETAILS

The section details to the right show the roof to wall edge condition details and header details of the acrylic panels. To maintain the seamless aesthetic, it was crucial to detail the condition in a way that had minimal visual impact while also maintaining the facade's performance qualities.

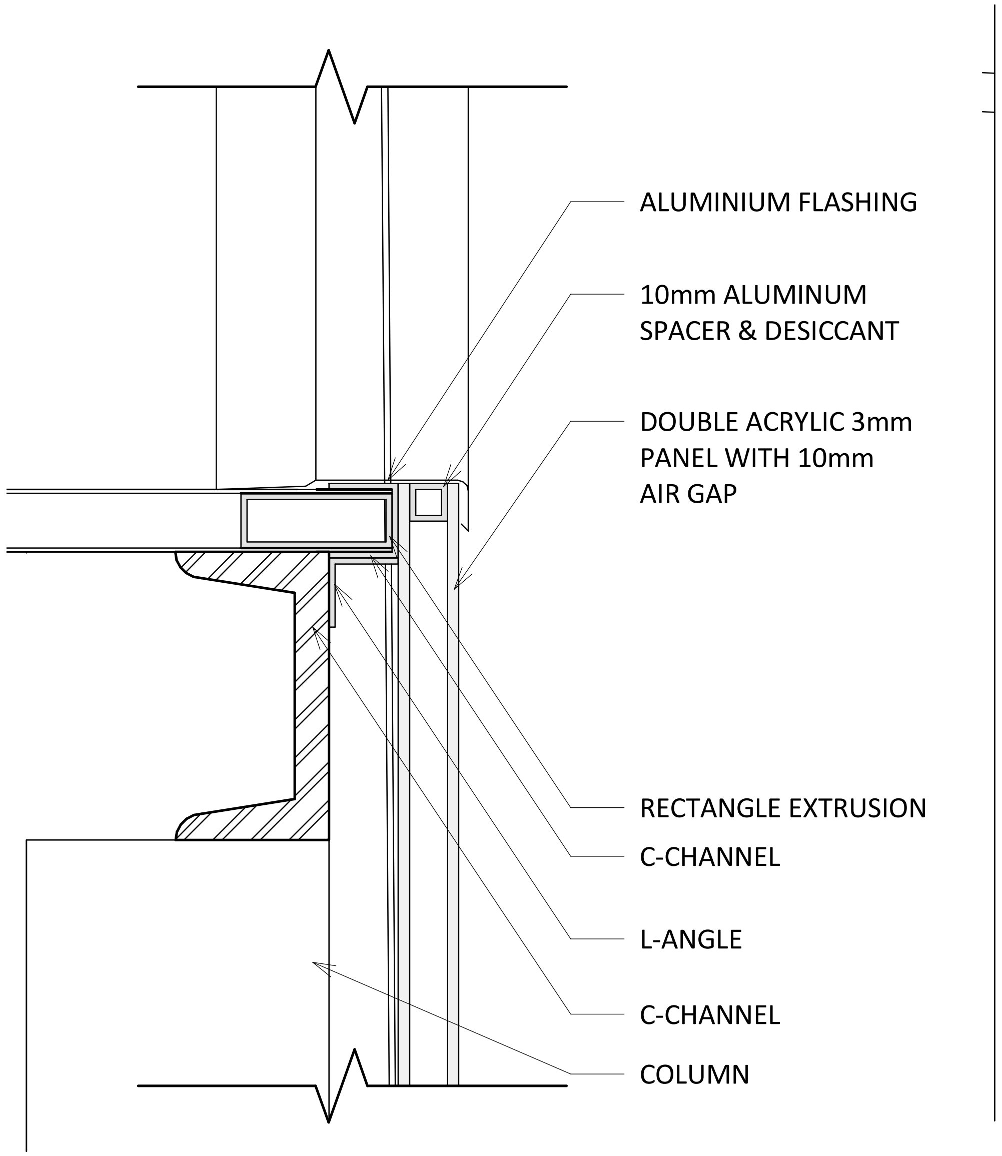
These details along with the previous plan details became the basis for creating a full scale prototype of the north east roof and wall corner.



