CLIMATE RESPONSIVE BUILDING FACADE

INDUSTRIAL DESIGN PROJECT III
MDP-456

BY
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146130012

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INDUSTRIAL DESIGN CENTRE
INDIAN INSTITUTE OF TECHNOLOGY BOMBAY
2016

Climate Responsive Building Facade

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APPROVAL

Industrial Design Project III

"Climate Responsive Building Facade"

Project III Report By:
Shashank Gautam
146130012
M.Des., Industrial Design Centre
2014-2016

Is approved as a partial fulfilment of requirements of a post-graduate degree in Industrial Design at IDC, IIT-Bombay.

External Examiner

Internal Examiner

Project Guide

Project Co-Guide

Chairperson

DECLARATION

I declare that this written submission represents my ideas in my own words and where others ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all the principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

Shashank
18/05/16

Shashank Gautam
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146130012

ACKNOWLEDGMENT

I would like to express my special thanks of gratitude to my project Guide **Prof. B.K.Chakravarthy** and my Co-Guide **Prof. Venkatesh Rajamanickam** also to our Industrial Design Faculties who gave me inputs throughout the project, which helped me in doing a lot of Research and I came to know about so many new things.

Secondly, I would also like to thank My Parents and Friends who helped me a lot in within the limited time frame.

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ABSTRACT

The project investigates responsive building facade systems that adapt to the dynamic environmental conditions to regulate the internal conditions in a habitable space over different periods of time by exhibiting a state of motion and dynamism. Heat, Light and wind are the primary parameters for regulation, leading to energy efficiency and dynamic spatial effects. Passive and active skins using pneumatic actuators are developed through investigations of smart systems that integrate smart materials and smart geometries. The precedents in this domain have rarely dealt with individually controlled multiple parameters of heat and light in a single system, which is attempted in this project.

CHAPTER 01

NEED IDENTIFICATION

Proposal of a new Office Campus of SRISTI and NIF in Gandhinagar, Gujarat, which should be described as a living ecosystem: a fine balance of natural and man-made processes employing environment-friendly energy, material and water management methods.
This new building will make a good context to do research upon building skins which would be climate responsive.

SRISTI:

SRISTI is a non-governmental organization set up to strengthen the creativity of grassroots inventors, innovators and ecopreneurs engaged in conserving biodiversity and developing eco-friendly solutions to local problems. *(Sristi,2016)*

NIF:

NIF is India's national initiative to strengthen the grassroots technological innovations and outstanding traditional knowledge. Its mission is to help India become a creative and knowledge based society by expanding policy and institutional space for grassroots technological innovators. *(National Innovation Foundation , 2016)*

LOGO of Sristi: image explains the ideology behind the organization

Img.1. a product displayed at food festival organized by Sristi. The festivals is to raise awareness about biodiversity conservation, promote traditional recipes and stimulate the demand for indigenous crops and varieties. Img.2.a low cost three-wheeler tractor for ploughing innovated by Sristi

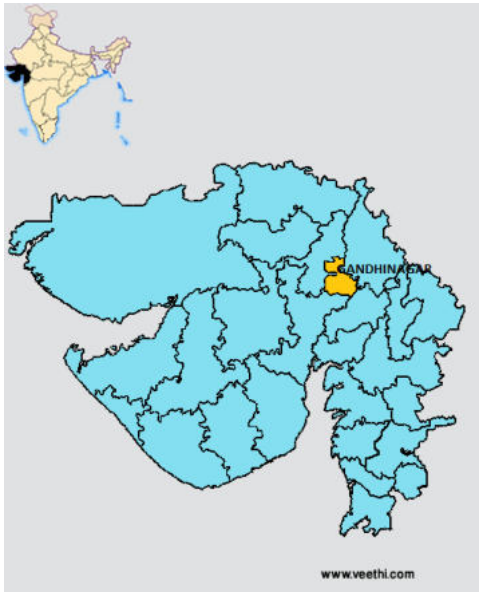
USER REQUIREMENTS

A visit to Sristi/NIF, Ahmedabad and Gandhinagar was made to understand the actual site conditions and their requirements. Based on a series of discussions with Prof. Anil Gupta (President of SRISTI) following desirables were listed down:

- A climate responsive façade - regulates and maintains the comfortable temperature inside.
- Low cost. (150-160rs/sqft)
- Aesthetics - reflect the continuity of Indian tradition.
- Minimum dependencies of Resources
- Maximum use of natural light inside.
- Saves Energy.

Proposed Site Plan

Satellite image of Site



Site located in village in Gandhinagar, Gujarat

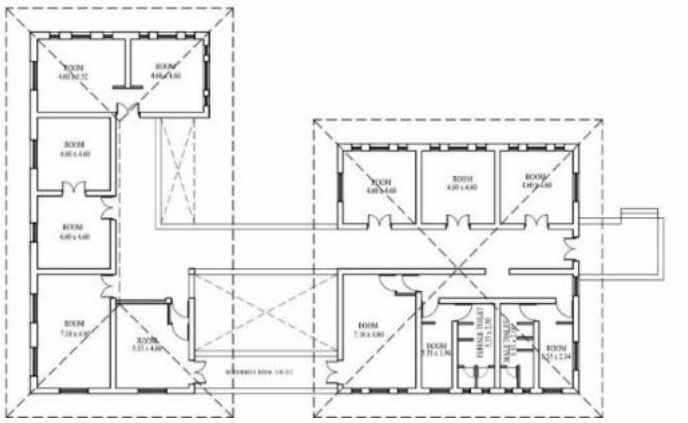
A 180 degree panoramic view of the site

A 180 degree panoramic view of the site

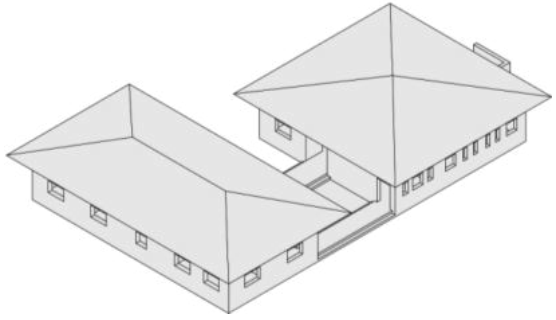
ADMINISTRATION BLOCK

Ground Cover: 584sqm
Built-Up: 584sqm
Open Area: 96sqm
Façade Facing South: 205sqm
Façade Facing West: 137sqm
Total South and West Facing: 342sqm

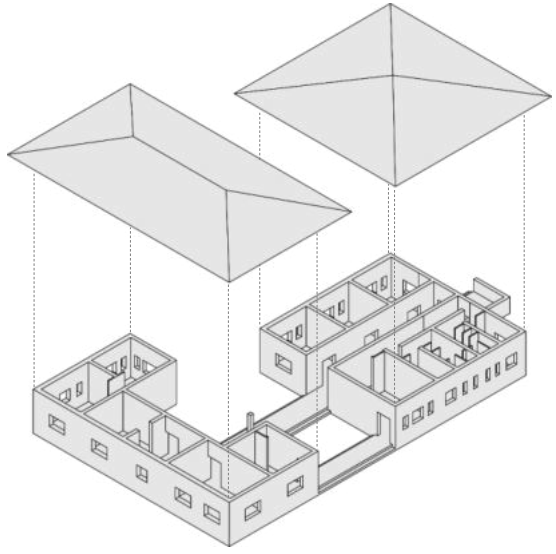
No. Of Occupants: 30 persons
Operational Hours: 8am to 6pm
Ventilation Type: Natural



Ground Floor Plan
Administration Block



Isometric View View
Administration Block

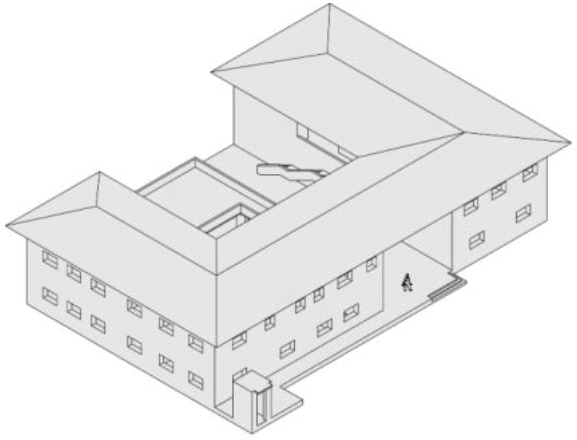


Exploded View
Administration Block

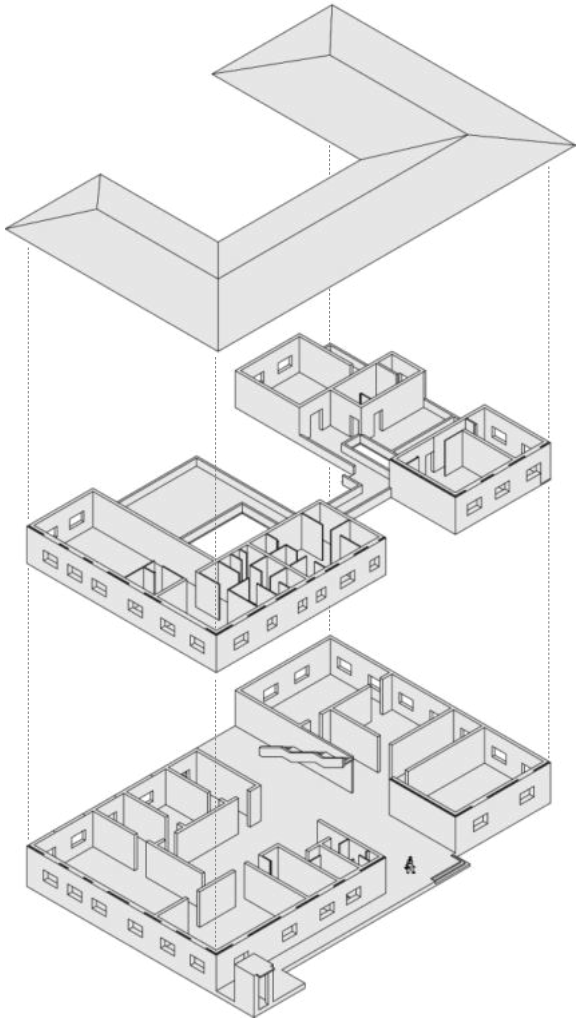
WORKSHOP BLOCK

Ground Cover: 1151sqm
Built-Up: 2087sqm
Open Area: 423sqm
Façade Facing South: 387sqm
Façade Facing West: 220sqm
Total South and West Facing: 607sqm

No. Of Occupants: 105 persons
Operational Hours: 8am to 6pm
Ventilation Type: Natural



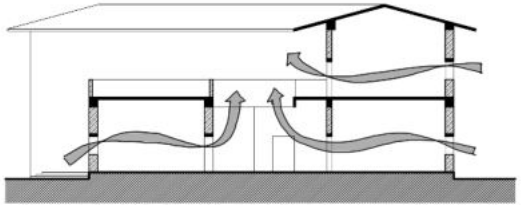
Isometric View View
Workshop Block



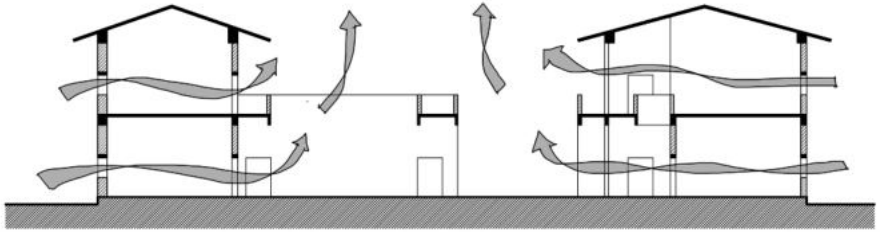
Exploded View
Workshop Block

Understanding Natural Ventilation

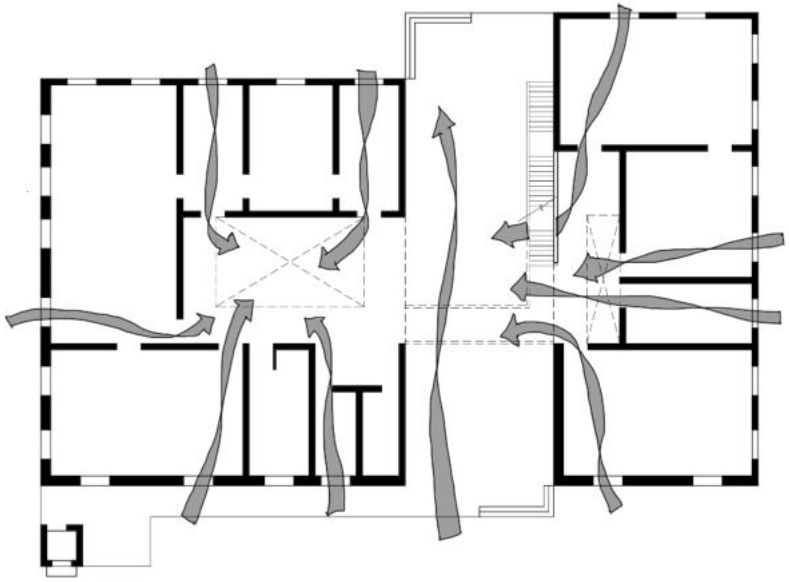
Whole building is designed on the basis of natural ventilation system. Hence each room in the building has at least two openings facing opposite direction to allow cross ventilation. Moreover the building has courtyards which provides in natural lighting and also helps in air movement throughout the building.
During day-time there's always low air pressure in the courtyard due to which there is a constant flow of air through the rooms surrounding it.



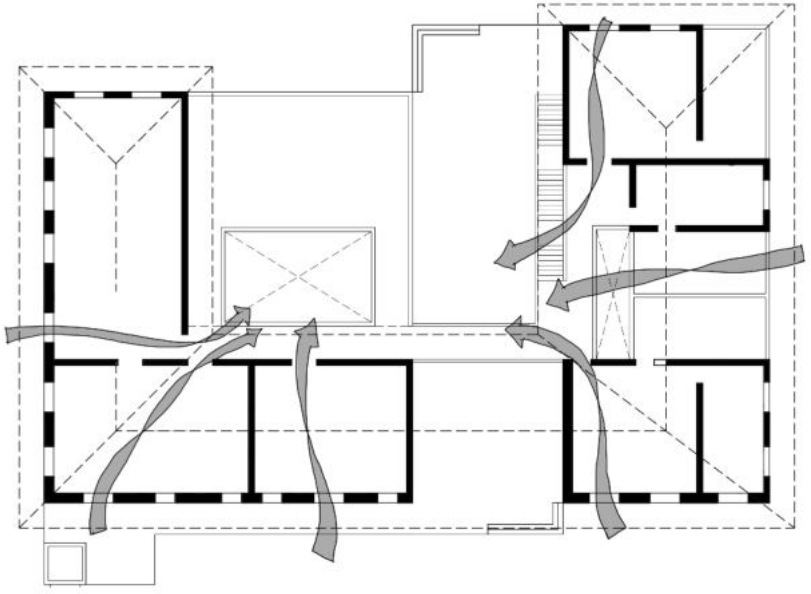
Section BB'
Natural Ventilation air wind flow diagram



Section AA'
Natural Ventilation air wind flow diagram



Ground Floor Plan
Natural Ventilation air wind flow diagram



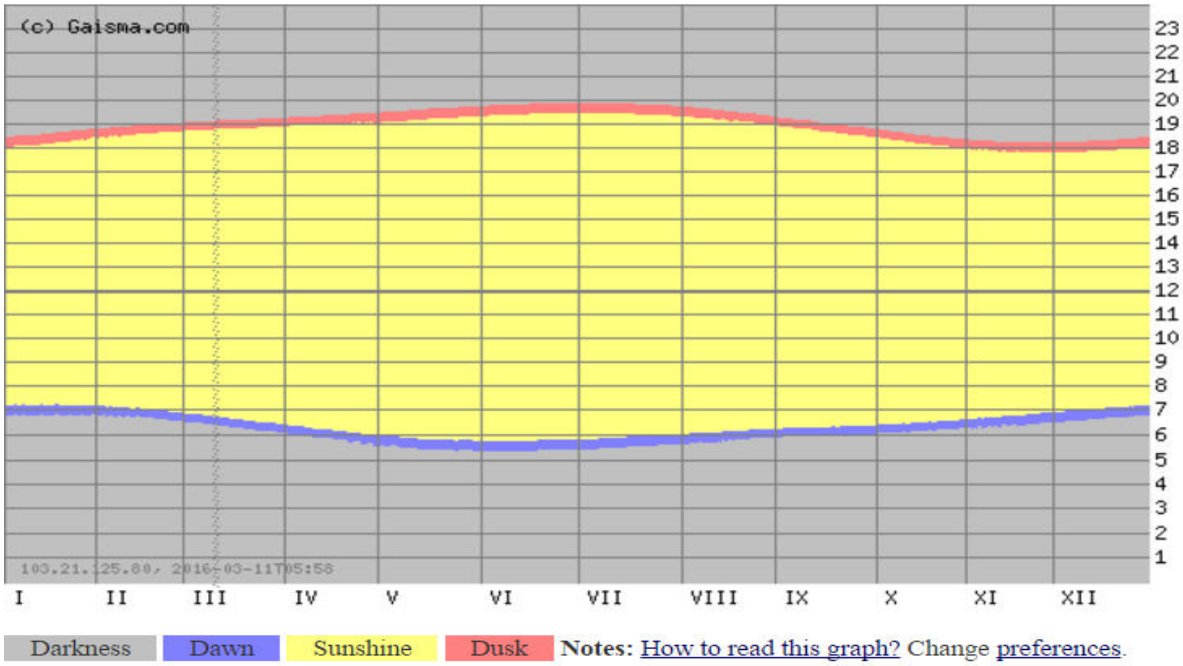
First Floor Plan
Natural Ventilation air wind flow diagram

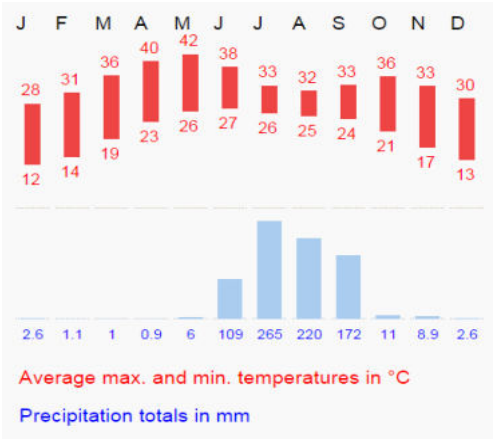
CLIMATIC CONDITION:

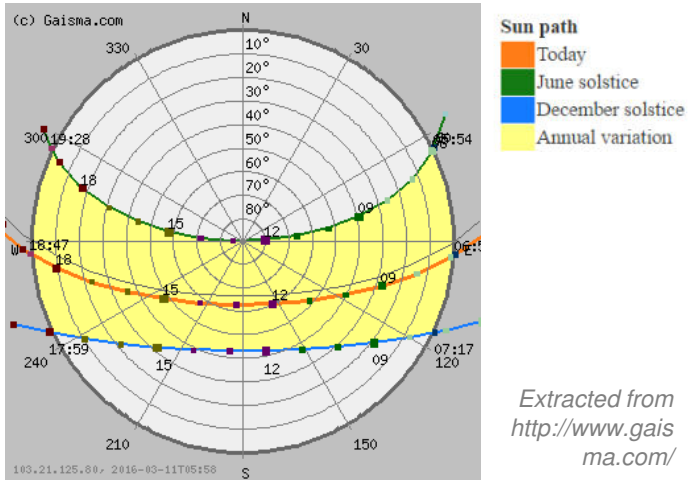
Gandhinagar has a tropical wet and dry climate with three main seasons: summer, monsoon and winter. The climate is generally dry and hot outside of the monsoon season.

- Summer temperature ranges of 36 to 42 °C , and the minimum in the range of 19 to 27 °C
- In winters the average maximum temperature is around 29 °C, the average minimum is 14 °C and the climate is extremely dry.
- The southwest monsoon brings a humid climate from mid-June to mid-September.
- The average annual rainfall is around 803.4 mm (31.63 in).

(Wikipedia, Gandhinagar, 2016)





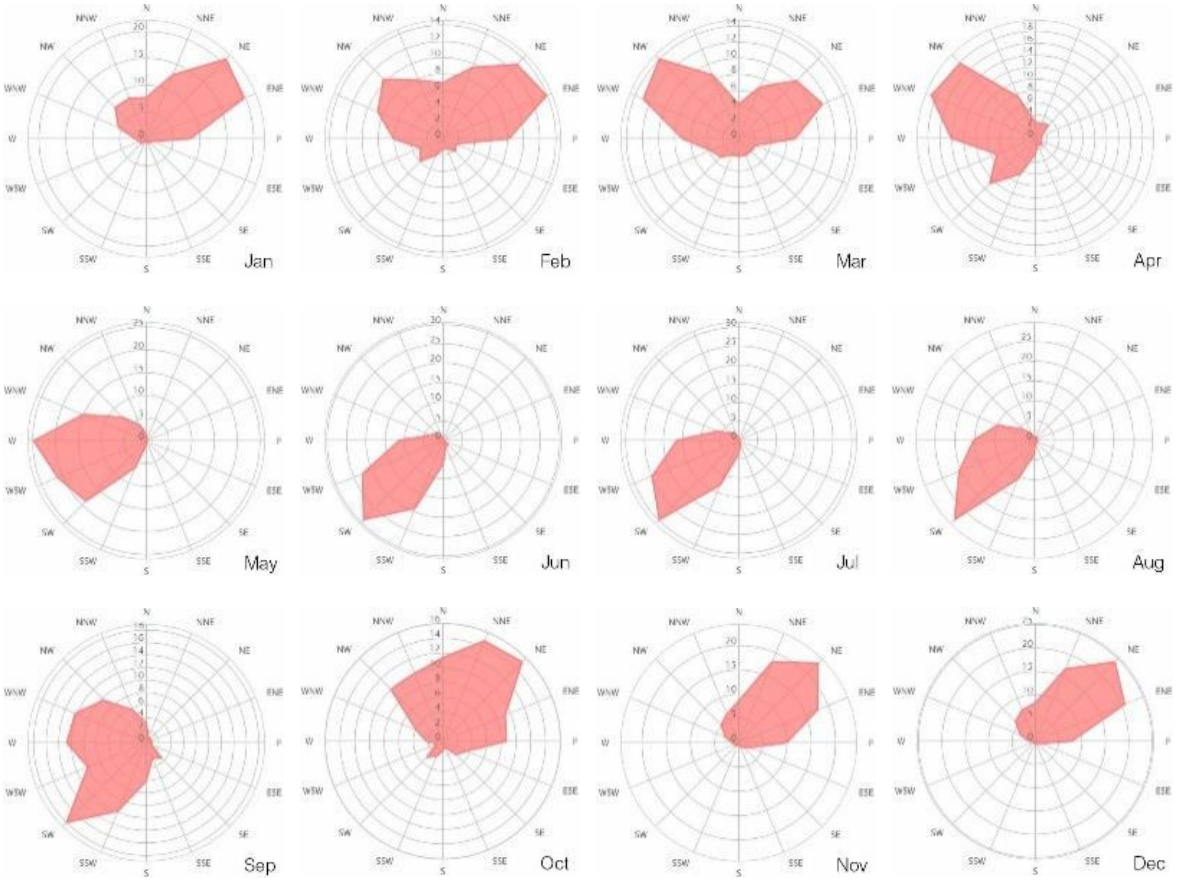


Extracted from http://www.gaisma.com/

WIND DIRECTION:

- Throughout the year Gandhinagar experiences wind flow from almost all the directions except South-East.
- Starting from January the wind changes its direction anti-clock wise Sept, where the wind direction is South-West and suddenly it swifts towards North-East from the month of October

(Windfinder, 2016)



Month of year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
	01	02	03	04	05	06	07	08	09	10	11	12	1-12
Dominant wind direction													
Wind probability >= 4 beufort (%)	2	3	1	3	7	16	10	4	2	0	0	1	4
Average wind speed (kts)	5	6	5	6	7	8	7	6	5	4	5	5	5
Average air temp	24	28	32	36	38	36	33	31	31	34	30	26	31