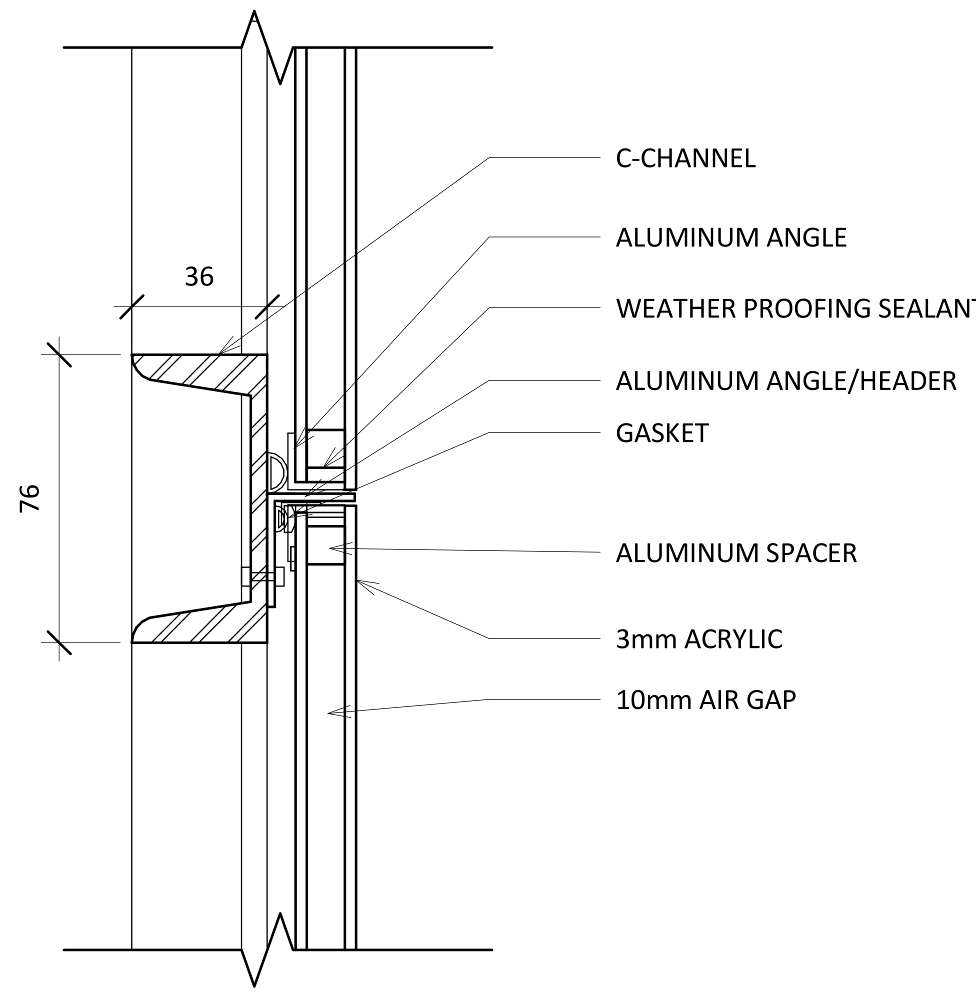
2 East Wall to PV roof
1 : 30



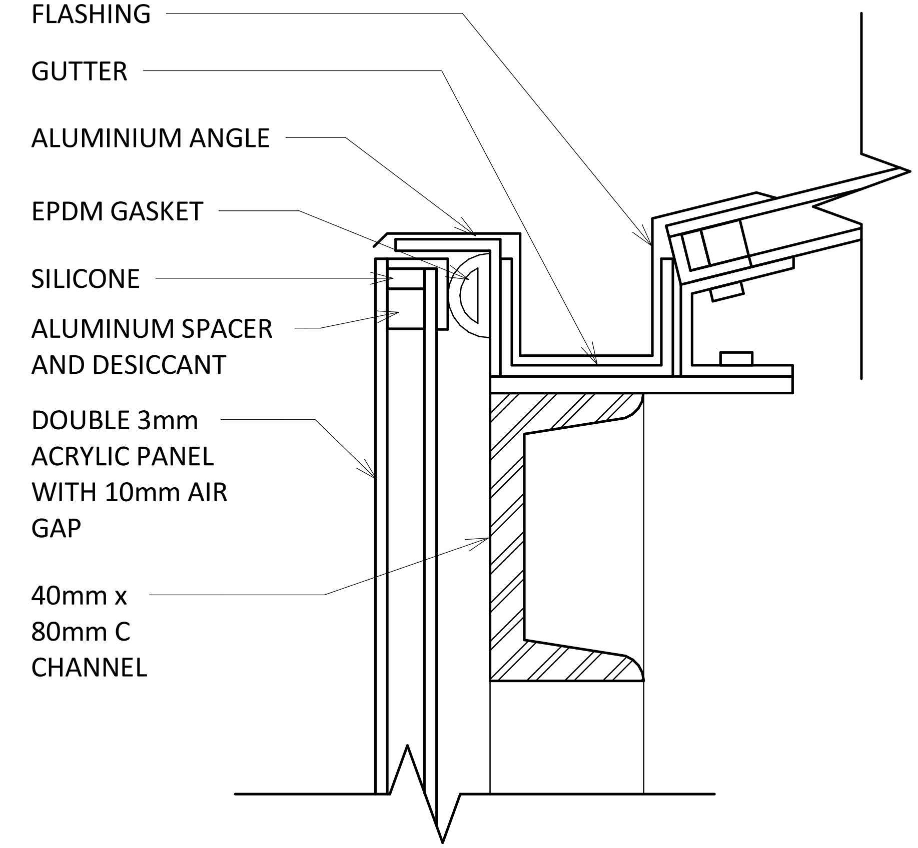
3 West Wall Section
1 : 30



1 East and West Roof Edge Detail