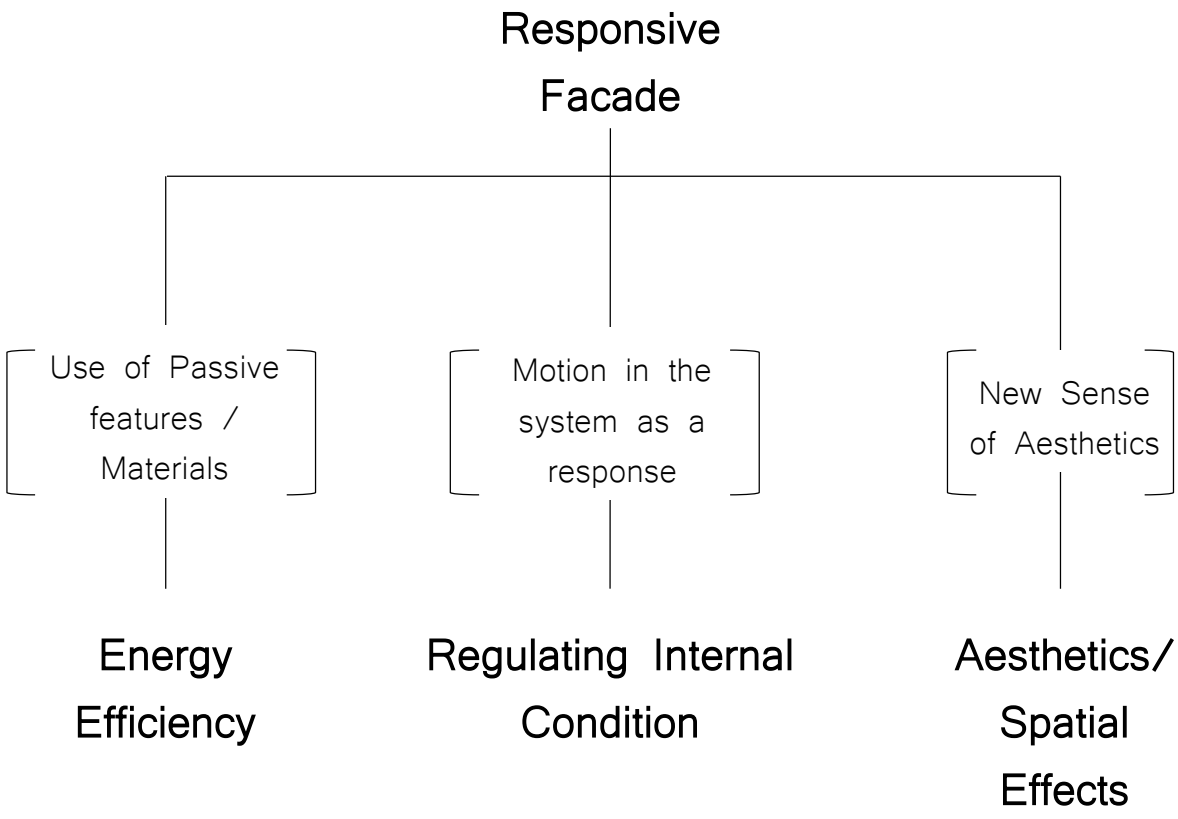
DESIGN BREIF

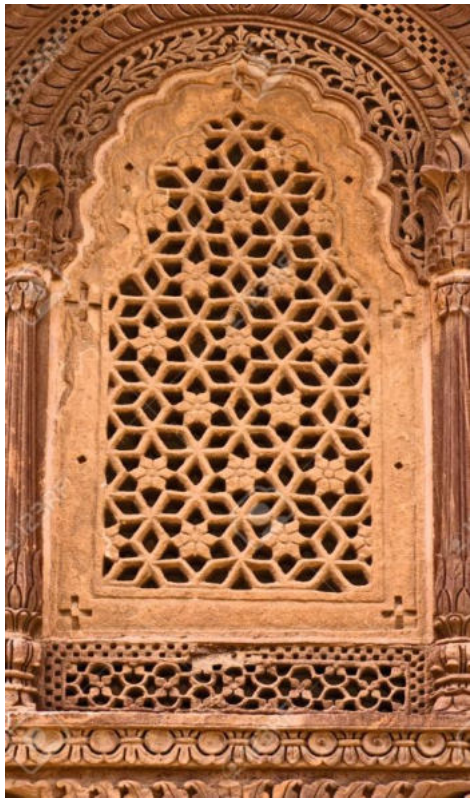
To design a low cost (150-160rs/sqft) climate responsive façade that adapts to the environmental changes and regulated the internal conditions in a habitable space, which is very easy to maintain and the aesthetics should reflect the continuity of Indian tradition.
(Style Sheet attached on next page)

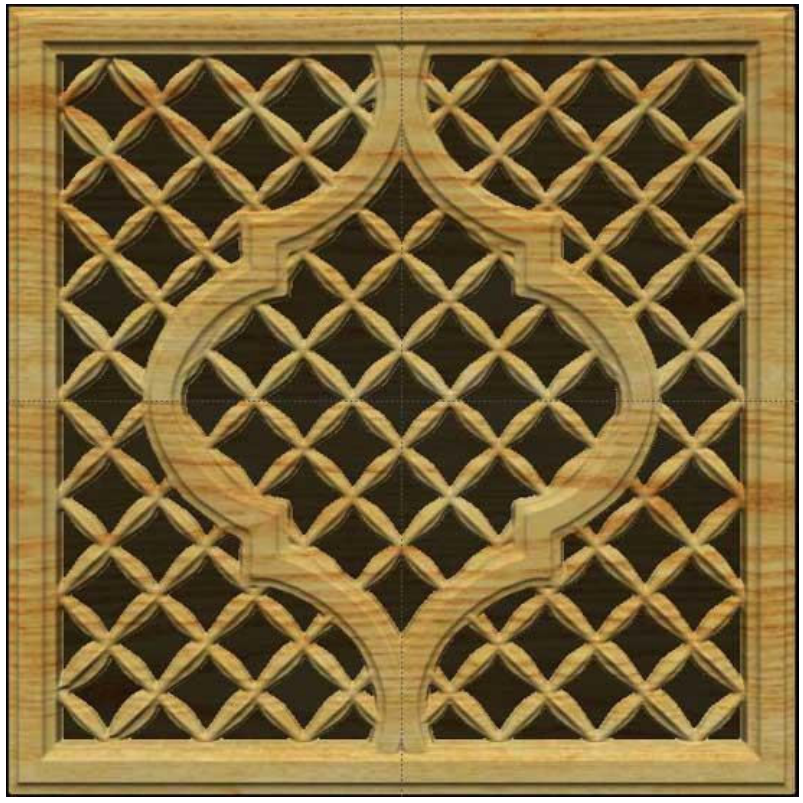
The three main aims of the projects are:

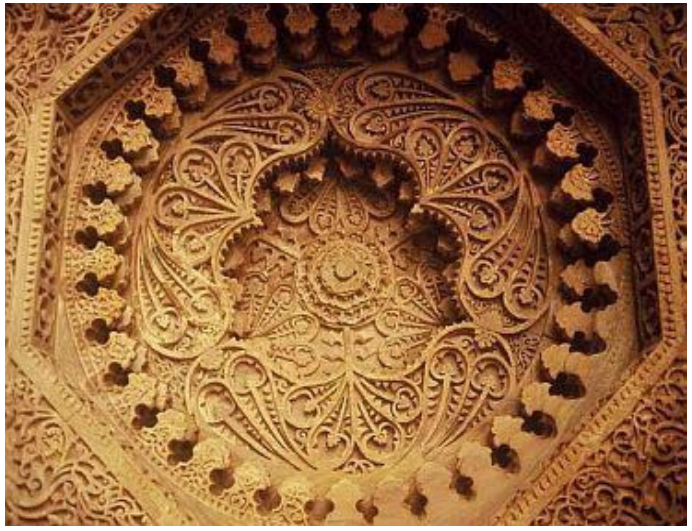
- Energy efficiency
- Regulating internal condition
- Aesthetics/Spatial Effects

Energy efficiency is aimed by developing a component based system which uses passive features and advanced materials that will lead to less usage of resources. The internal climate is aimed to be regulated by a state of motion in he system as response to the changing weather conditions, a significant change is possible in the internal space by modulating the façade. A new sense of aesthetics can be achieved by the virtue of its form and dynamism.










asianstones.com

CHAPTER 02

UNDERSTANDING PASSIVE

Solar Windows
Solar Chimney
Solar Wall
Solar Rooms
Vegetation
Ventilation
Jaali (Lattice Scren)
Evaporative Cooling

SOLAR WINDOWS

These are conventional windows with 'Chajjas'. In summers the sunlight are blocked since the slab obstruct the sunlight and in winters the sunlight enters the room since the sun-path is in more sharper angle.

Advantages

- Inexpensive
- Light and airy feeling

Disadvantage

- Not effective in west facade

SOLAR CHIMNEY

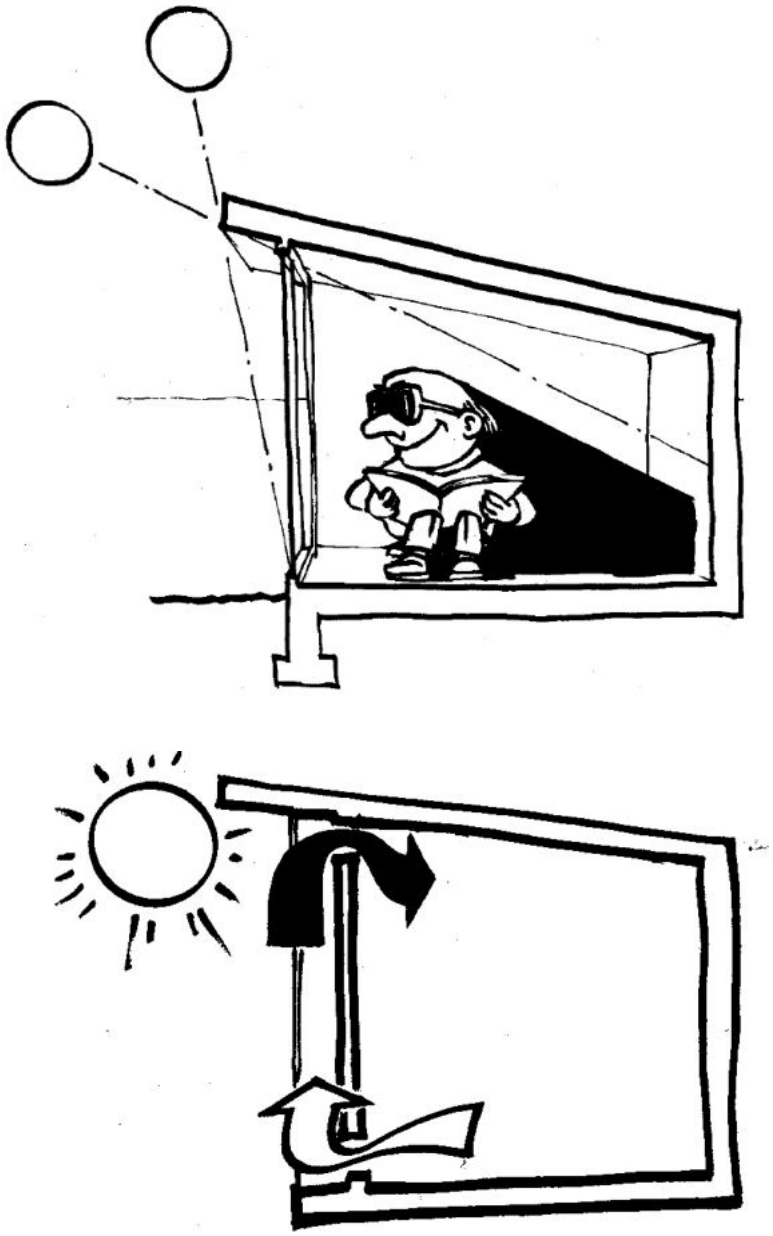
Air is warmed as it touches a solar-heated surface. The warmed air rises, and cooler air is drawn in to replace it. The process of natural convection can occur in a continuous loop between the room and a solar collector attached to its south wall.

Advantages

- Inexpensive
- Light and airy feeling

Disadvantage

- Visual Barrier
- Less openings in building envelope



Extracted from Passive Building Illustrated Book

SOLAR WALL

When the mass for absorbing the sun's heat is located right in the material. These materials should have high thermal mass which stores the heat for longer durations. For example: Water, Stone, etc.

Advantages

- Durable

Disadvantage

- Huge Investment
- Effective in extreme climates like Rajasthan

SOLAR ROOMS

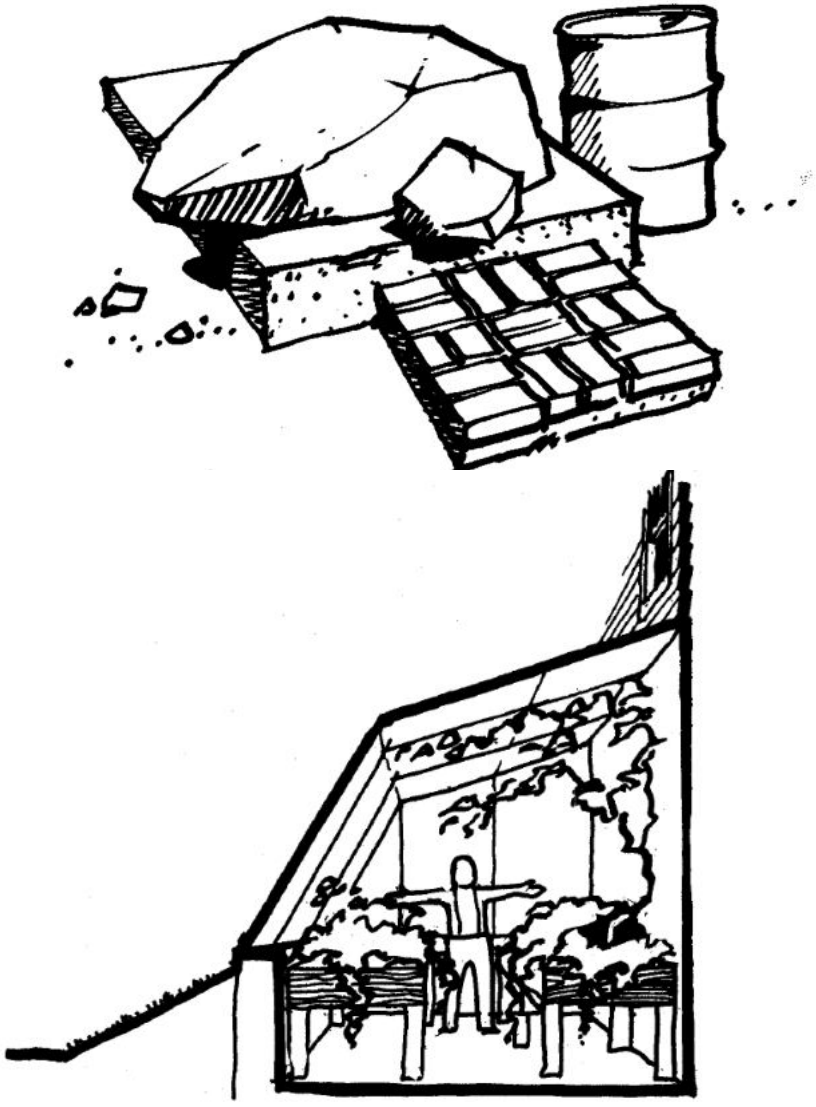
Solar-heated rooms such as greenhouses, sun porches, and solariums are the best examples of passive solar systems for cold regions.

Advantages

- May increase the temperature to very high

Disadvantage

- Expensive
- Not effective in Indian Climate



Extracted from Passive Building Illustrated Book

VEGETATION

Usually the easiest, most inexpensive and effective way to "solar" cool building is to shade it-keep the sun from hitting the windows, walls, and roof.

Advantages

- Inexpensive
- Green

Disadvantages

- Specific Vegetation can only help

VENTILATION

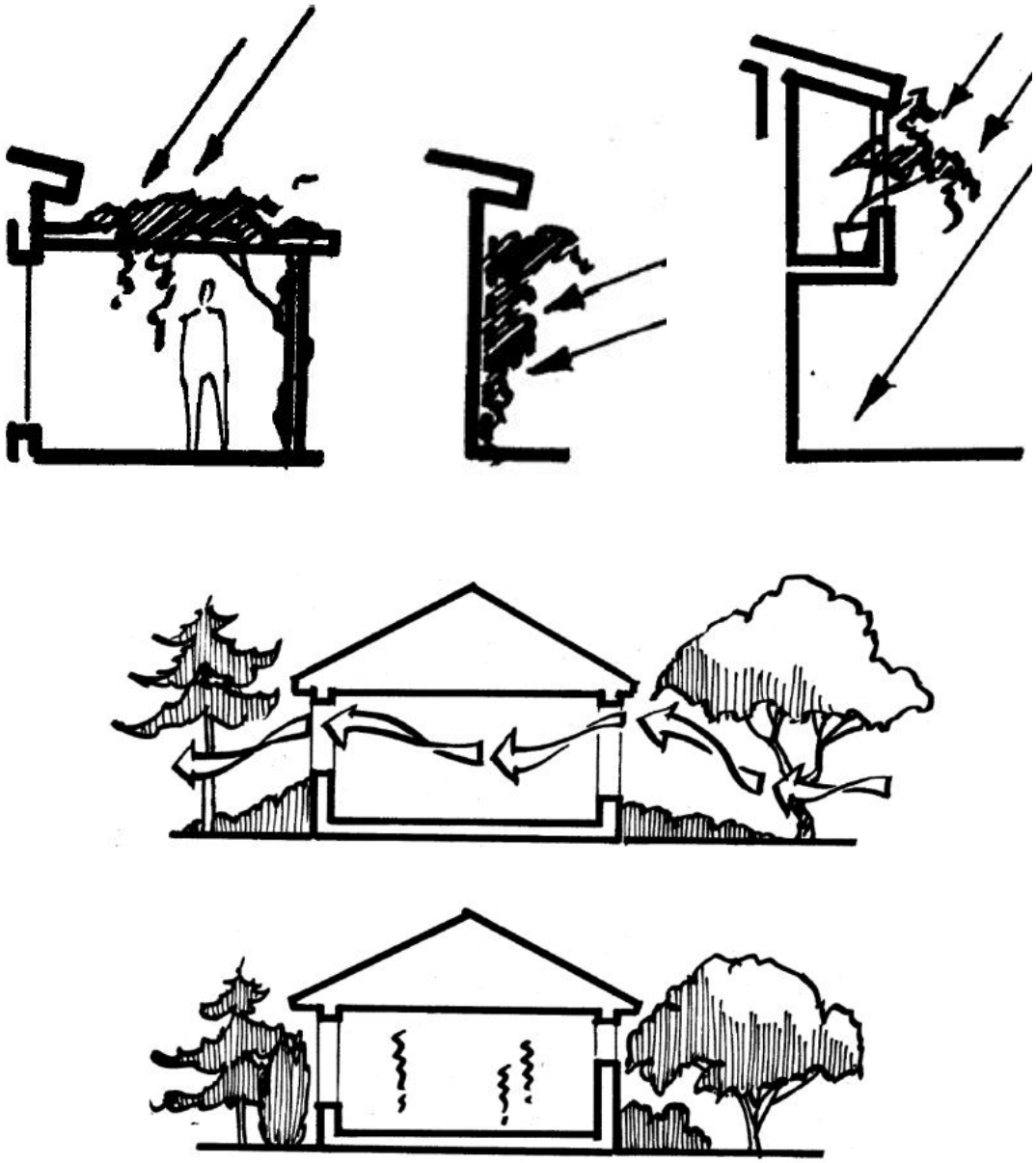
The movement of even slightly warmer air across our skin causes a cooling sensation. The most common way to cool a house with moving air without using mechanical power is to open windows and doors.

Advantages

- Inexpensive
- Light and airy feeling

Disadvantage

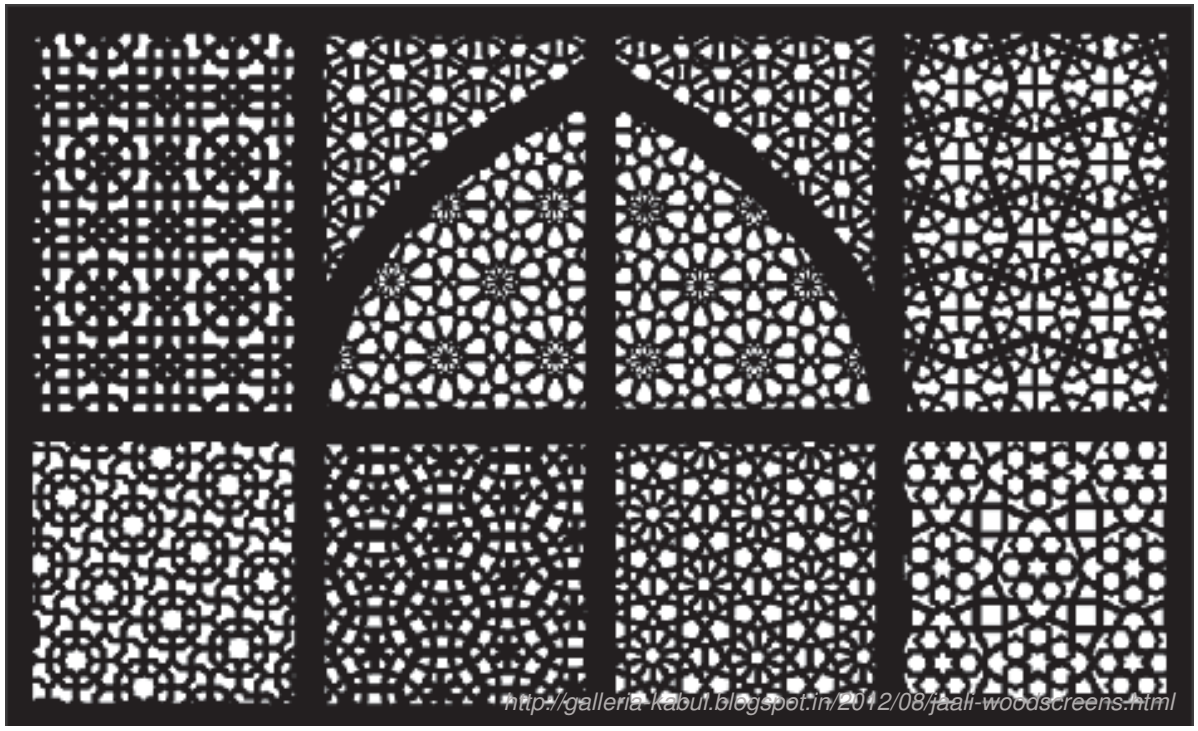
- Dust



Extracted from Passive Building Illustrated Book

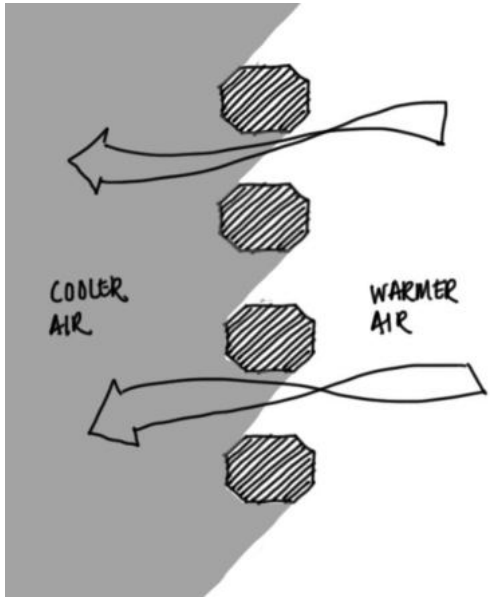
JAALI （Latticed Screen）:

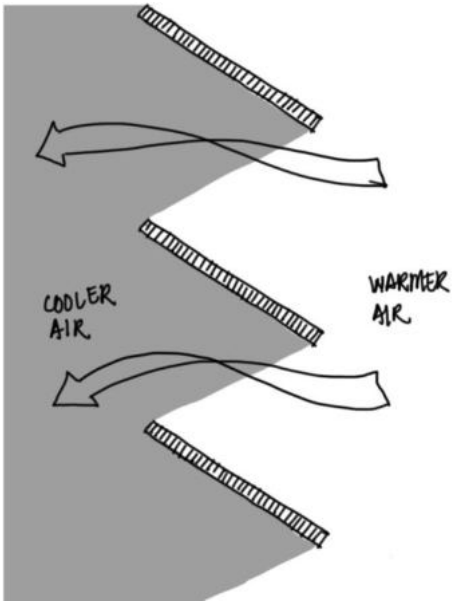
This form of architectural decoration is found in Indian architecture. The jali helps in lowering the temperature by compressing the air through the holes. Also when the air passes through these openings, its velocity increases giving profound diffusion. It has been observed that humid areas like Kerala and Konkan have larger holes with overall lower opacity than compared with the dry climate regions of Gujarat and Rajasthan.



Features

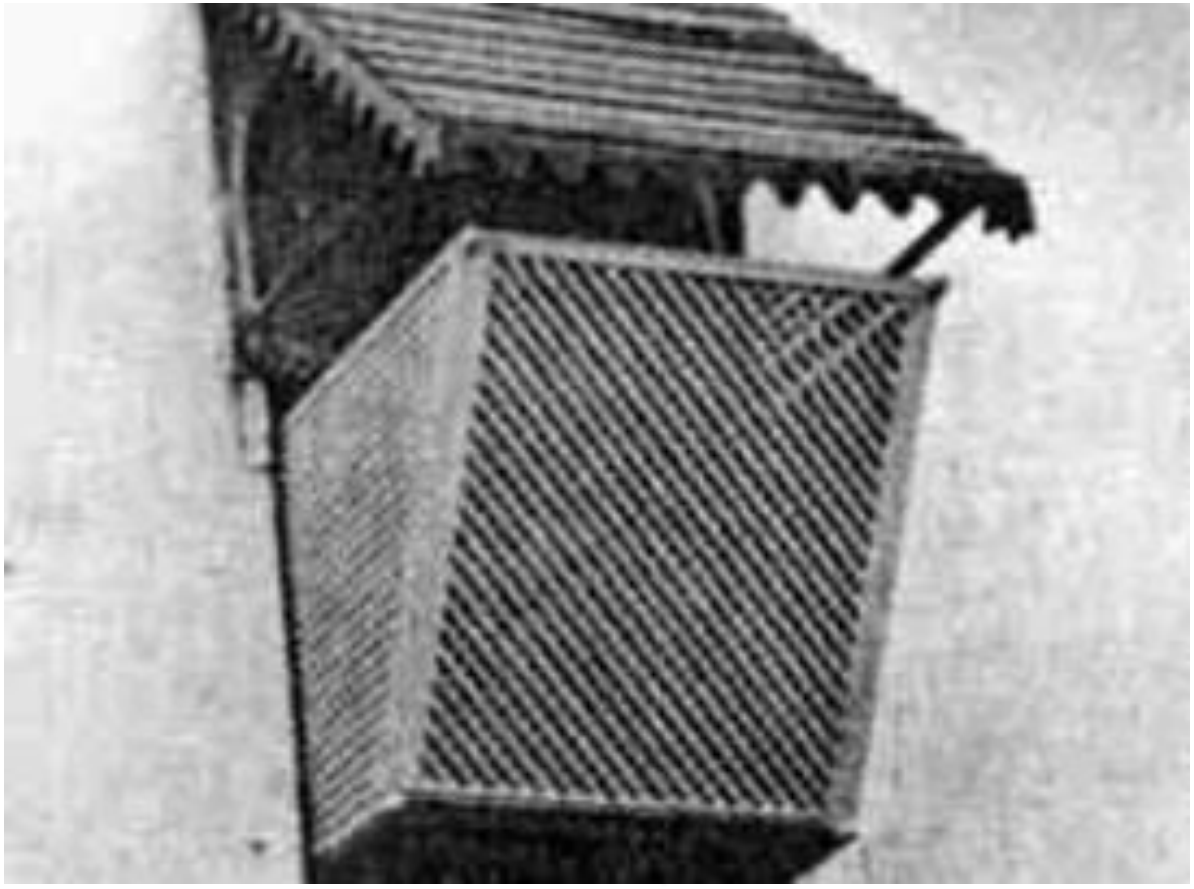
- controls the airflow and lower down the temperature of internal spaces on the other.
- the internal spaces are not visible from outside during day.
- the diffused light is spread throughout the interiors.
- Jaali in Mughal buildings mostly have a low sill or sometimes without sill so that the air could move near the floor.

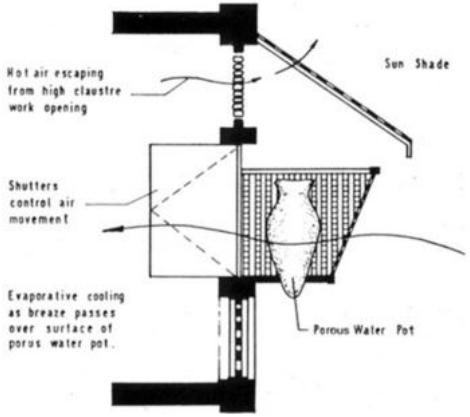




EVAPORATIVE COOLING:

Evaporative cooling is a passive cooling technique in which outdoor air is cooled by evaporating water before it is introduced in the building. Its physical principle lies in the fact that the heat of air is used to evaporate water, thus cooling the air, which in turn cools the living space in the building. However passive evaporative cooling can also be indirect.





http://galleria-kabul.blogspot.in/2012/08/jaali-woodscreens.html

CHAPTER 03

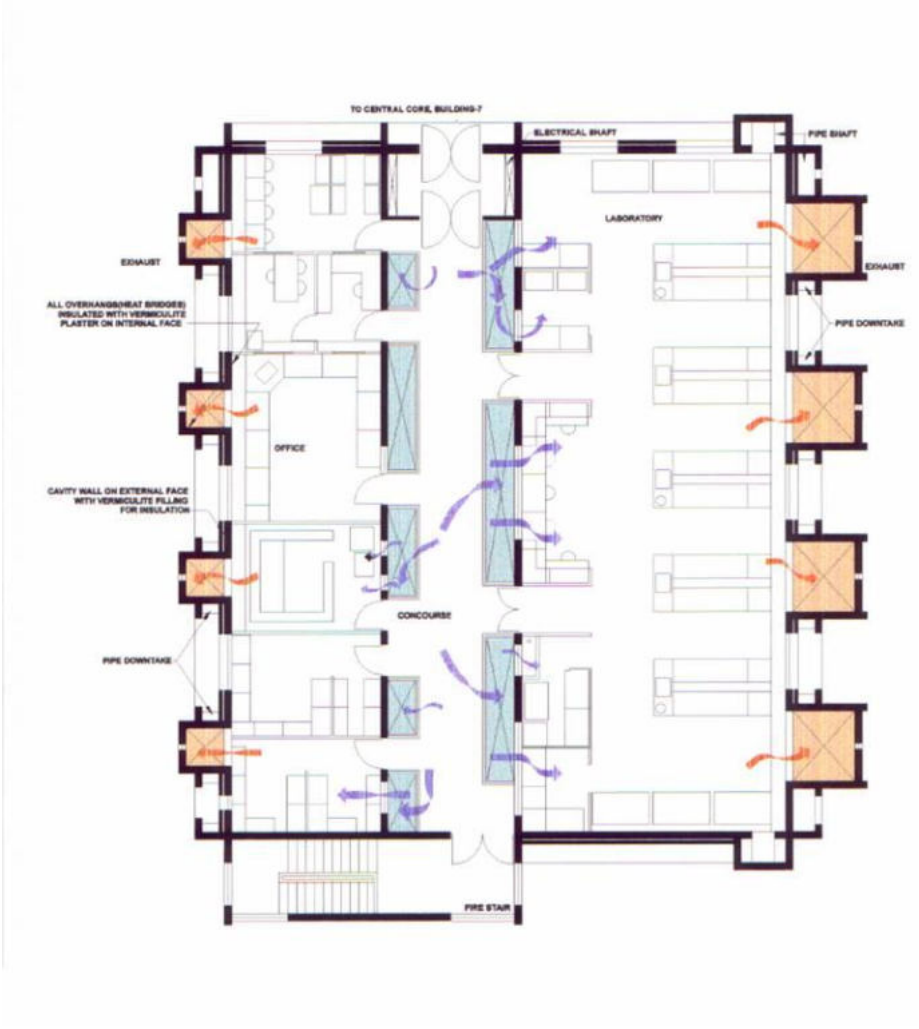
CASE STUDIES

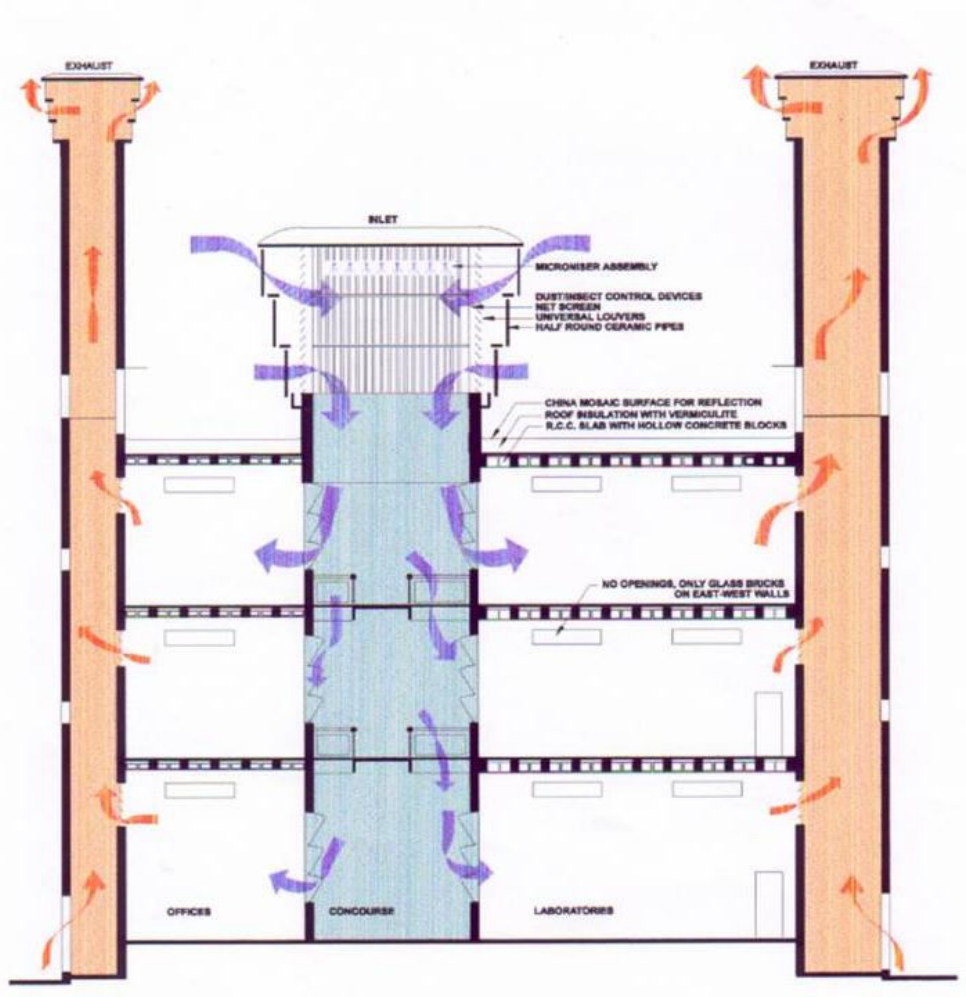
TORRENT RESEARCH CENTRE:

This building uses Passive Downdraft Evaporative Cooling for a large scale office building and demonstrates that it is possible to achieve human comfort in dry hot regions without using regular HVAC.

- Approximately 64% less electrical energy
- The building cost of 4% more, but paid back by the first year itself due to energy saving.
- Expenditure on plant was reduced by 36%, which will provide further savings in maintenance costs.
- Humid during monsoons
- Lower temperature in winter

(Abhikram, 2016)

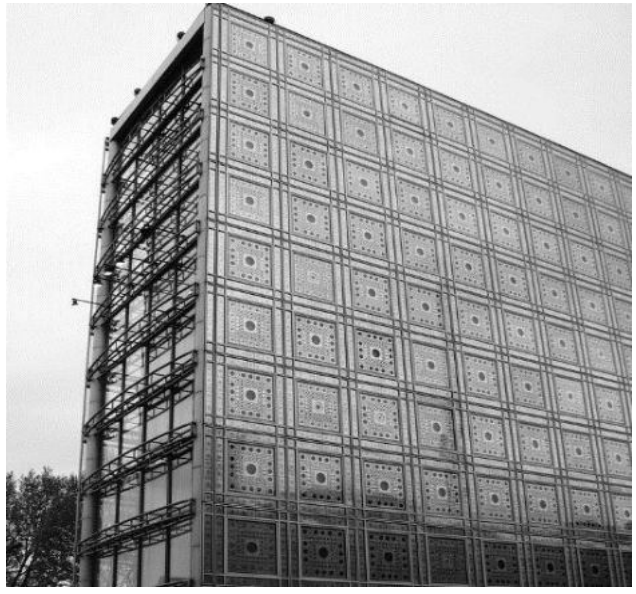


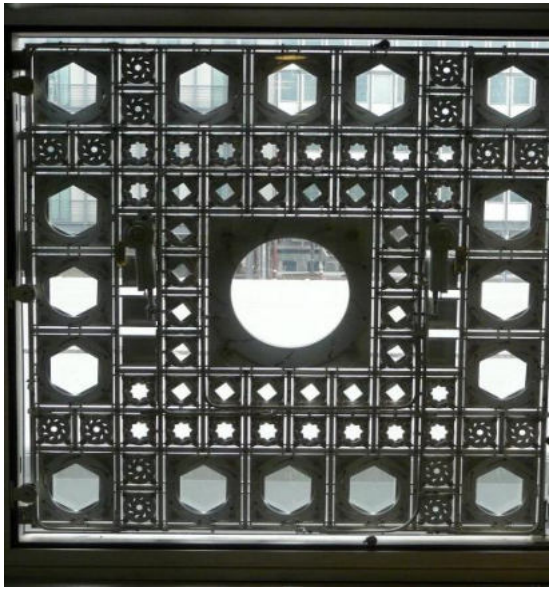


http://www.abhikram.com/

02 INSTITUT DU MONDE ARABE:

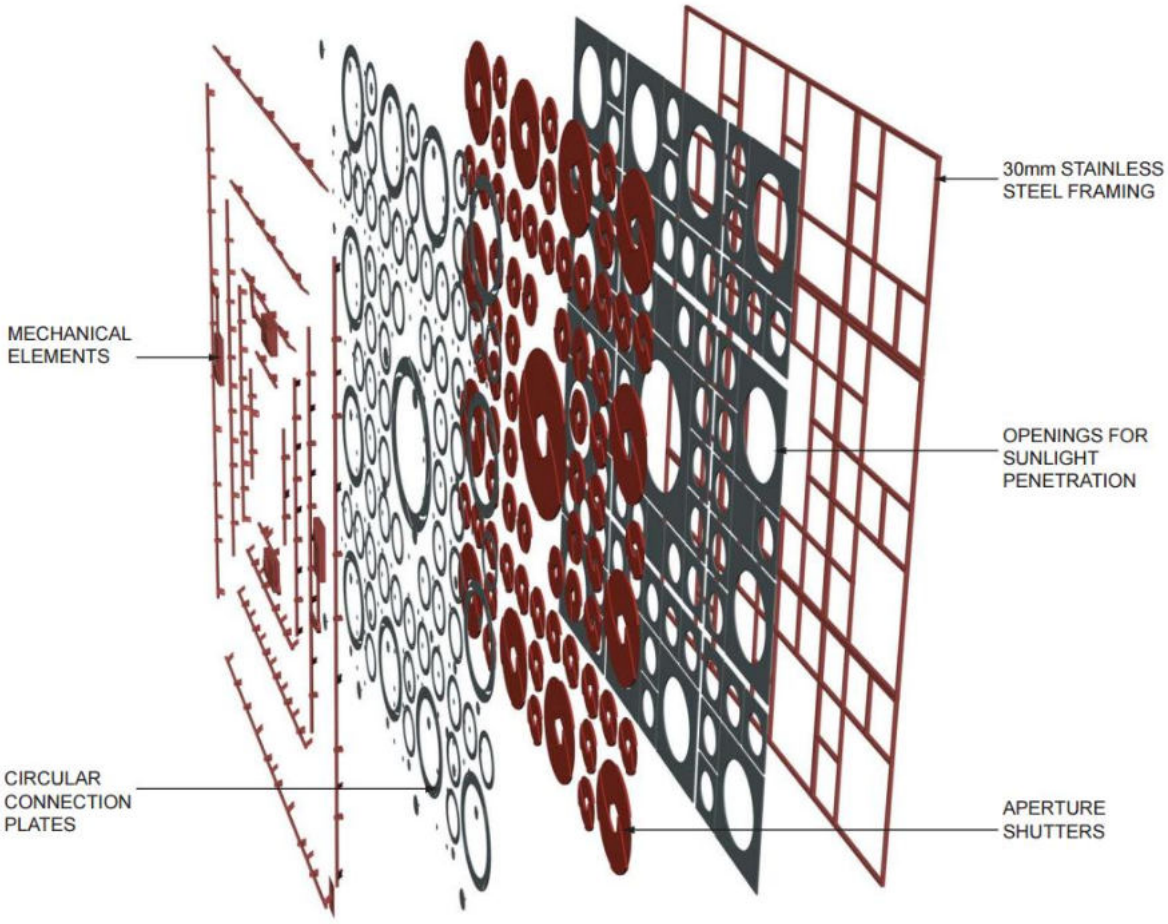
The system incorporates several hundred light sensitive diaphragms that regulate the amount of light that is allowed to enter the building. During the various phases of the lens, a shifting geometric pattern is formed and showcased as both light and void. Squares, circles, and octagonal shapes are produced in a fluid motion as light is modulated in parallel. Interior spaces are dramatically modified, along with the exterior appearance.
(Archdaily, 2016)





- integrated with a series of layers in the mechanical aspect. these panels are divided and supported by a structural steel grid and are then encased behind a glass facade.
- dynamic integration relates to the mechanized facade that responds to the change in lighting conditions and adjusts apertures to create a cohesive environmental response.

(Archdaily, 2016)



http://institut-du-monde-arabe

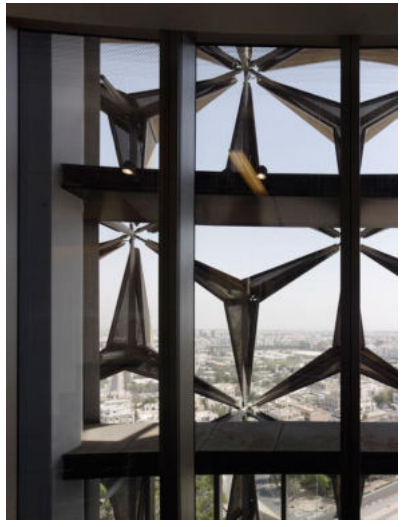
AEDAS CLADS:

Al Bahr Towers With Dynamic Shading Device

By combining technologically advanced solutions while considering the country's architectural heritage, the dynamic façade opens and closes in response to the movement of the sun, reducing solar gain by up to 50%. Referencing the 'mashrabiya', a wooden lattice system found in vernacular islamic architecture, a series of translucent umbrella-like components which open and close in relation to the sun.

(Al Bahar, 2012)

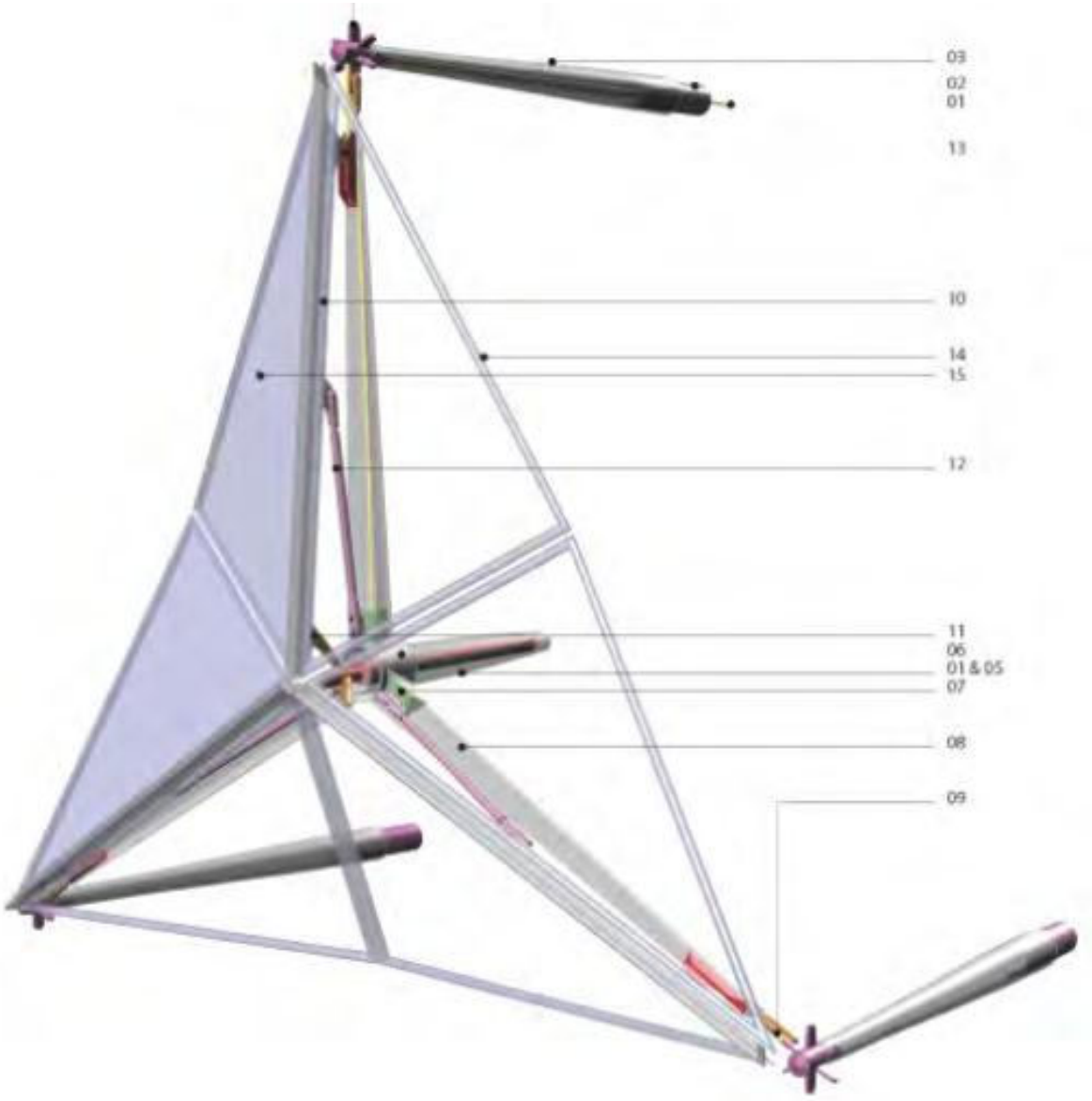
http://inhabitat.com/exclusive-photos-worlds-largest-computerized-facade-cools-aedas-al-bahr-towers/



http://www.theplan.it/images/stories/State-of-the-art/024/aedas/1-img/7.jpg

Main Components:

- Actuator
- Strut Sleeves: penetrates the curtainwall & connects to the main structure
- Supporting cantilever Struts: hooks on the sleeves
- Star Pin Connection: receives the unitized Y-Arm ends
- Actuator Casing: protects the actuator
- Y-Structure Ring Hub: joins the Y-Arms and actuator together
- Y-Structure Sleeves: connects the Y-Arms to the Hub
- Y-Structure Arms: supports the whole mechanism
- Y-Mobile Tripod: drives and supports the fabric mesh frames
- Actuator Head Pin Connection: pins to the Mobile Tripod
- Stabilizer: takes the loads to the hub releasing the actuator shear forces
- Slider: allows the Mobile Tripod to travel along the Y-Arms
- Fabric Mesh Frame & Sub-Frame: supporting the fabric mesh
- Fabric Mesh *(Al Bahar, 2012)*

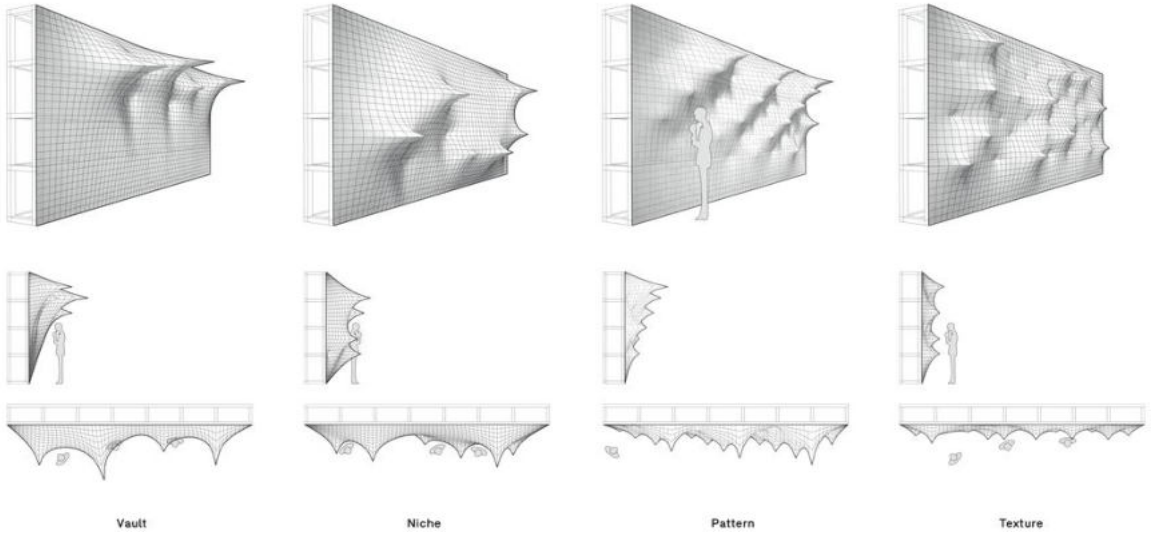


KINETIC WALL

Barkow And Leibinger

Kinetic Wall is designed to "revisit the utopian dream of an architecture that can move", creating an ever-changing surface that rhythmically expands and contracts. The surface is activated by a grid of motorized nodes, masked behind translucent layers of synthetic fabric. These are programmed to move in and out periodically to produce what the architects describe as "peaks and valleys". *(Face Design, 2016)*

http://ww...o.com/kinetic-w...l-barkow-and-leibinger/

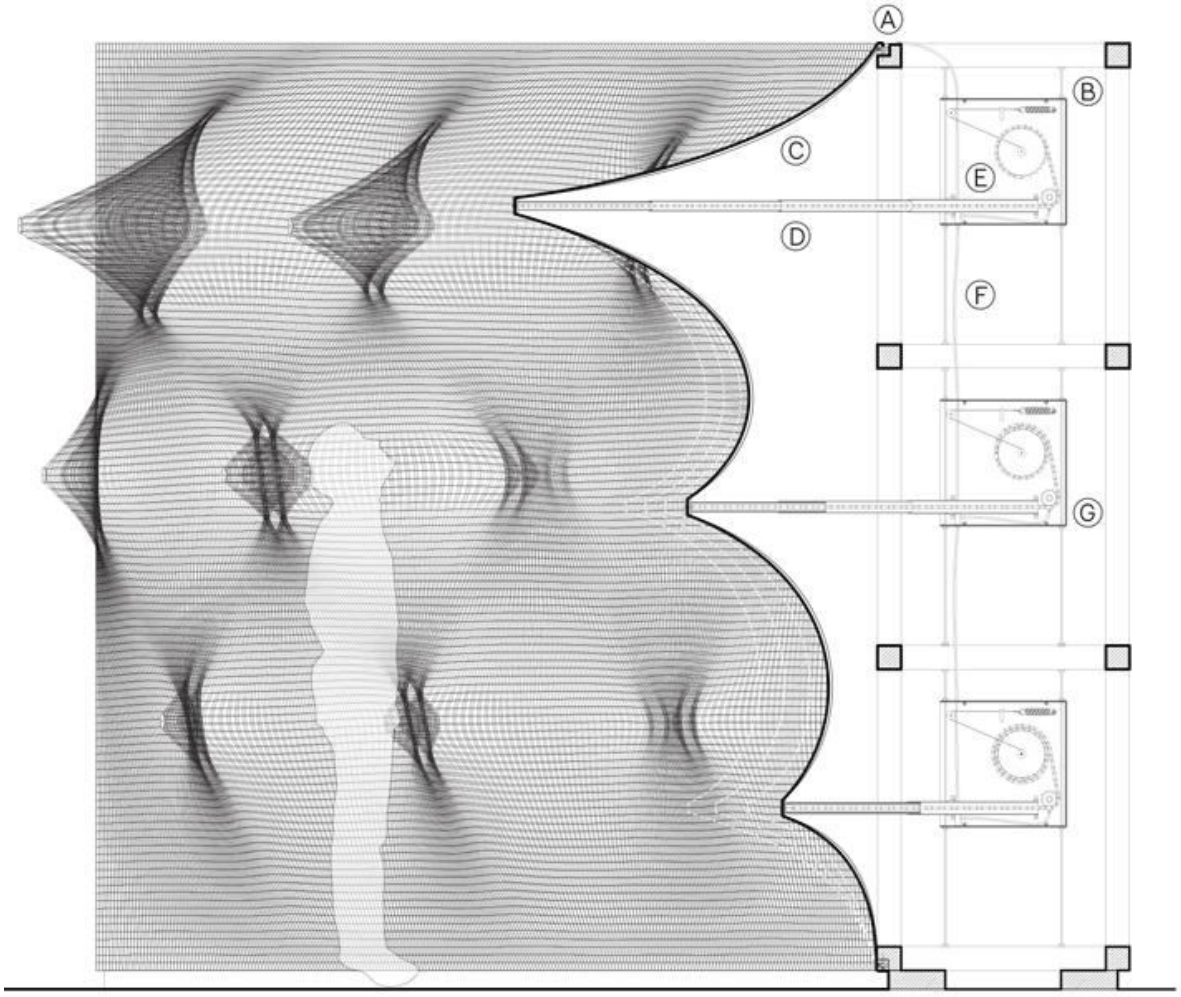


https://static.dezeen.com/uploads/2014/06/Kinetic-Wall-by-Barkow-Leibinger_dezeen_12_1000.gif/

Components:

A. Revolving Mounting Profile
B. CNC milled Laminated Wood
C. Two Layers of Gridded Elastane
D. Telescoping Rod
E. 24V Motor
F. Electric Cable
G. Programmable Activator
H. Connection Plate

(Face Design, 2016)



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CHAPTER 04

MATERIALS

Bamboo

Aluminum composite Panel

UPVC

Weatherboard

PTFE Fabric

BAMBOO

Bamboo is light weight natural material with high mechanical properties. And it is durable, only if it is well treated. The major advantage of using bamboo as material is, it's a renewable resource which grows rapidly.

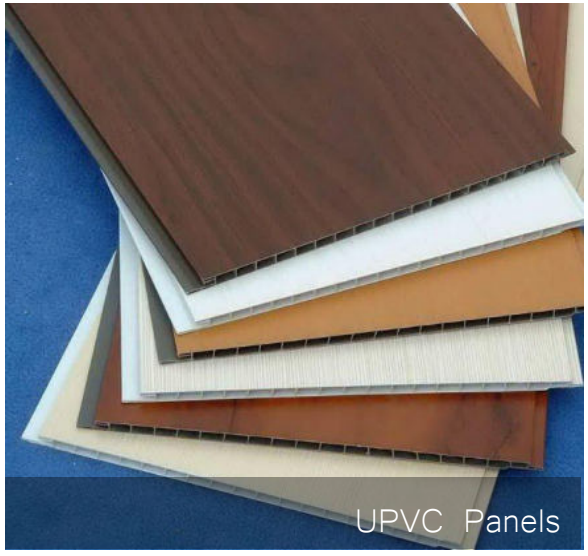
ALUMINIUM COMPOSITE PANEL

Aluminum Composite Panel is one of the most popular options for cladding purposes. This is primarily because aluminum, unlike other metals, cannot rust or corrode, making it highly desirable for homes, buildings or other structures located close to an ocean. Aluminum is also very lightweight, making it usable for both side and roof cladding. Also, like most other metals, it can be painted nearly any color.

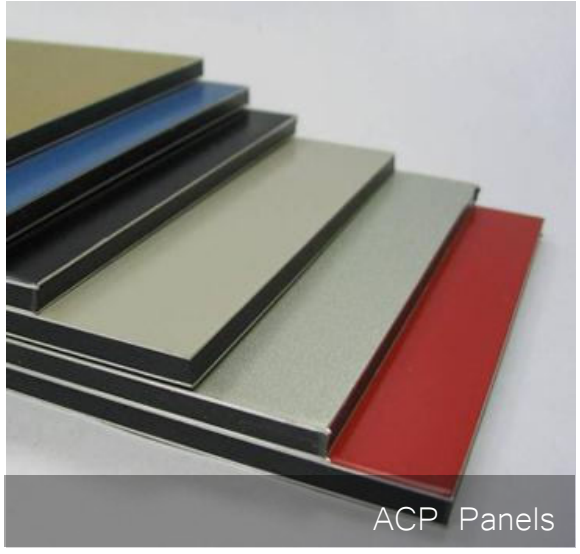
UPVC

These are polymer based light weight cladding panels. These cladding are economical, easy to install and durable. But not as durable as ACP. Unlike other cladding systems UPVC does not corrode. The panels are available in various colors.

Bamboo used in building facade



UPVC Panels



ACP Panels

WEATHERBOARD

Weatherboards are usually made from reconstituted hardwood or timber that can be painted or stained however you would like them to be. They can be fixed to all kinds of underlying material such a brick. The slight downside is that weatherboard requires ongoing maintenance to stay in a good condition.

PTFE FABRIC

These fabric are maintained in tension in all directions to provide stability. PTFE comprises of a woven glass fiber base fabric coated with polytetrafluoroethylene (PTFE fabric). This coating is highly inert and generally unaffected by environmental contaminants and ultra-violet light, and additionally has superior fire resistant properties.

Weatherboard used in building facade

PTFE Tensile Structures

CHAPTER 05

CONTROLLING METHODS

Understanding Building Envelope

Resources

Design Approach

Wind Control Methods

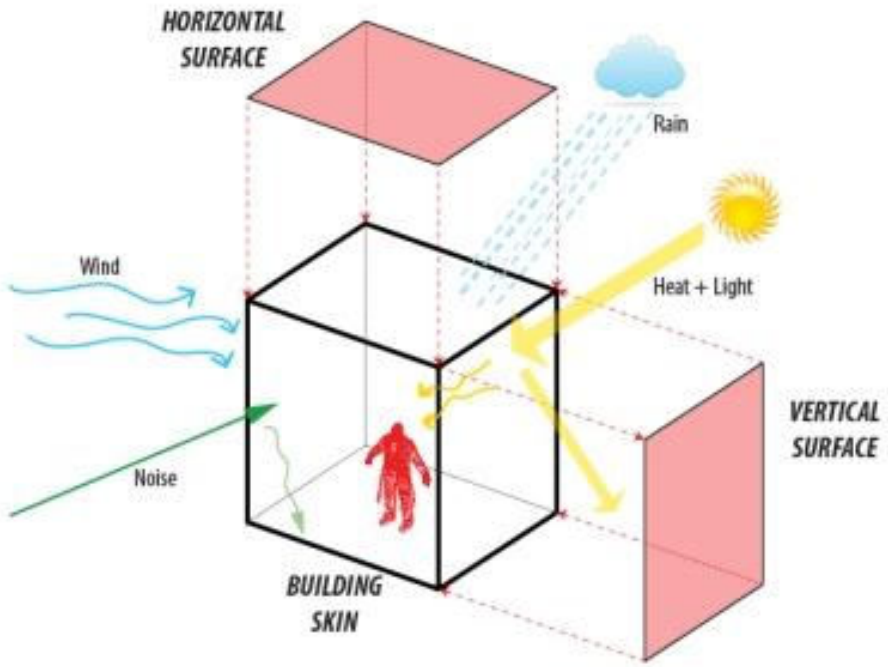
Light Control Methods

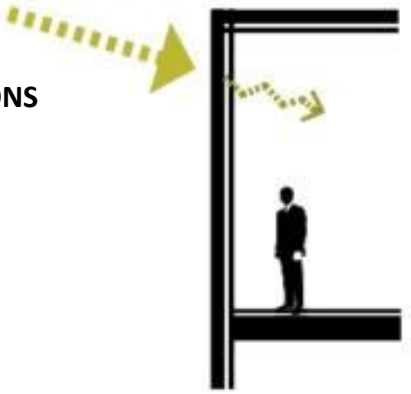
Heat Control Methods

UNDERSTANDING BUILDING ENVELOPE

A building envelope consists of a vertical (wall) and horizontal (roof) components which protects buildings from direct external environment and helps in maintaining comfortable interiors along with providing structure and stability to the building.

Building facades are a vital components to resolve the issue of responsive architecture as they are a medium through which the intelligence can be imparted to the building system to response to an environmental stimulus. The key characteristics of an responsive building façade is to modify the energy flows through the building envelope by regulation, attenuation, rejection or entrapment.





EXTERNAL CONDITIONS (DYNAMIC)

HEAT
LIGHT
WIND
NOISE
RAIN

INTERNAL CONDITIONS (REGULATING)

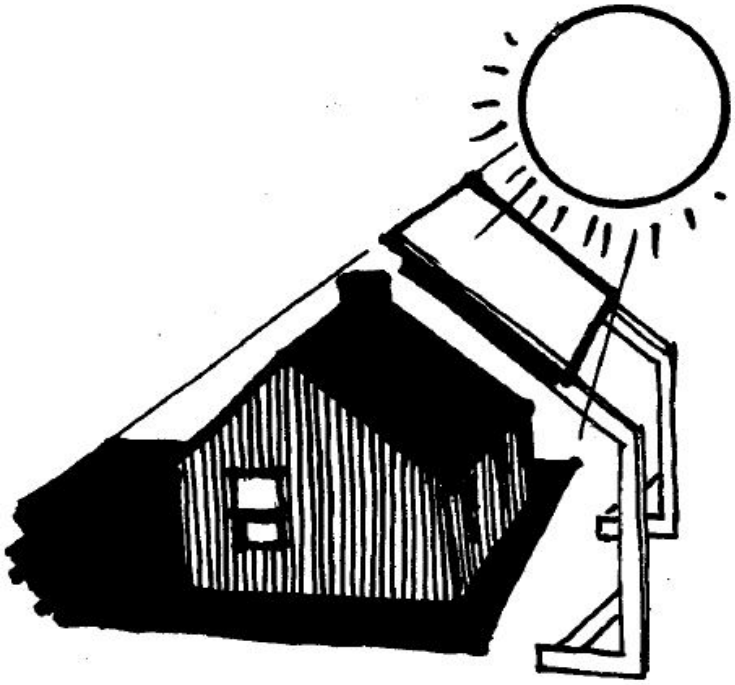
LOCAL and GLOBAL level responses are made by buildings to maintain constant INTERNAL CONDITIONS

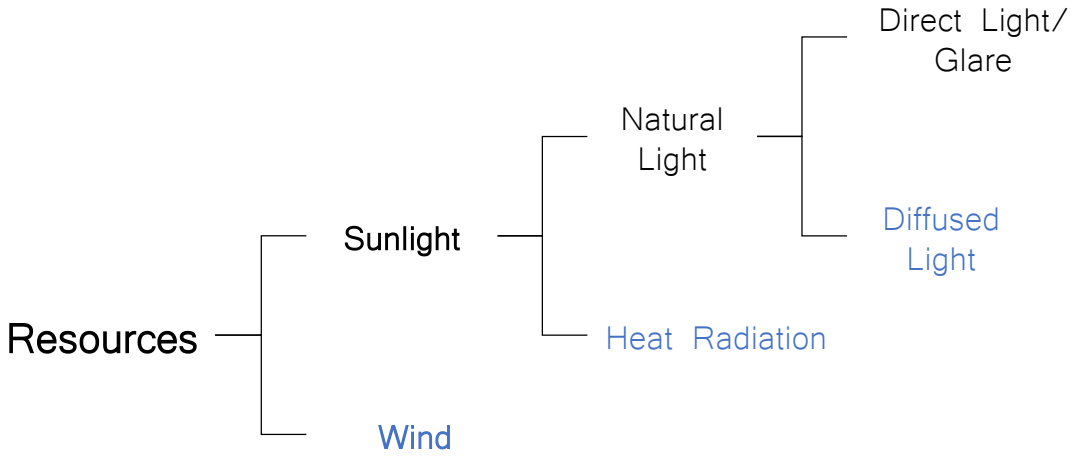
RESOURCES

Sunlight is the major cause of heat during summers. Due to thermal mass the building components absorbs heat and then radiates which again increases the ambient temperature. The easiest, most inexpensive and effective way to "solar" cool the building is to shade it- keep the sun from hitting your windows, walls, and roof. So by making an secondary envelope to shade with continuous air circulation so that the air behind the envelope should exchange with comparatively cooler air can be solution for regulating the internal climate.

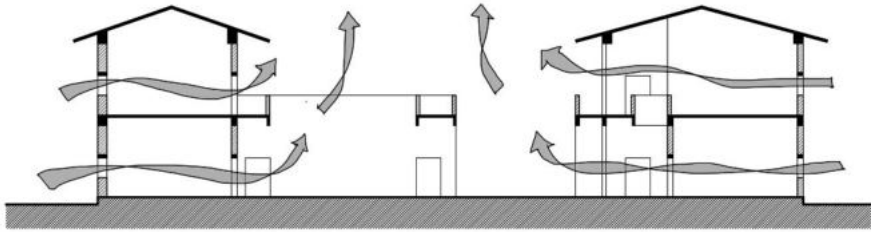
The resources we are getting Passively:

- Sunlight
- Wind

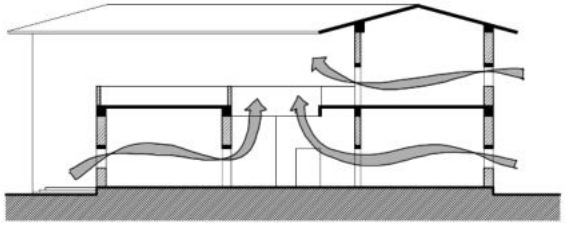




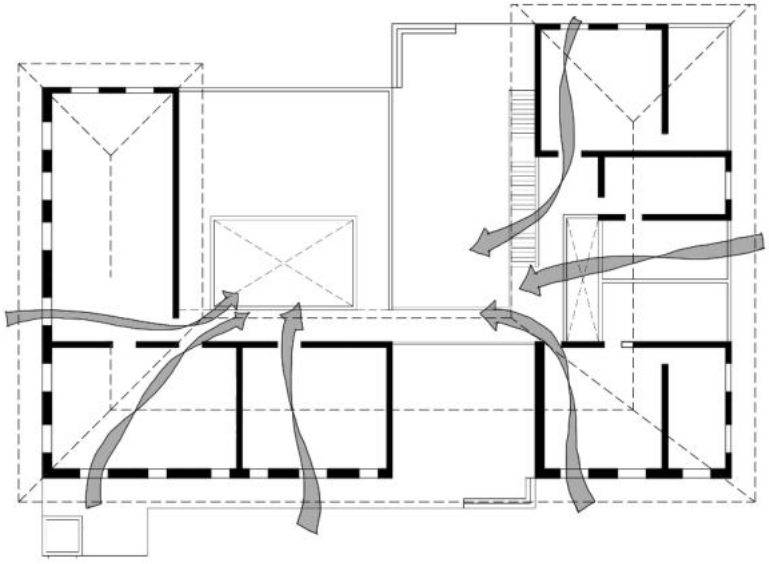
Understanding the current Architectural Design proposal



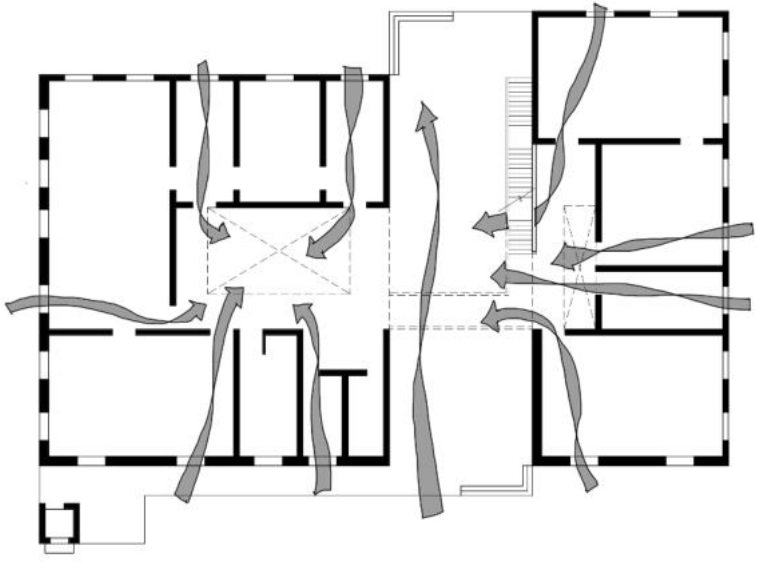
WORKSHOP BLOCK
SECTIN AA'



WORKSHOP BLOCK
SECTIN BB'