1 : 2



2 Header Detail
1 : 2



3 North Header Detail
1 : 2

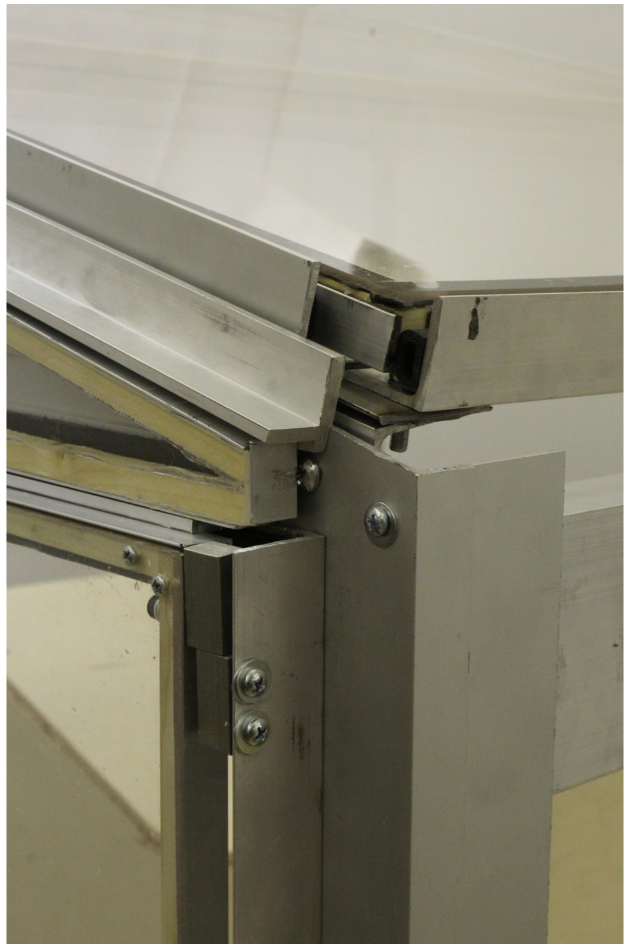
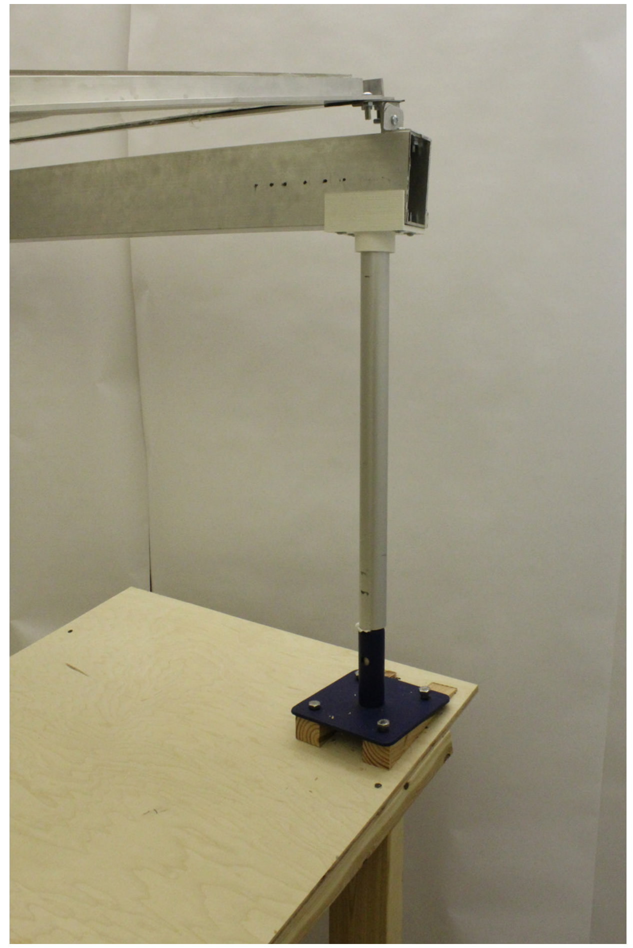
CONSTRUCTION DOCUMENTATION

ROOF TO WALL CORNER DETAIL

The building of a full scale roof to wall corner detail prototype was to assess the details that had been previously generated and accommodate changes to the details. The prototype is built from aluminum extrusions similar to those shown in the details. Through the process of working with the physical material and understanding the assembly, the team quickly realized the conflictions that occur with maintaining the alignment of members and incorporating methods of fastening. The importance of construction tolerances quickly became apparent during the process.

A 3D printed component was used to connect the stand-off to the horizontal roof structure. Custom pin connections were fashioned from left over angles to accommodate the slope of the roof. Silicone and VHB tape were experimented with to assemble two acrylic sheets together.

The roof panel is held in place by friction in a perimeter of gaskets.

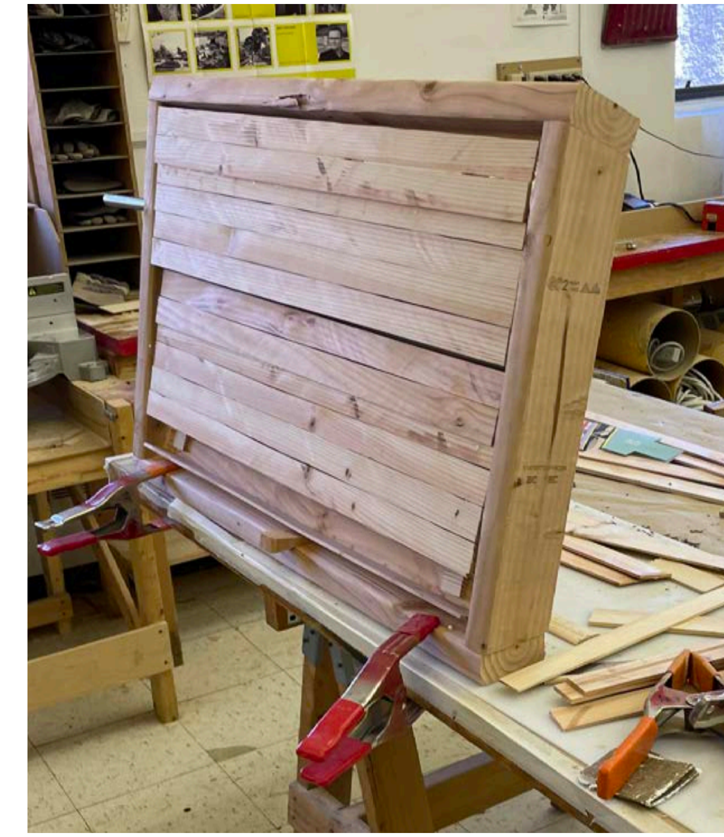



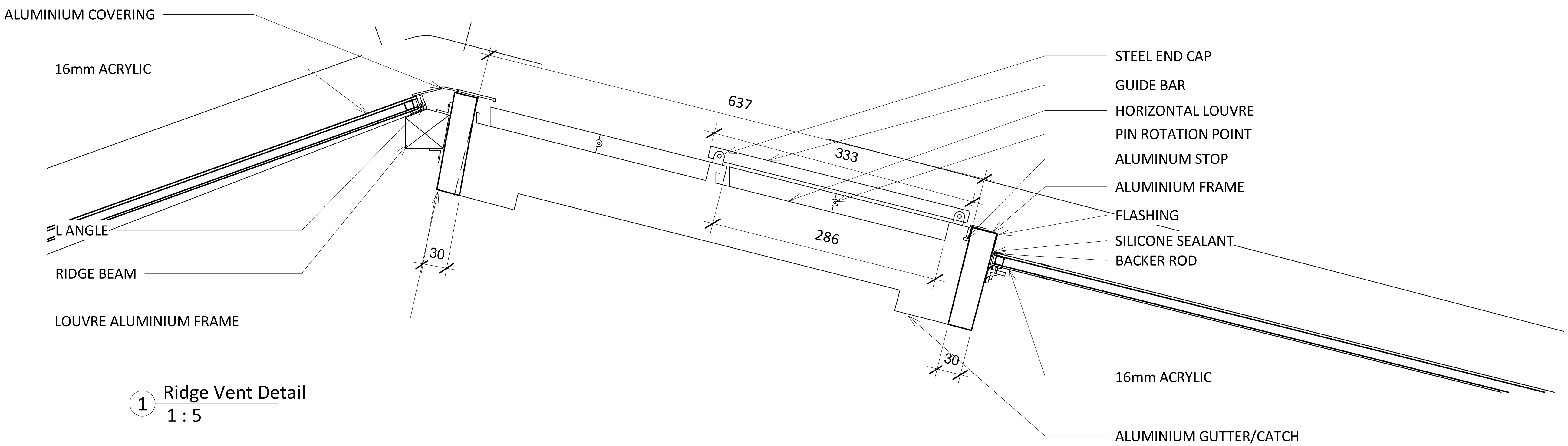


CONSTRUCTION DOCUMENTATION

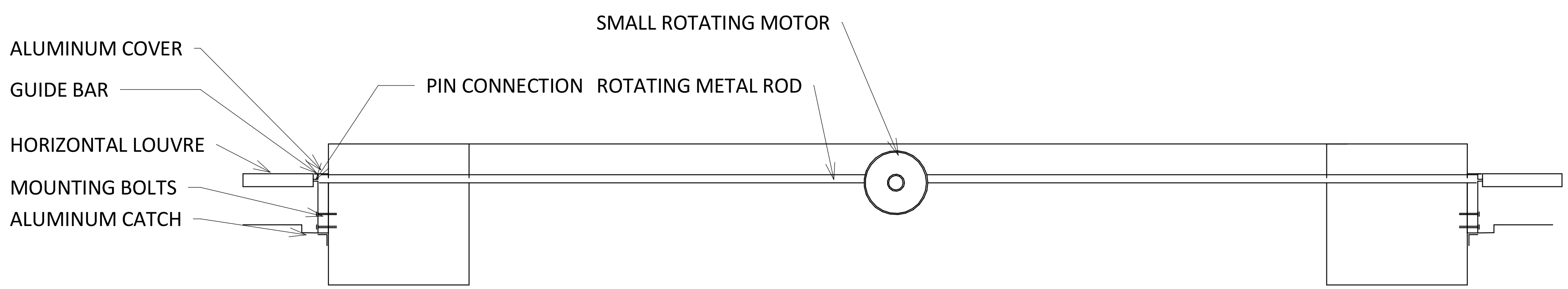
SOLARIUM BI-FOLDING DOOR PROTOTYPE

The Photos on the right are showing the prototype model that displays how the ridge vent will be assembled. The mockup is made of wood but the actual panel will be made of aluminum framing with sheet metal louvers. The top louver will be moved by the motor located in the solarium space, mounted to the substructure for the outer acrylic. The motor will rotate the top louver on both side bays to allow for heat to escape out of the double skin system. The bottom louver moves based on the top; the metal bar connects the top to the bottom which enables the bottom louver to move in sync with the top. The system will have a gutter on the bottom to help catch debris or water that enters the system. It will use seals and gaskets to make a watertight connection and metal flashing to cover the bottom opening. The two louvers interlock with one another to create a tight seal, along with a stop on the inside of the aluminum frame. The drawings give the dimensions of the panels along with the locations within the building.