WORKSHOP BLOCK
1ST FLOOR PLAN



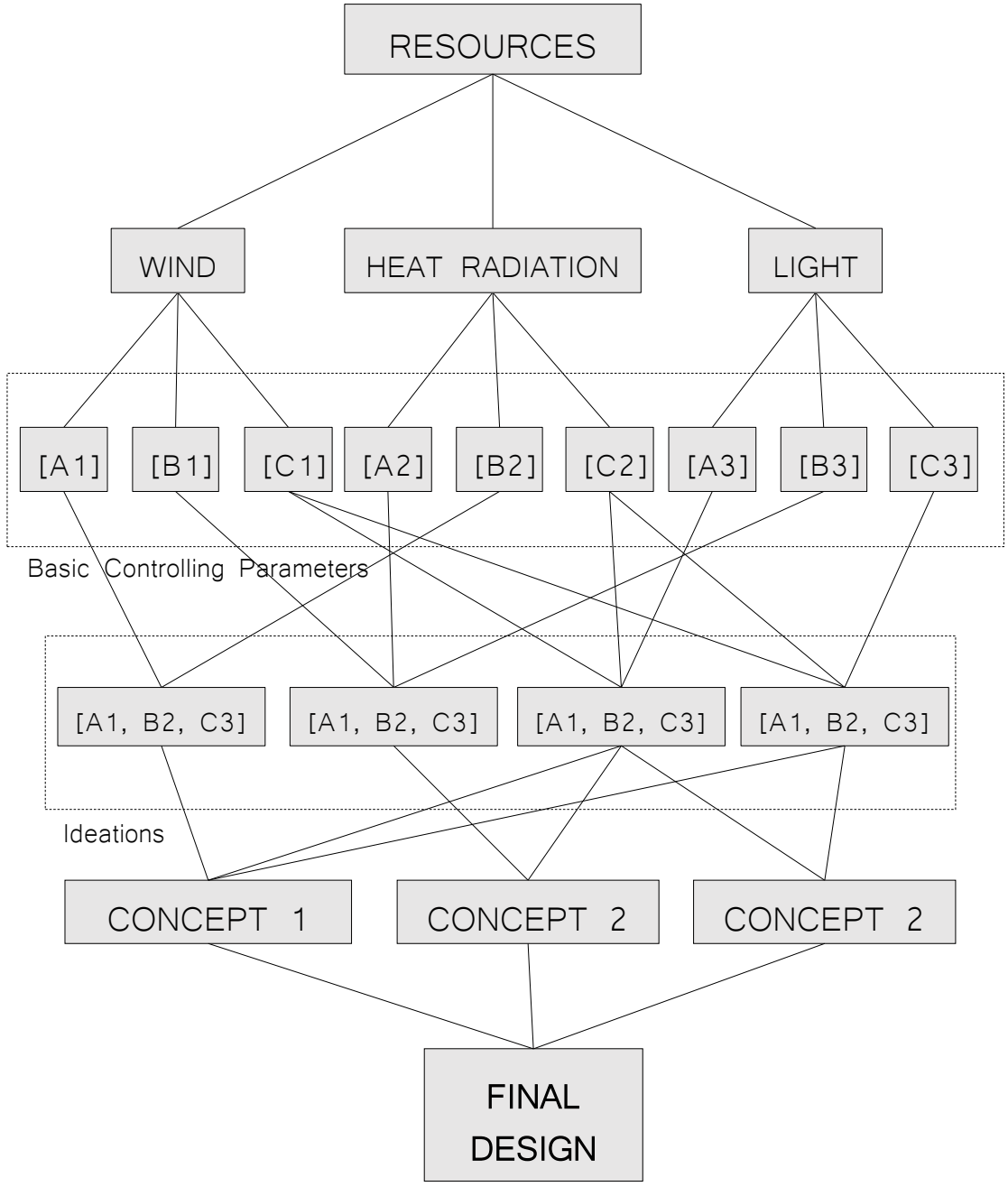
WORKSHOP BLOCK
GROUND FLOOR PLAN

DESIGN APPROACH

And after breaking down these two major element, we will get three parameters to control

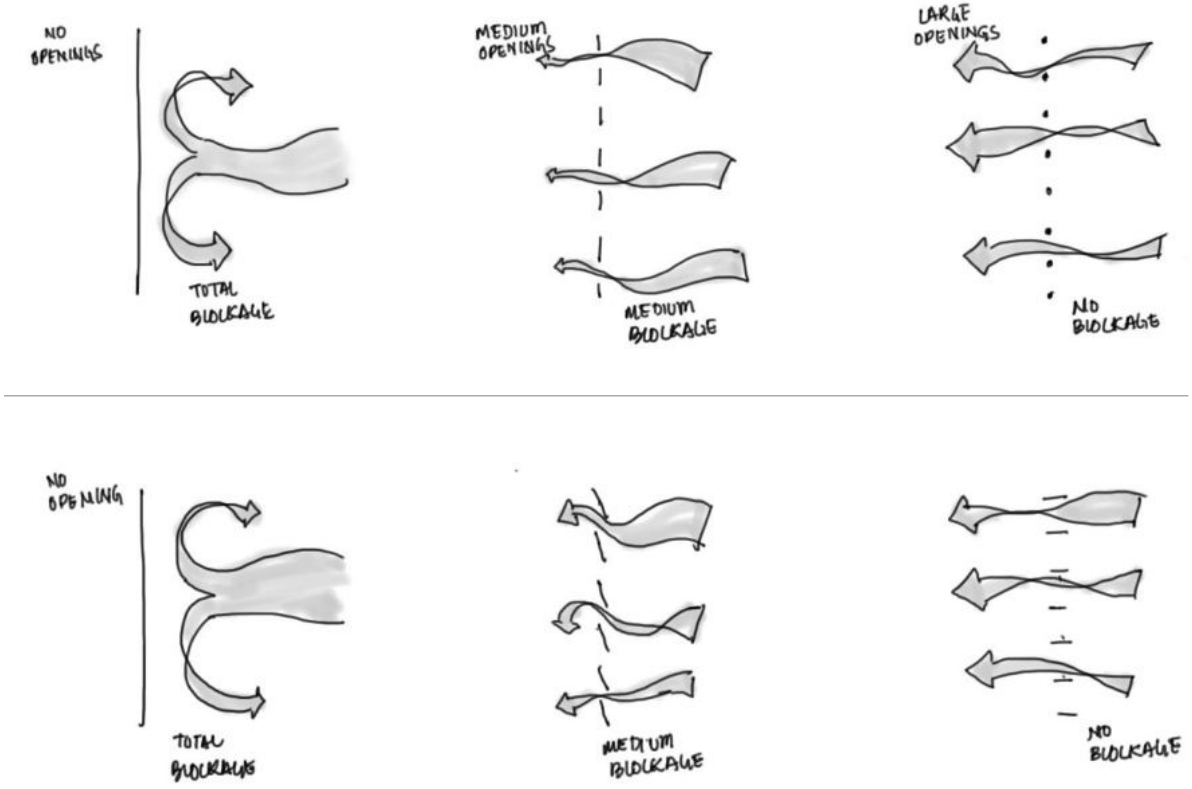
- Wind
- Heat
- Diffused light

Now these three parameters are considered and explored various basic ways to control each of them individually. By combining these ways and coming up with various solutions will generate a number of ideas, which can be further evaluated and finalized.



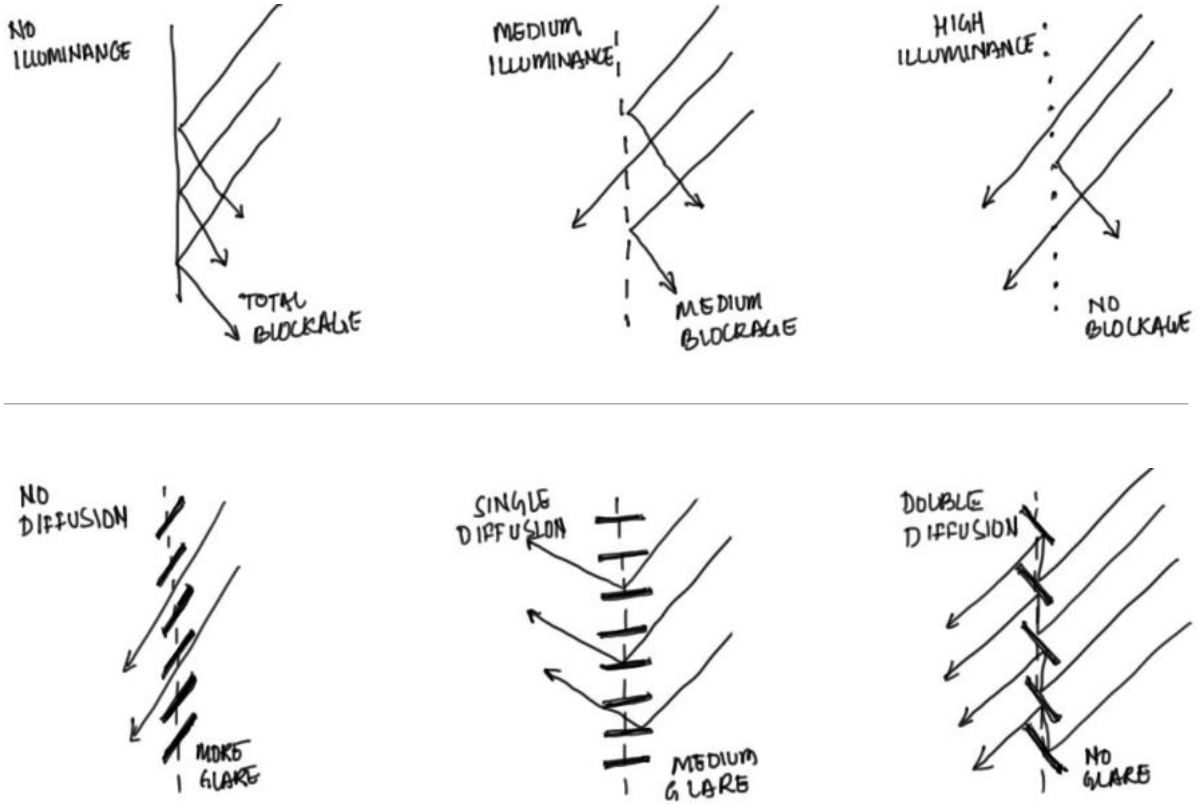
WIND

Wind can be controlled by simply regulating the openings of barrier; the more the openings, more is the air exchange between two spaces. During summers in hot regions there should be sufficient amount of air exchange and flow which helps to replace hot air in the space and also gives a cooling sensation when water evaporates from our body.



Light

Similar as wind, light can also be blocked by providing a screen and the amount can be adjusted by controlling the number and the size of perforations. Again direct glare is usually avoided for interior lighting of the buildings. Glare can again be controlled by changing the angle of the incident surface, which results in spreading and diffusing the concentrated light which is more desirable in interiors of office spaces.



HEAT RADIATION

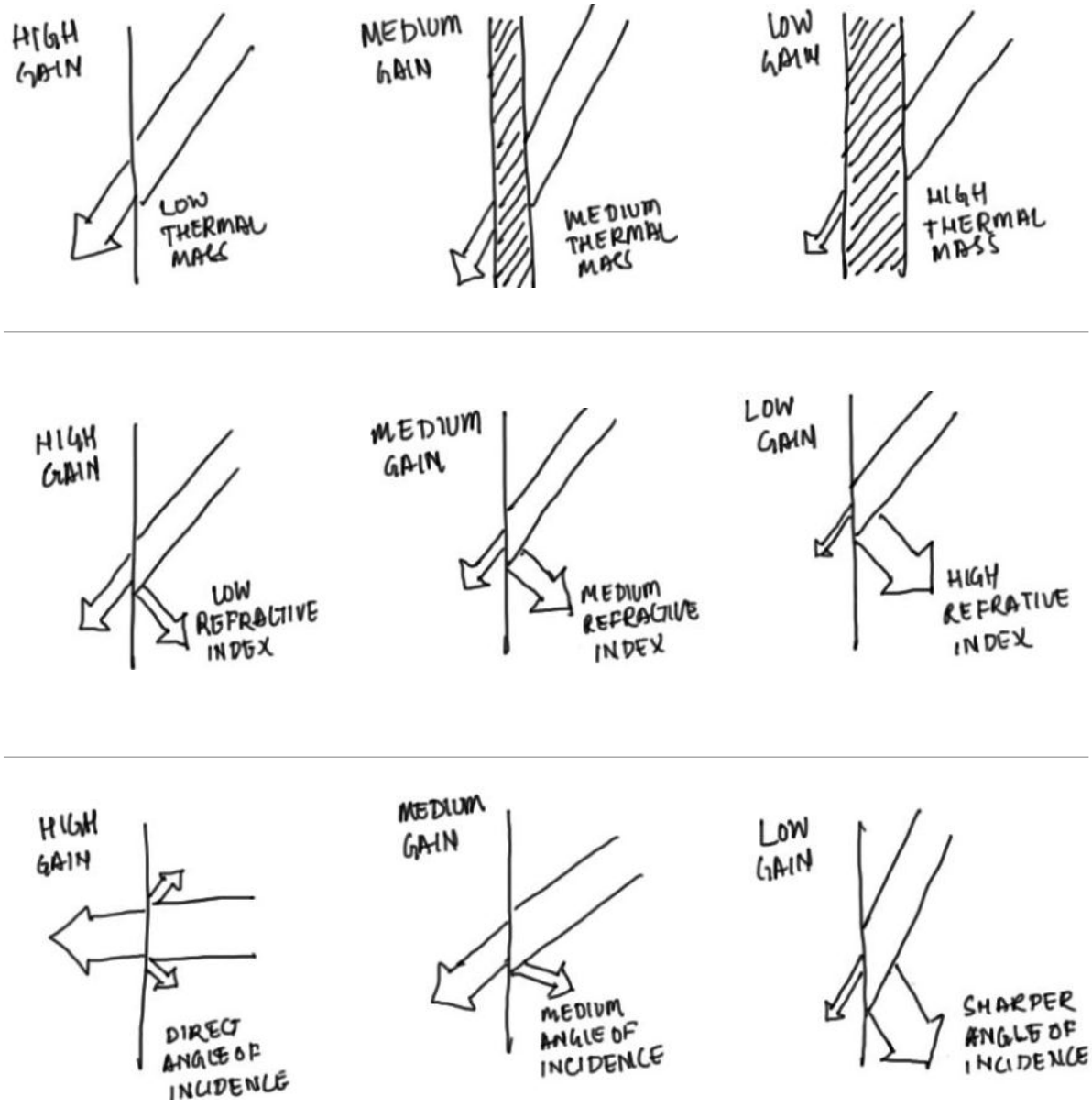
Heat or Solar Radiation depends upon the material on which the Sunlight is falling on. It can by controlled by various methods:

- Thermal Mass
- Refractive Index
- Angle of Incidence

By using materials with high thermal mass Solar radiation can be blocked. Since high thermal mass material absorbs the sunlight and doesn't allows the radiation to go on the other side.

Refractive Index is another parameter of controlling the solar gain inside. Materials with high refractive index can restrict the radiations to penetrate inside.

By regulating the orientation of the surface Angle of Incidence can be regulated which again affects the solar gain.



CHAPTER 06

IDEATIONS

IDEATION #1

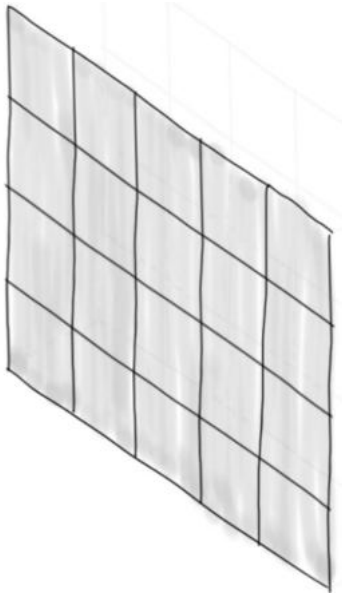
The ideation is developed by taking the inspiration from jaali where the air is cooled where the shade is and then then it gets replaced by warmer air.

Started with a simple plane and divided them into a grid-iron pattern, every alternate modules is again separated and aligned in another plane so that we can have gaps for air to get in.

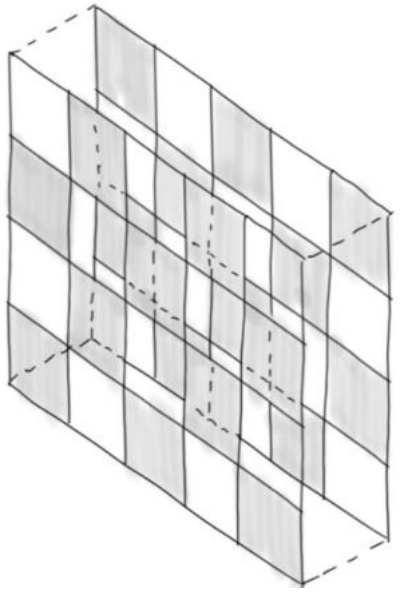
Now the gaps between the two planes can be adjusted to regulated the air flow. For example when the two plane are too close, its acts as surface with no perforations hence no air movement.

The plane can also move on along X,Y axis to adjust itself according to the direction of the sun-light and manipulate the amount of shade of should drop on the walls.

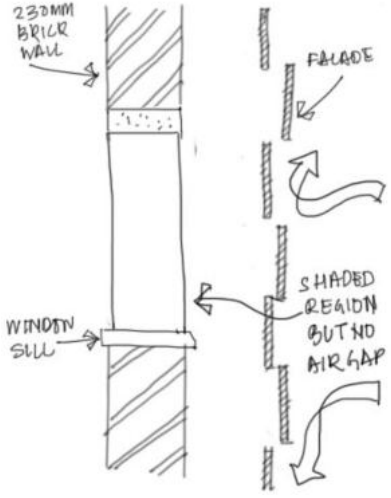
Due to the alternate arrangements of the panels the sunlight will get reflect internally and resulting diffused light.



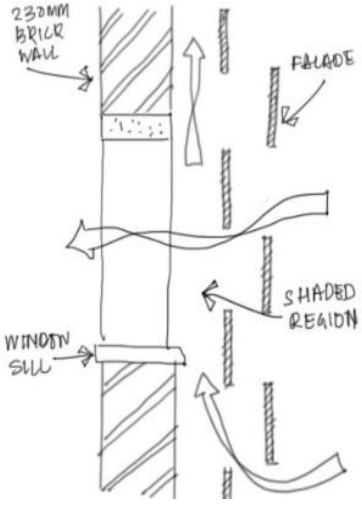
A simple rectangular frame further divided in grid-iron pattern



Alternate modules separated and aligned in another plane



Section of wall along with façade, showing no air-flow.



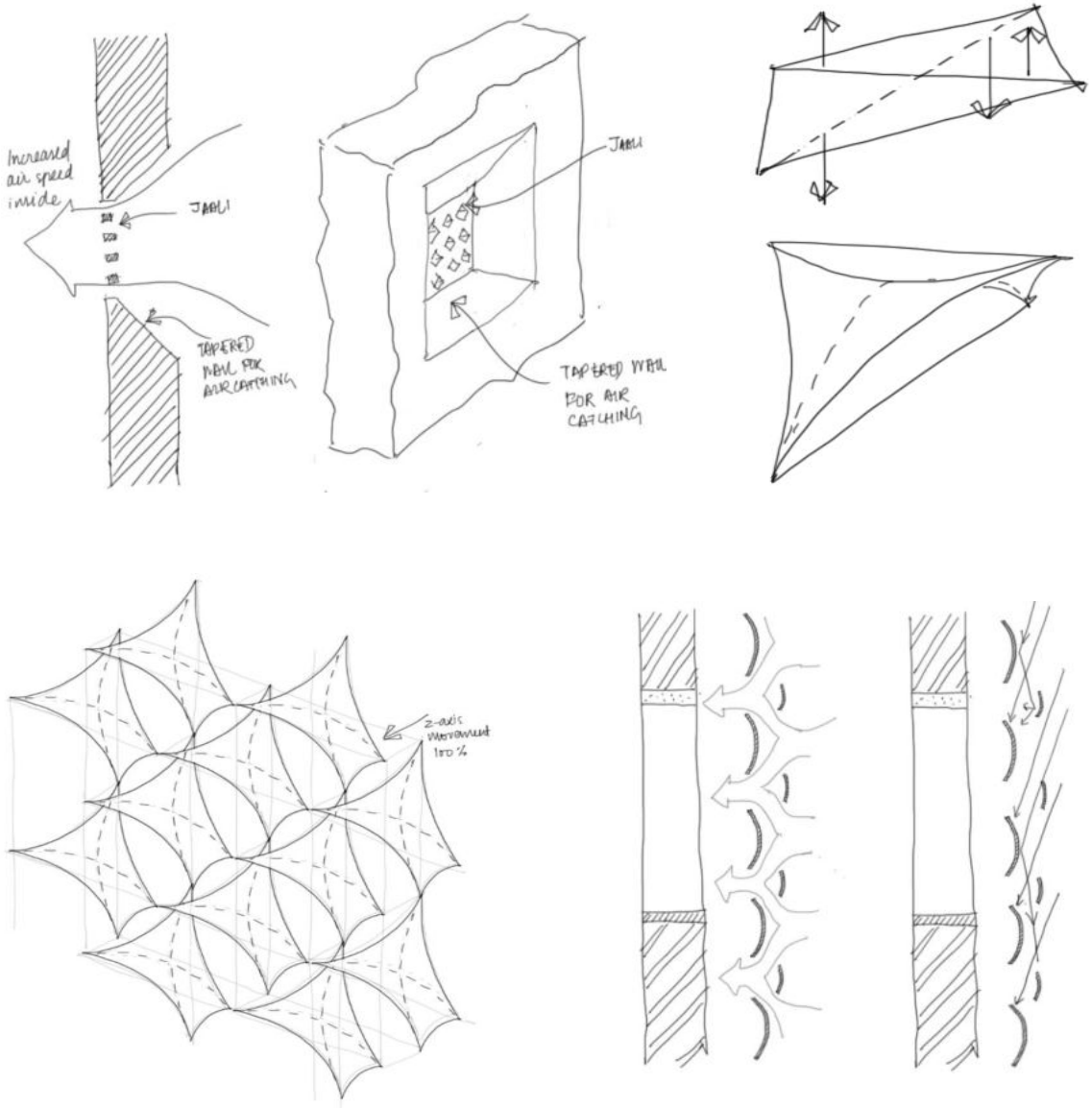
Section of wall along with façade, showing the air-flow.

IDEATION #2

This ideation is inspired by the Jhrokhas which is typically used in Rajputana and Mughal Architecture.

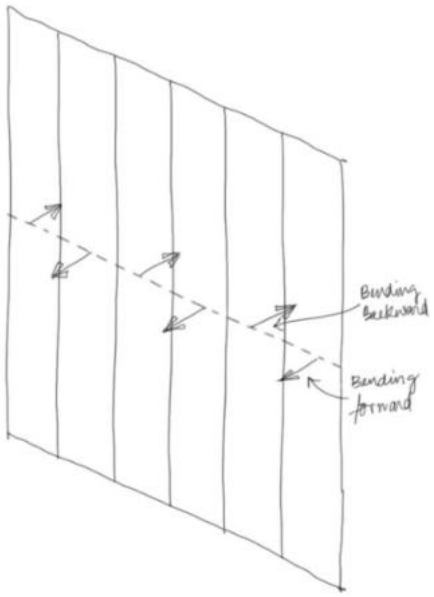
In this system the surface of the wall is tapered towards the opening of the window which acts as wind catcher. And since the area of the flow gets reduced air tends to increase its speed giving a comfortable sensation.

Took a square sheet which has tensile properties and pulled the alternate corners in to two opposite directions that makes a hyperbolic-paraboloid. Now these modules are rearranged in a grid system. Since the alternate corners of each modules are connected to two different planes, the whole system can be arranged on two different grids and we can regulate the distance between the two.

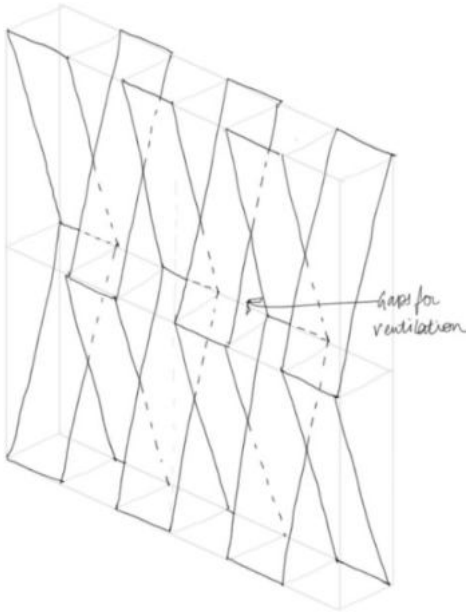


IDEATION #3

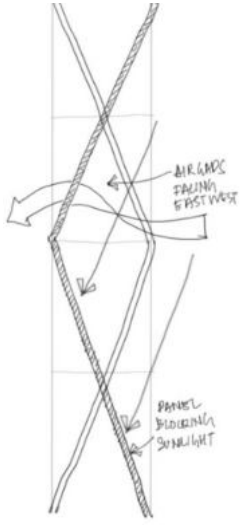
The idea is inspired from origami. A plane is divided into several vertical components and can be made bent at the middle of each component at the middle alternatively creating air gaps facing east and west sides. And the sunlight are blocked by the vertical components. Since the average wind flow direction of Gandhinagar is south-west, the gaps in the system facing east west direction will help the air to flow very effectively.



No displacement of z-axis, hence no gaps for air-flow



displacement of z-axis, hence results air-flow



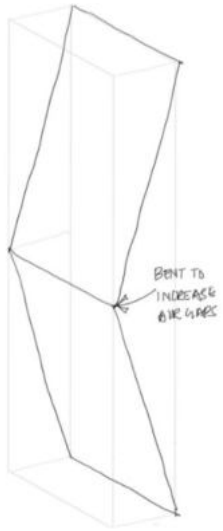
More displacement of z-axis, hence More gaps.

Less displacement of z-axis, hence less gaps.

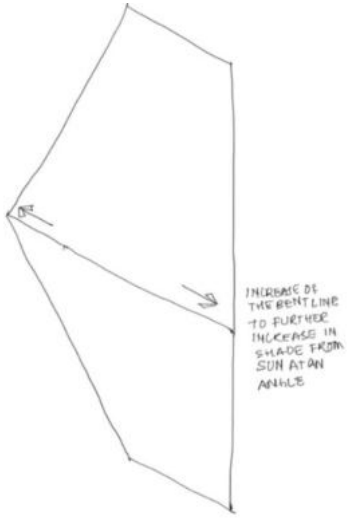
IDEATION #4

This Ideation is the alteration of previous ideation. The bent line was increased on width which resulted a basic rectangle to transform in to a hexagon. By doing this the light penetration gap is reduced for the sunlight which are at angle hence more shade, and air gap is the same as previous.

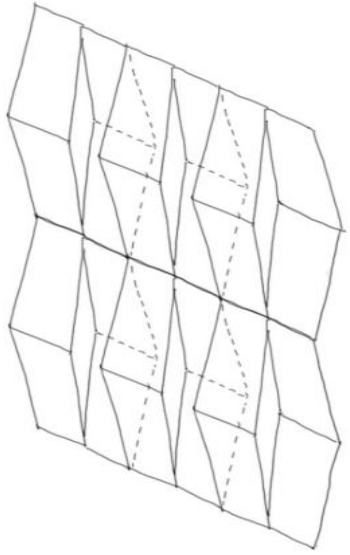
No displacement of z-axis, hence no gaps for air-flow



displacement of z-axis, hence results air-flow



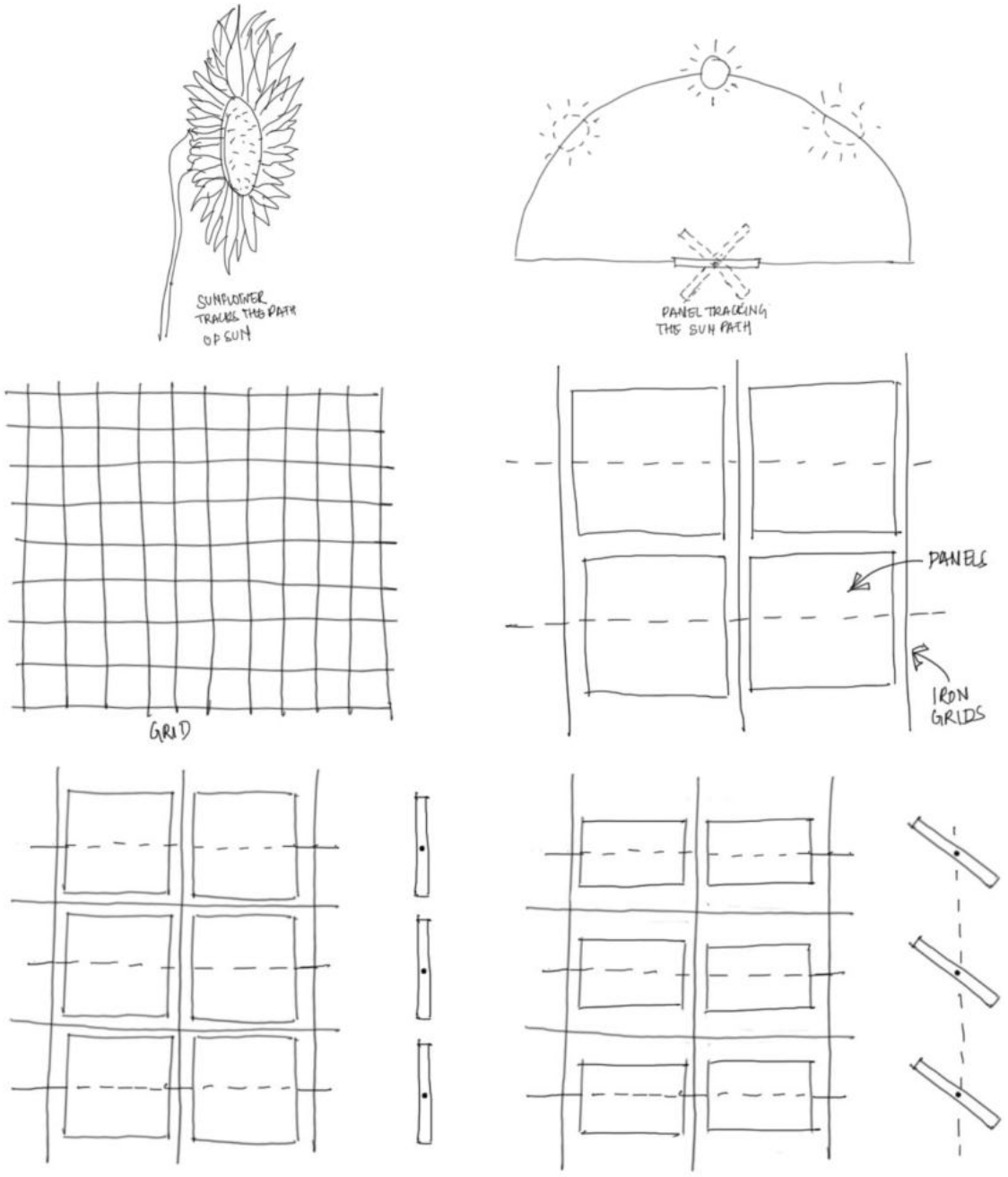
The length of bending lines increased resulting more shading



More shade than the previous ideation

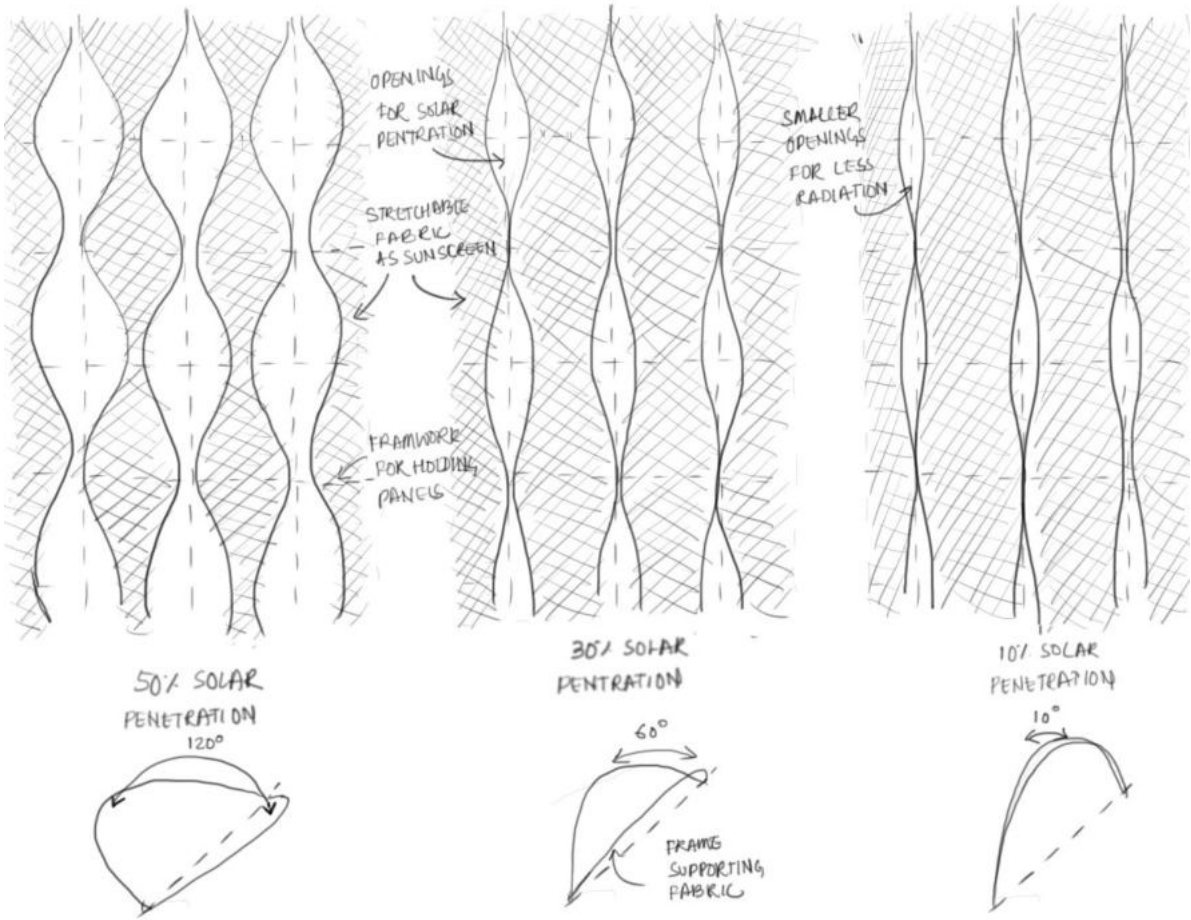
IDEATION #5

Heliotropism, a form of tropism, is the diurnal motion or seasonal motion of plant parts (flowers or leaves) in response to the direction of the sun.
The ideation is inspired from the above concept. The panels in the façade tracks and faces the sun blocking the radiations during summers and does the opposite in winters.



IDEATION #6

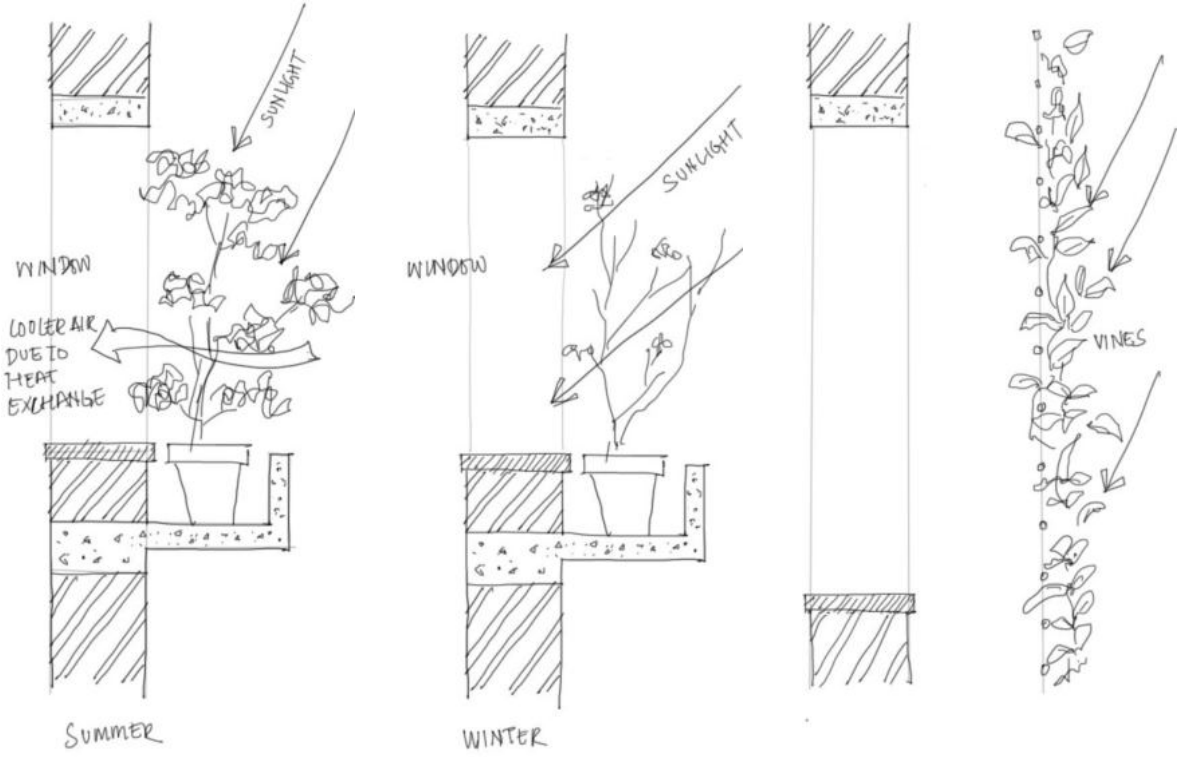
Inspired by the idea of Venus Flytrap, how they open and closes to catch an insect. Each module has a frame consist of two semicircular members hinged in an axis. And these frames holds a stretchable membrane which will act as a screen for blocking sun radiation. These modules opens and closes according to the light and heat requirements.



IDEATION #7

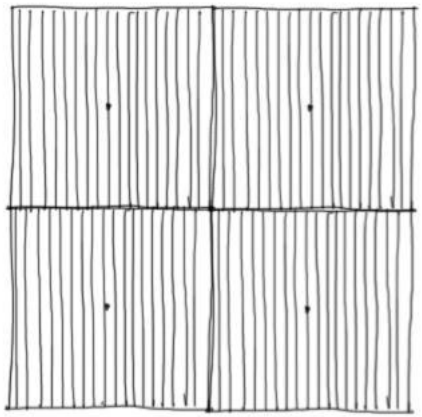
By planting vegetation throughout façade can give a efficient control of interior climate according to the change of season.

During summer these plants blocks solar radiations by its foliage and during winters these plants shade their leaves which allows solar penetration that results in the increase of internal temperature.

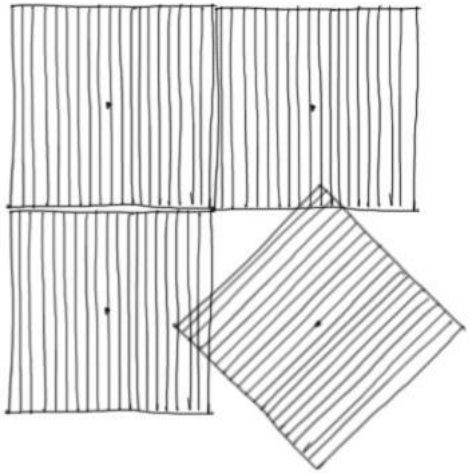


IDEATION #8

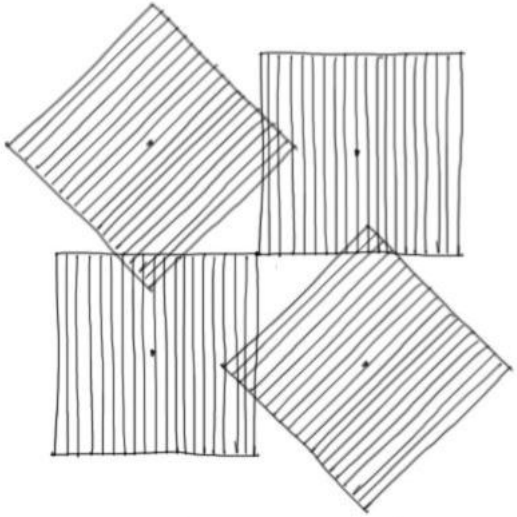
These panels can be rotated along the axis which is at the center of itself. By variations in rotation angles the façade can regulate the amount of light and wind flow.



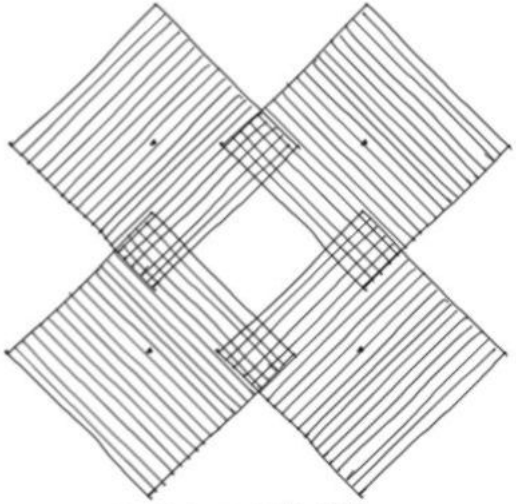
0% SUN AND WIND PENETRATION



12% SUN AND WIND PENETRATION



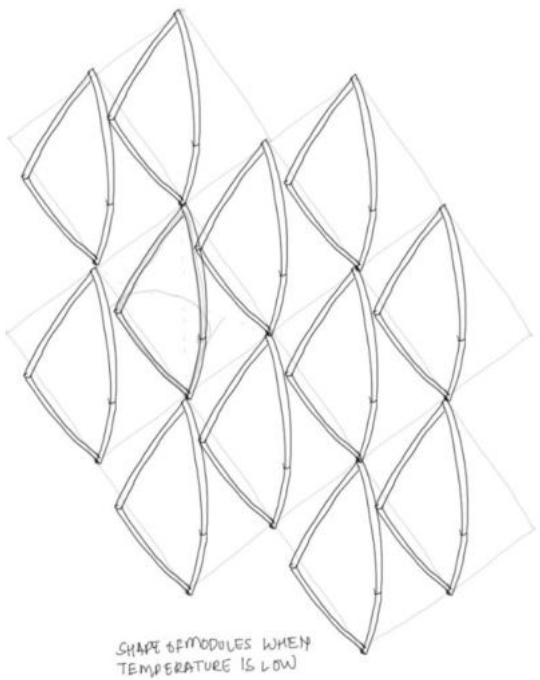
25% SUN AND WIND PENETRATION

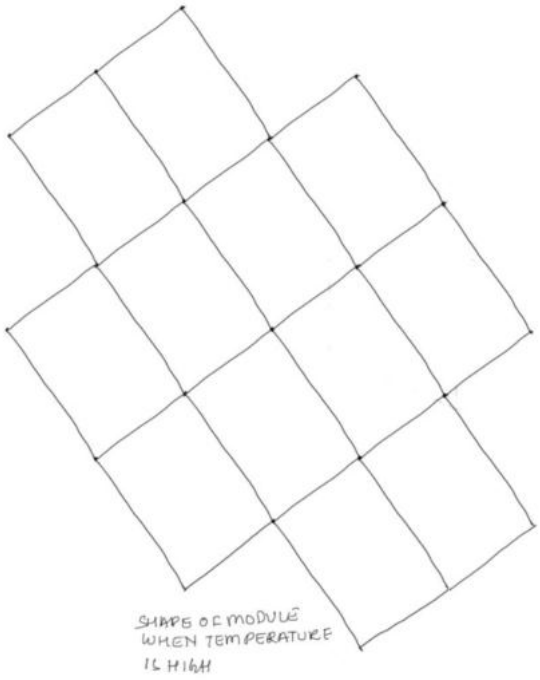


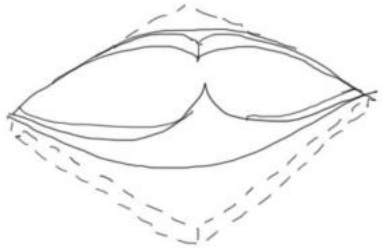
50% SUN AN WIND PENERATION

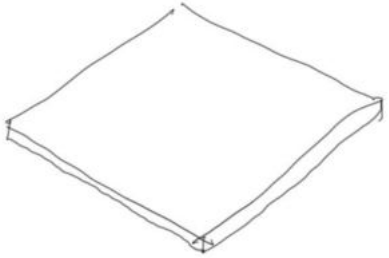
IDEATION #9

By use of bimetallic material the shape of the modules can be changed. In this ideation I have used flexible material and it has been reinforced with Nitinol wires. So these are memory wires and can retain their original shape when exposed to small amount of heat.









CHAPTER 07

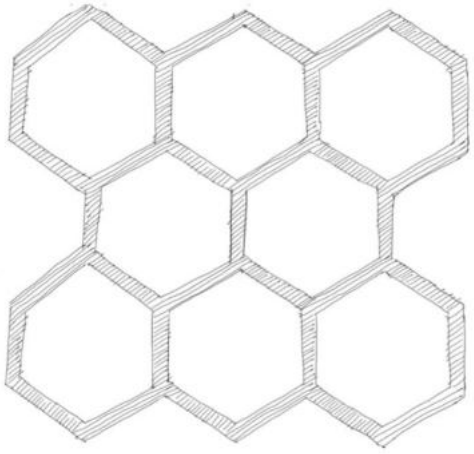
CONCEPTS

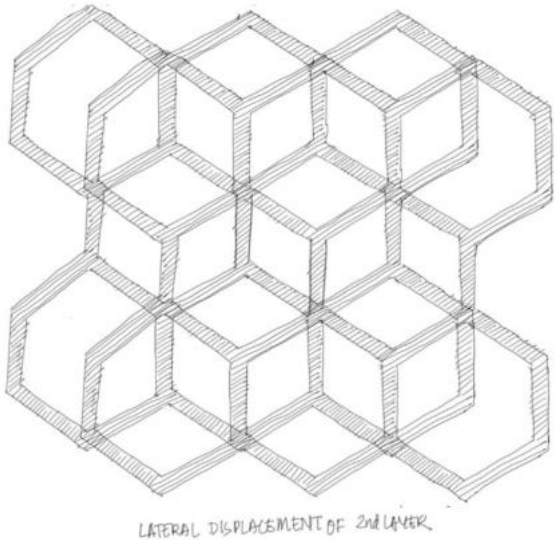
The champion ideas were selected and developed to understand the potential of those as per the requirements.

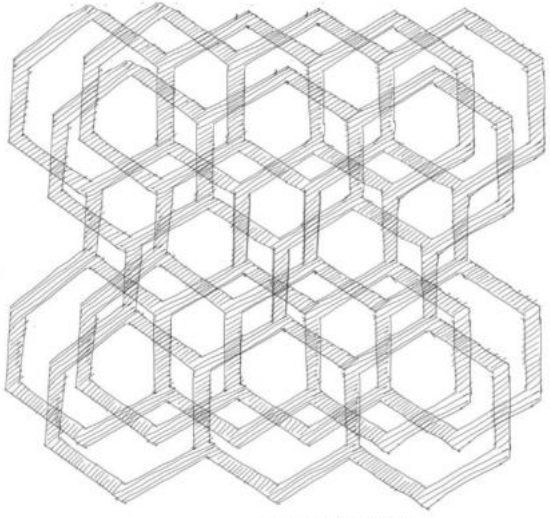
Concept 01
Concept 02
Concept 03

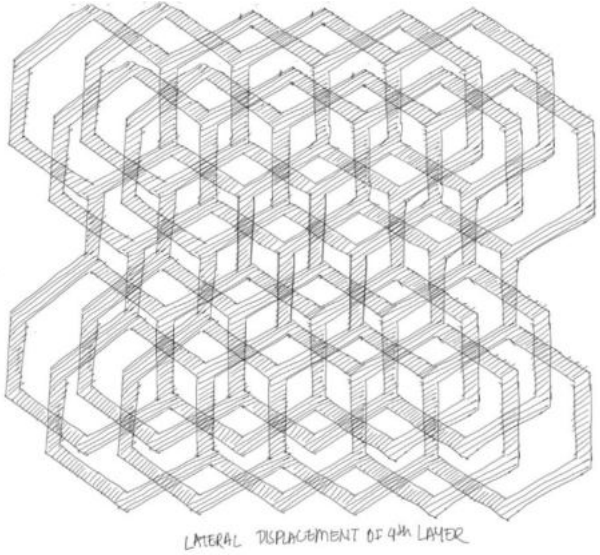
CONCEPT #01

The concept is evolved from ideation 01, which inspired by Jaali.
There are four layers of the lattice screens one behind other. When these screens moves laterally on their respective planes individually, they create interesting patterns and also regulates the gaps to light and air to get in. the facade can adapt itself according to the climatic conditions outside. For example when the humidity is high the gaps opens up to the maximum such that their will be more air movement. And gaps are small when do not want light and air exchange.