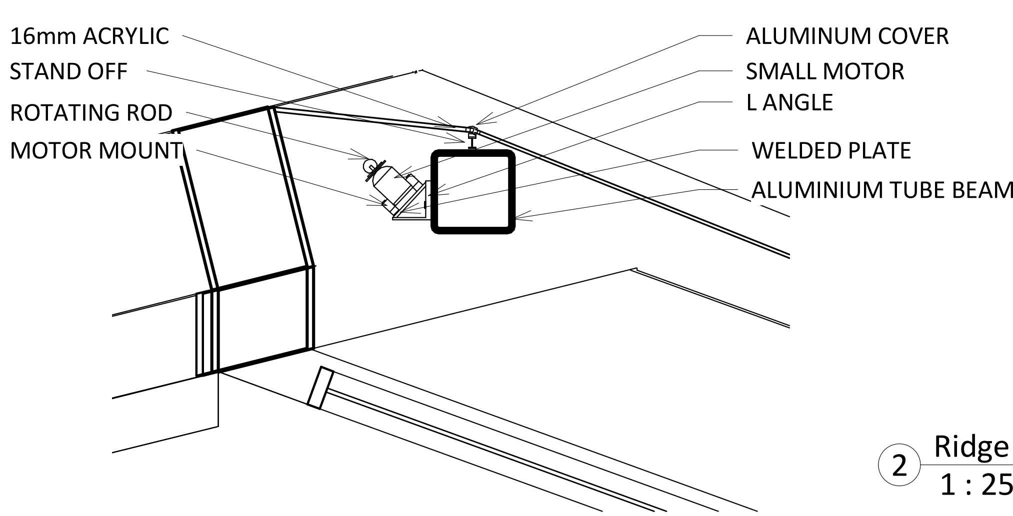




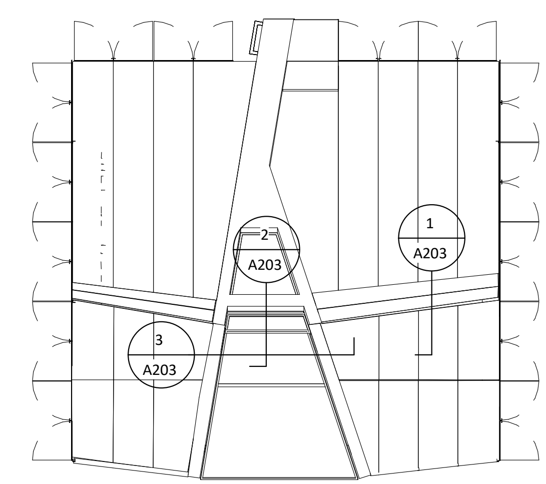
1 Ridge Vent Detail
1 : 5



3 Ridge Vent Linear Section
1 : 5



2 Ridge Vent Section
1 : 25



4 Site
1 : 200

CONCLUSIONS

The Design 10: Material Futures design studio was an intensive two semester long project in collaboration with students and faculty at XJTLU. Students in the studio were able to not only able to work on a project that was highly collaborative and interdisciplinary, but were able to get a sense of the challenges associated with a project's reality. The many constraints of the project (i.e. time and budget) were an challenge, but ultimately brought new opportunities for design and innovation.

Collaborating with industry professionals was an invaluable experience that taught students how to communicate their ideas while gaining insight into real world products and assemblies that could further develop their design intents. Additionally, this collaboration provided the opportunity for networking and establishing connections that will be useful for and beyond the Solar Decathlon China Y-Project.

The studio was able to obtain $10,000 worth of funding from the Eileen Martinson '86 Capstone Experience Grant as well as XJTLU. These funds made the full scale prototyping and performance testing of the facade design possible. The prototyping and fabrication of the project provided unique experiences that taught students the skills necessary to evaluate their design concepts and intentions.

The Solar Decathlon China studio stands apart from other studios and projects because of the international collaboration, prototyping, and above all, the ability to participate on a project that will be constructed across the world. The studio was an opportunity to be a part of a unique experience in architectural education.

What's Next?

Y- Project will continue to develop the design and drawings to prepare for construction in September of 2021. Afterwhich it will be part of a two week competition period where the architecture will be assessed and evaluated.