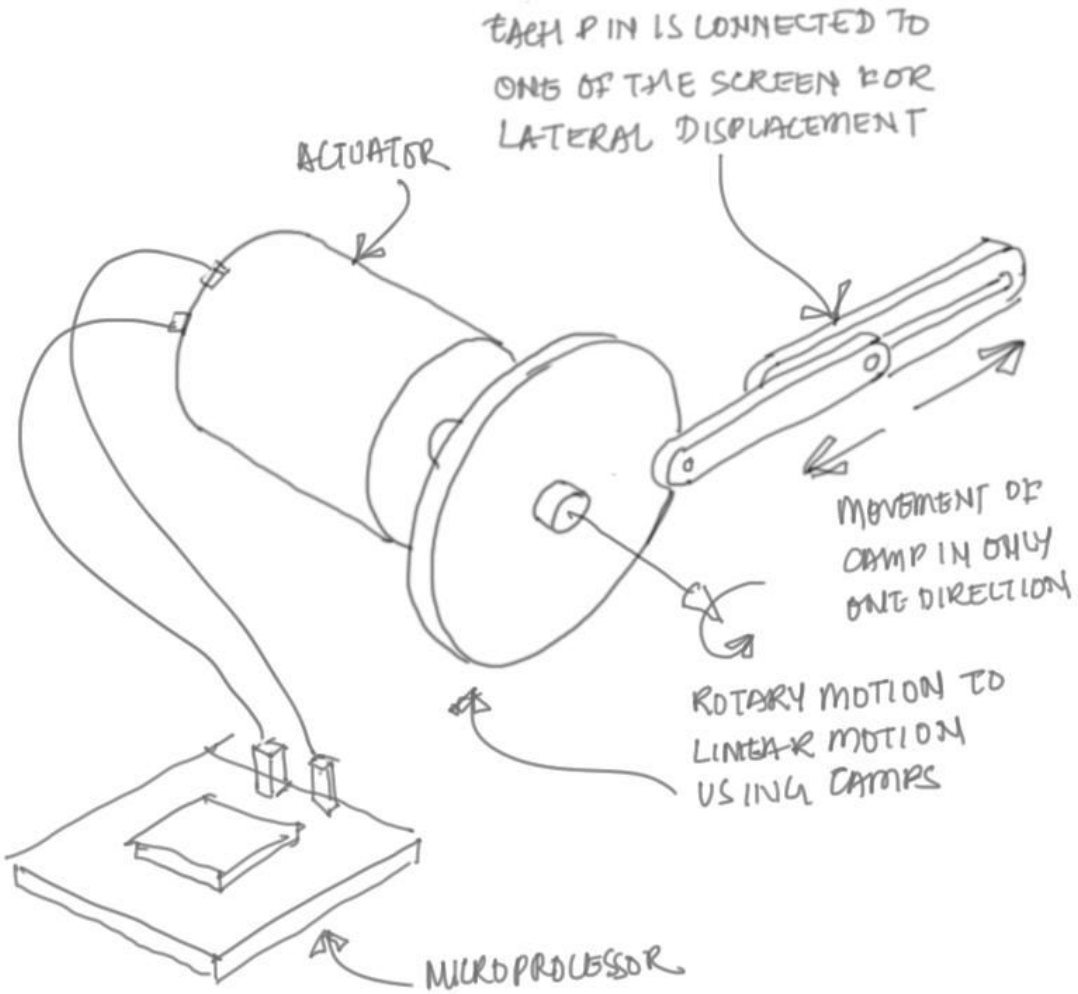


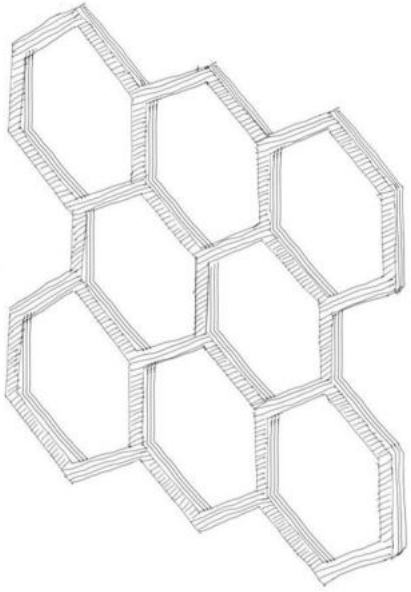




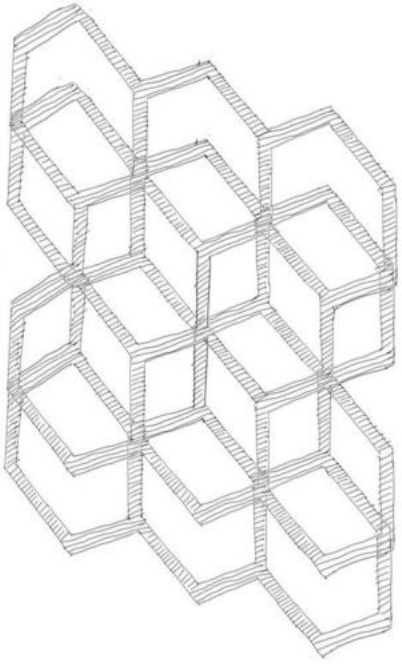


The screens are moved laterally by the help of an actuator, where the rotational motion is converted to liner motion. Even all the four screen can be connected to a single actuator. A slight rotation can result different patterns on the facade with variations of openings.

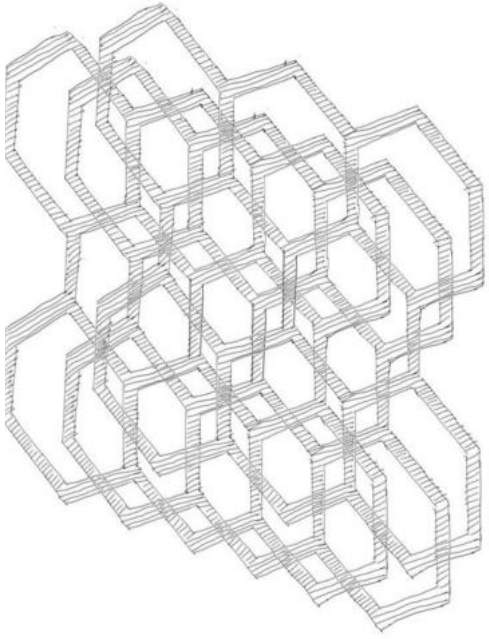




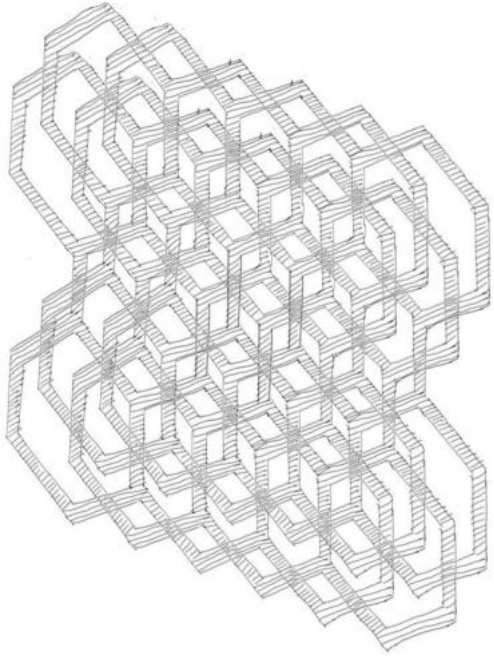
When all four screens aligned, maximum gaps and air flow



When one screen is displaced, increased the shading area twice as previous.



When two screens are displaced, increased the shading area thrice as previous.



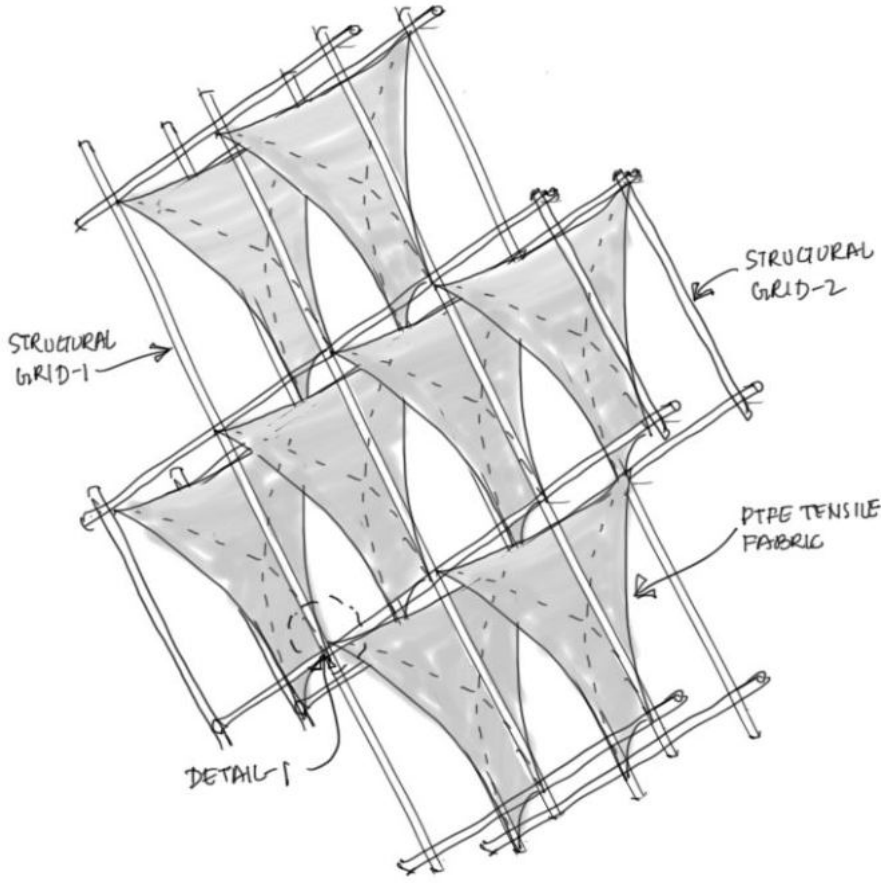
Maximum shading area and minimum air gaps when all are displaced and not aligned.

CONCEPT #02

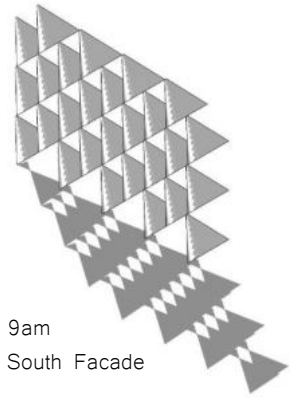
The concept is evolved from ideation 2. Since the alternate corners of each modules are connected to two different planes, the whole system can be arranged on two different grids and we can regulate the distance between the two.

By varying the distance between the two grids amount of light and air can be regulated.

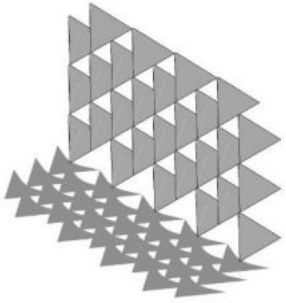
Because its a double layered structure, a good quality of diffused natural light is possible inside.



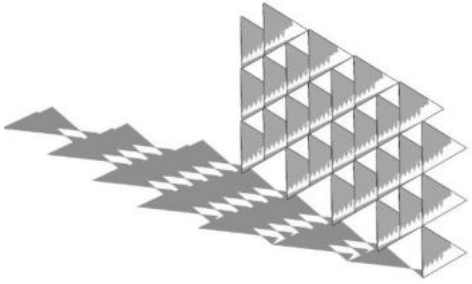
STRUCTURAL GRID-1



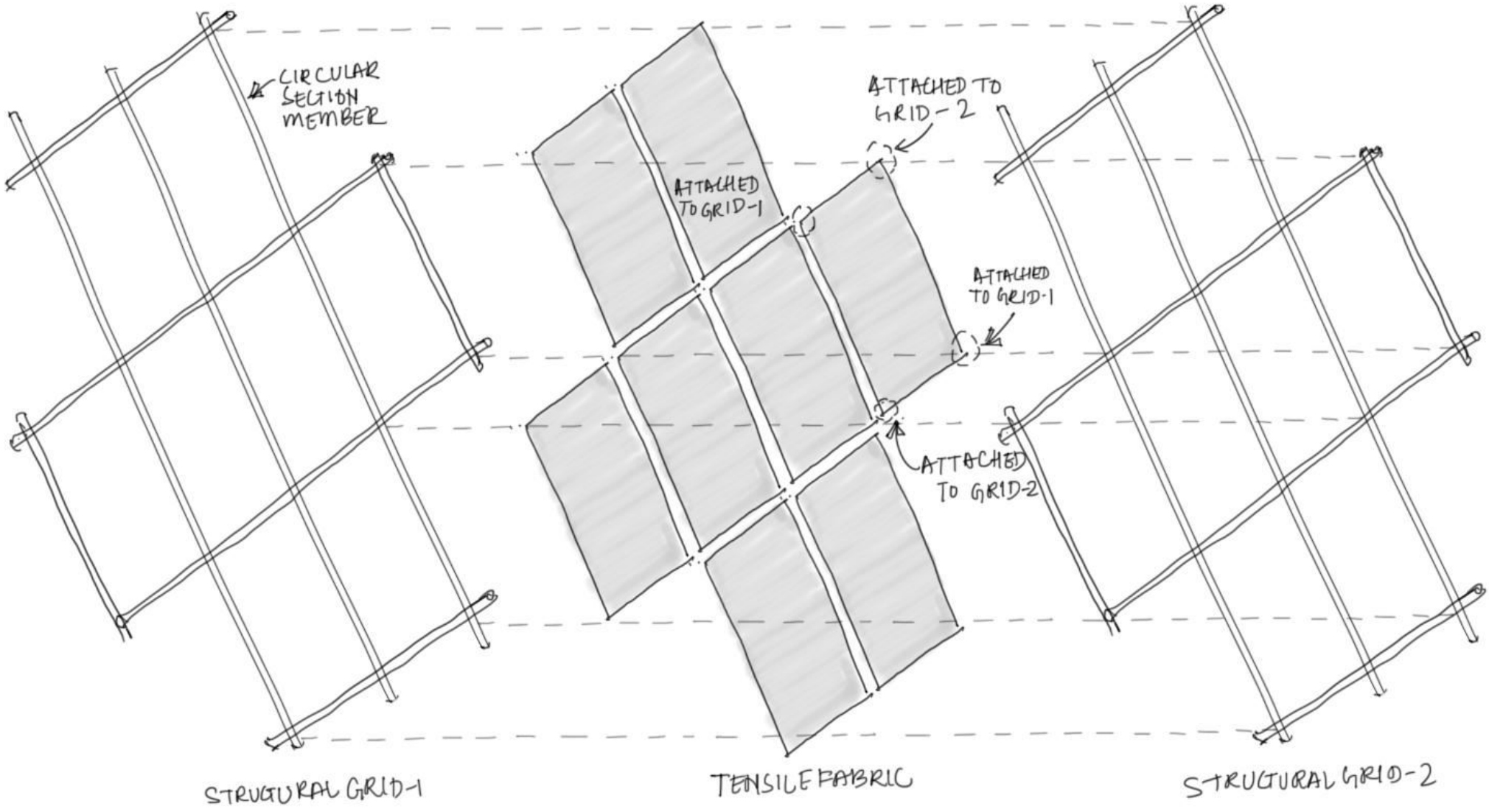
9am
South Facade

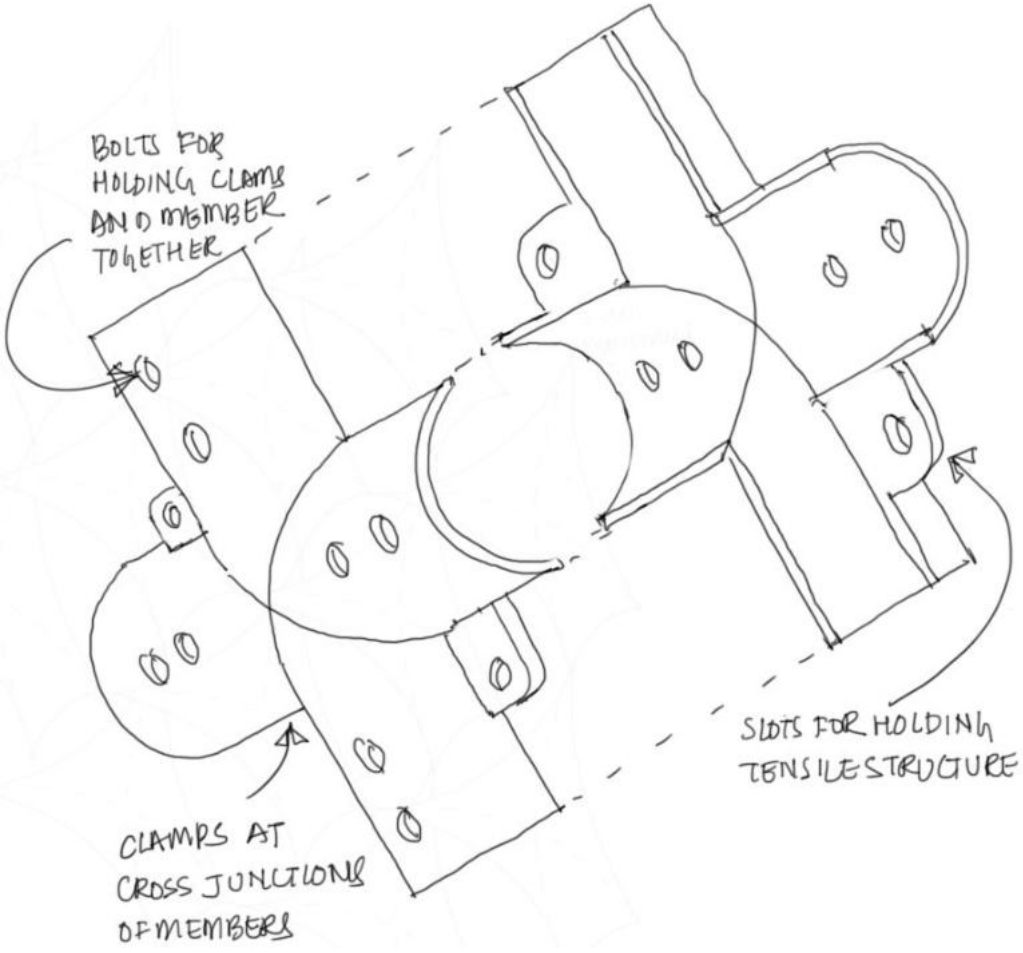


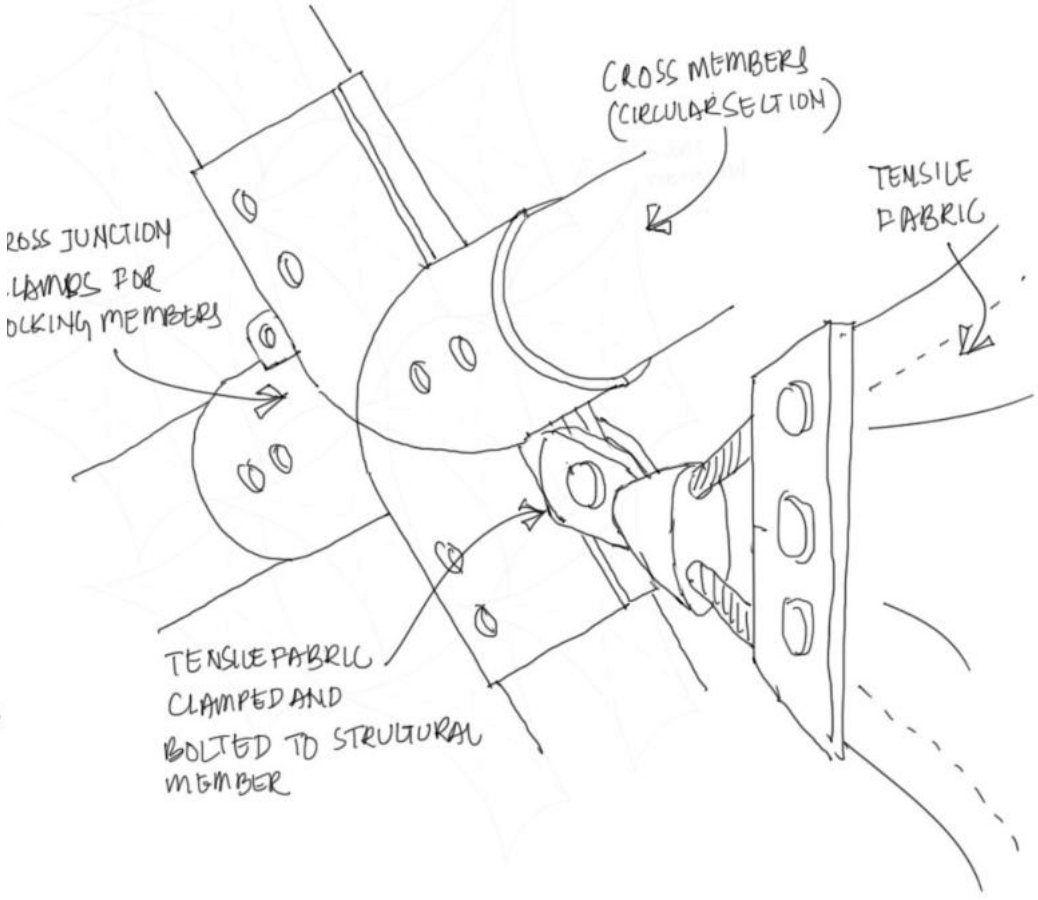
12pm
South Facade



3pm
South Facade

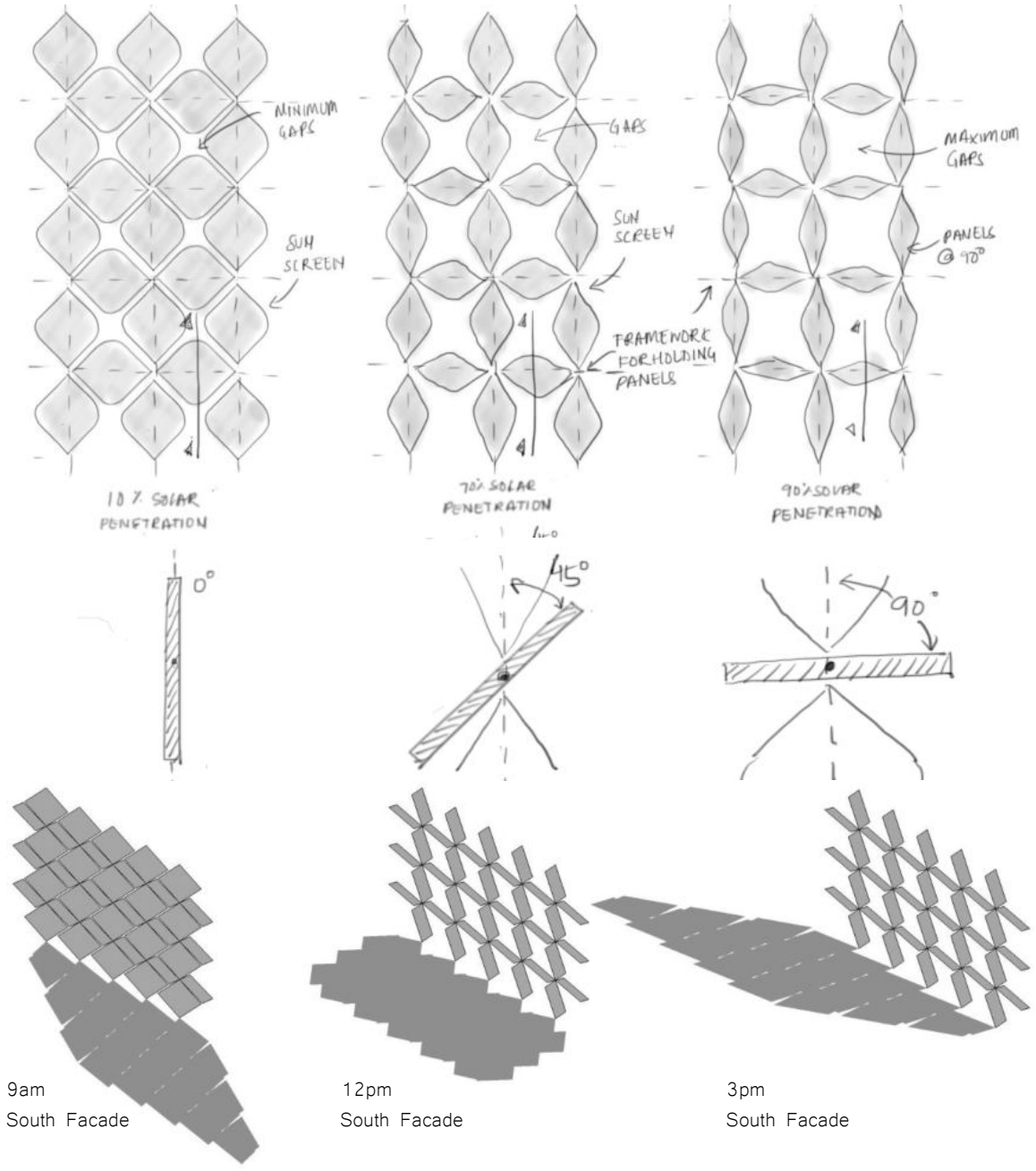

CIRCULAR SECTION MEMBER
ATTACHED TO GRID-2
ATTACHED TO GRID-1
ATTACHED TO GRID-1
ATTACHED TO GRID-2
STRUCTURAL GRID-1
TENSILE FABRIC
STRUCTURAL GRID-2

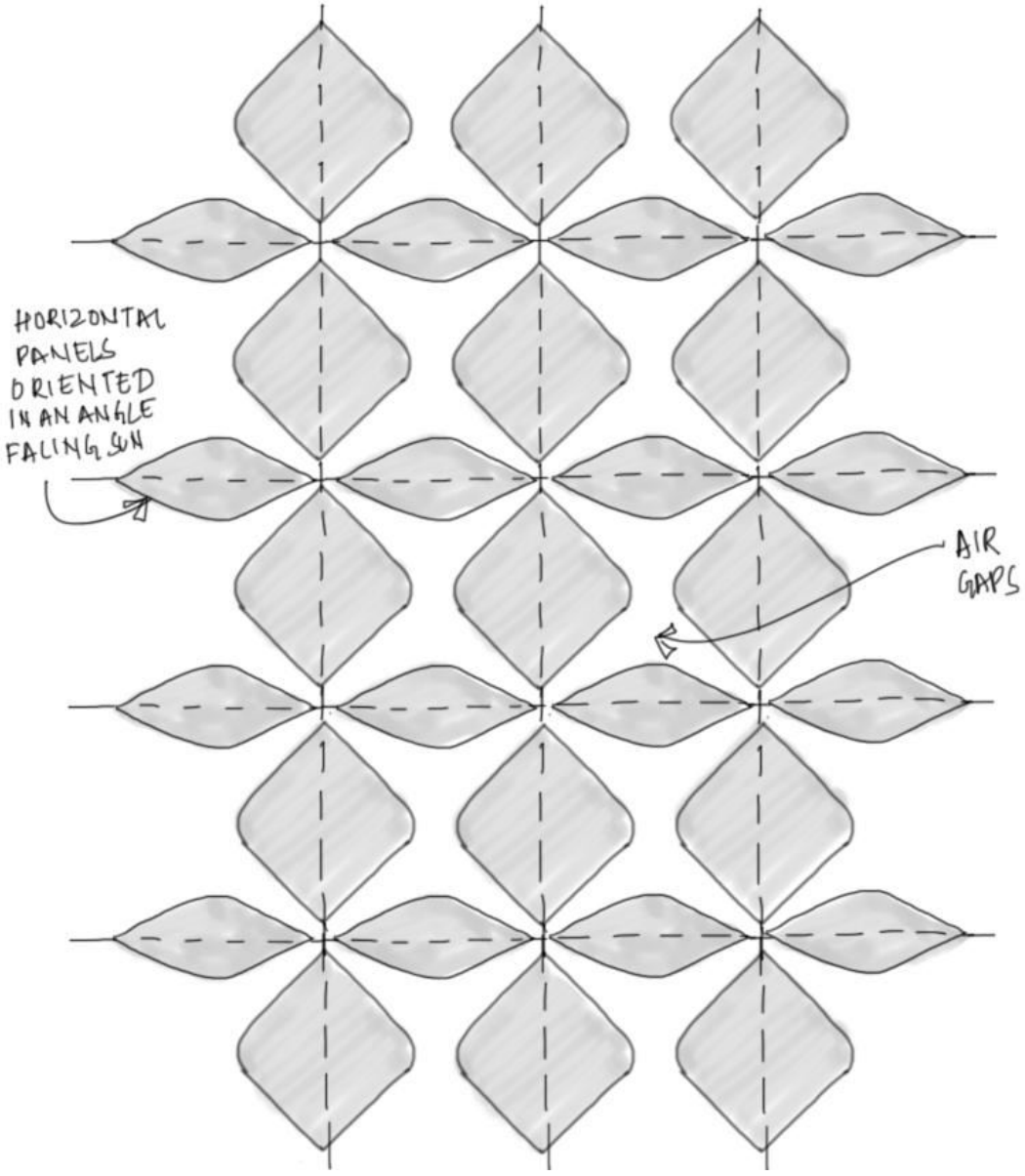

BOLTS FOR HOLDING CLAMPS AND MEMBER TOGETHER
SLOTS FOR HOLDING TENSILE STRUCTURE
CLAMPS AT CROSS JUNCTIONS OF MEMBERS

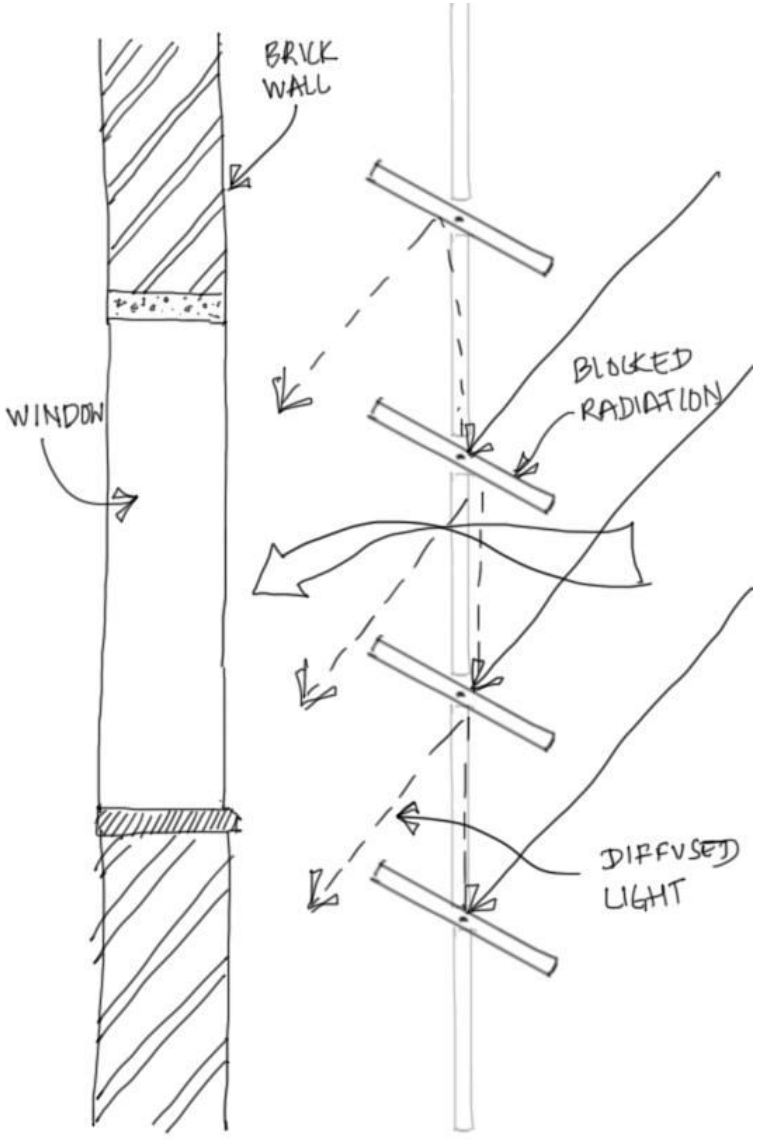

CROSS MEMBERS (CIRCULAR SECTION)
TENSILE FABRIC
TENSILE FABRIC CLAMPED AND BOLTED TO STRUCTURAL MEMBER

CONCEPT #03

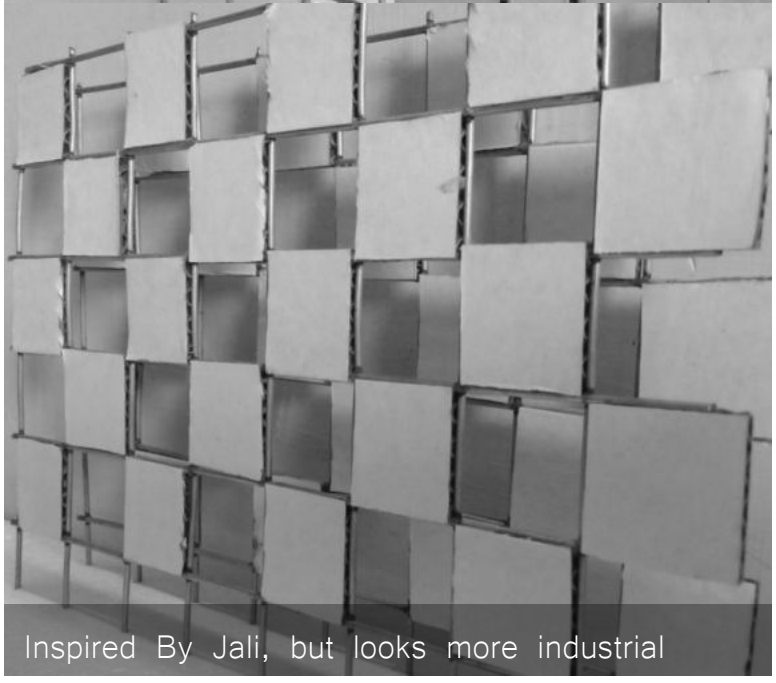
The concept is inspired by the ideation 5, and is an evolution of the previous one. The concept id based on the idea of Heliotropism. In this system the panels are arranged in crisscrossed pattern and it's a series of rows and columns, in which each column and row can individually rotate. The columns tracks the horizontal displacement of sun and rows tracks the vertical displacement of sun. Both making different patterns together and 100% shade throughout the day.



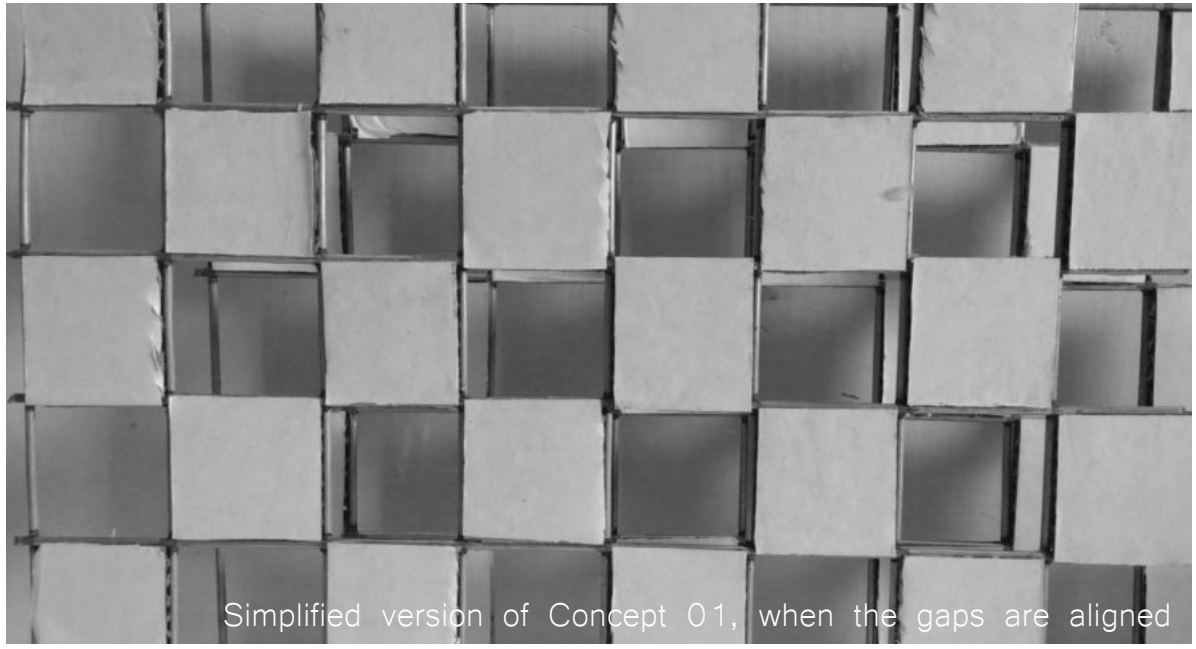

HORIZONTAL PANELS ORIENTED IN AN ANGLE FACING SUN
AIR GAPS


BRICK WALL
WINDOW
BLOCKED RADIATION
DIFFUSED LIGHT

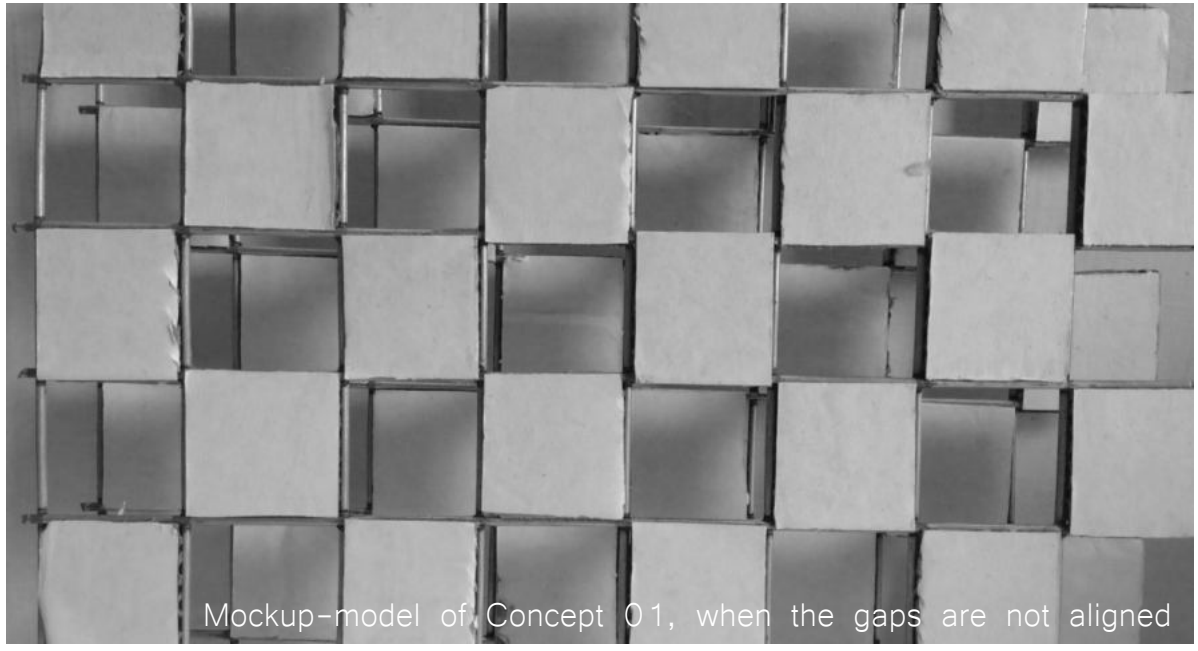
MOCK-UPS



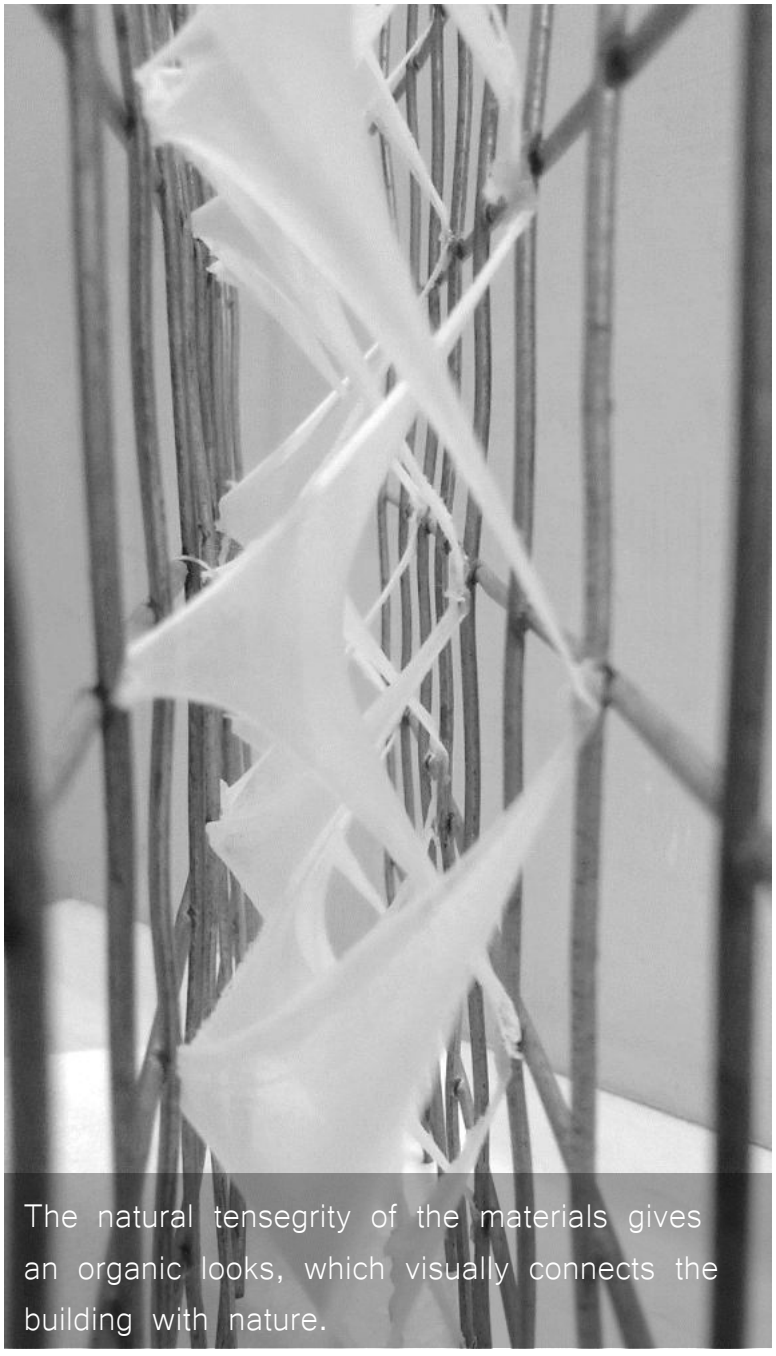
Inspired By Jali, but looks more industrial



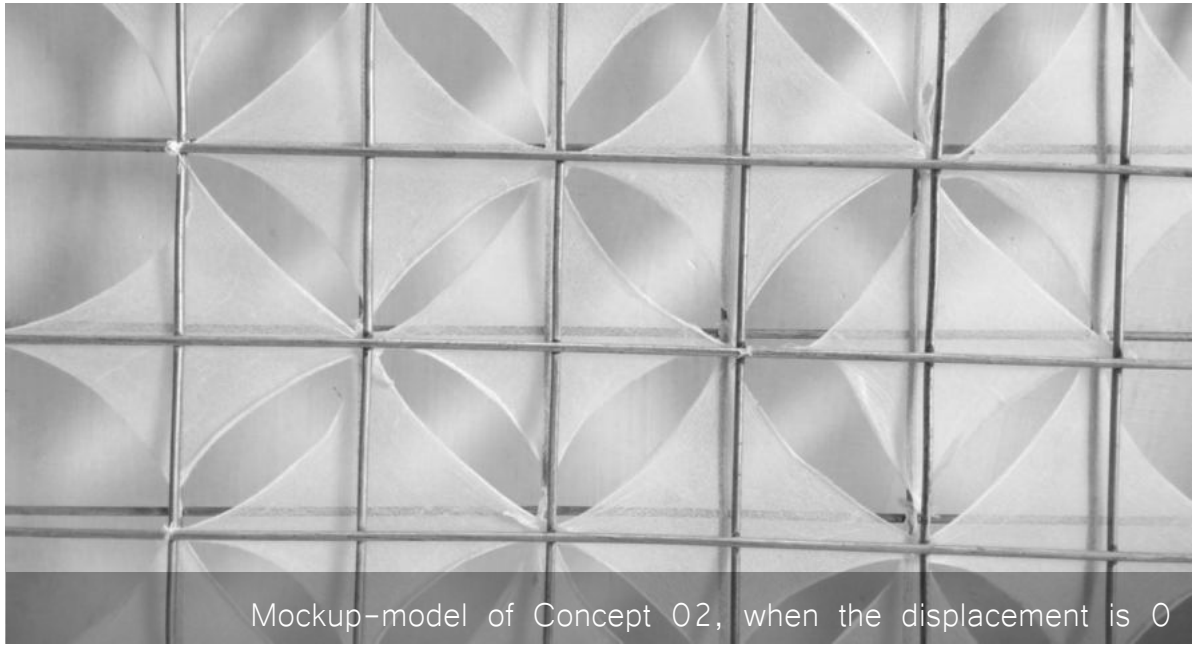
Simplified version of Concept 01, when the gaps are aligned



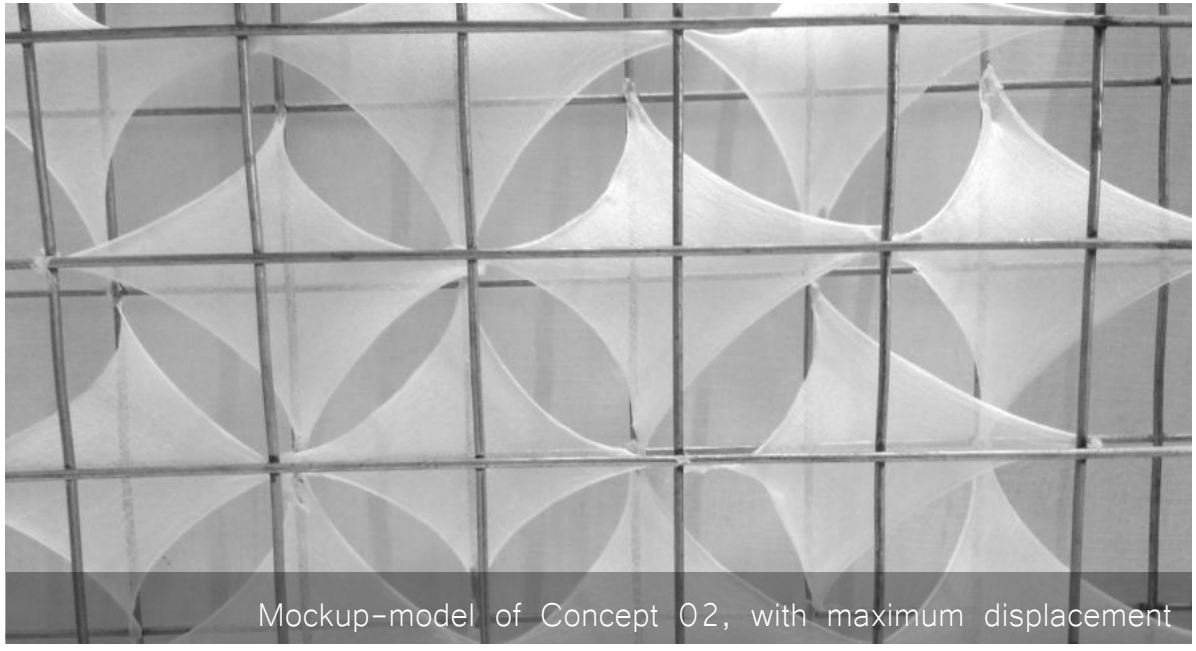
Mockup-model of Concept 01, when the gaps are not aligned



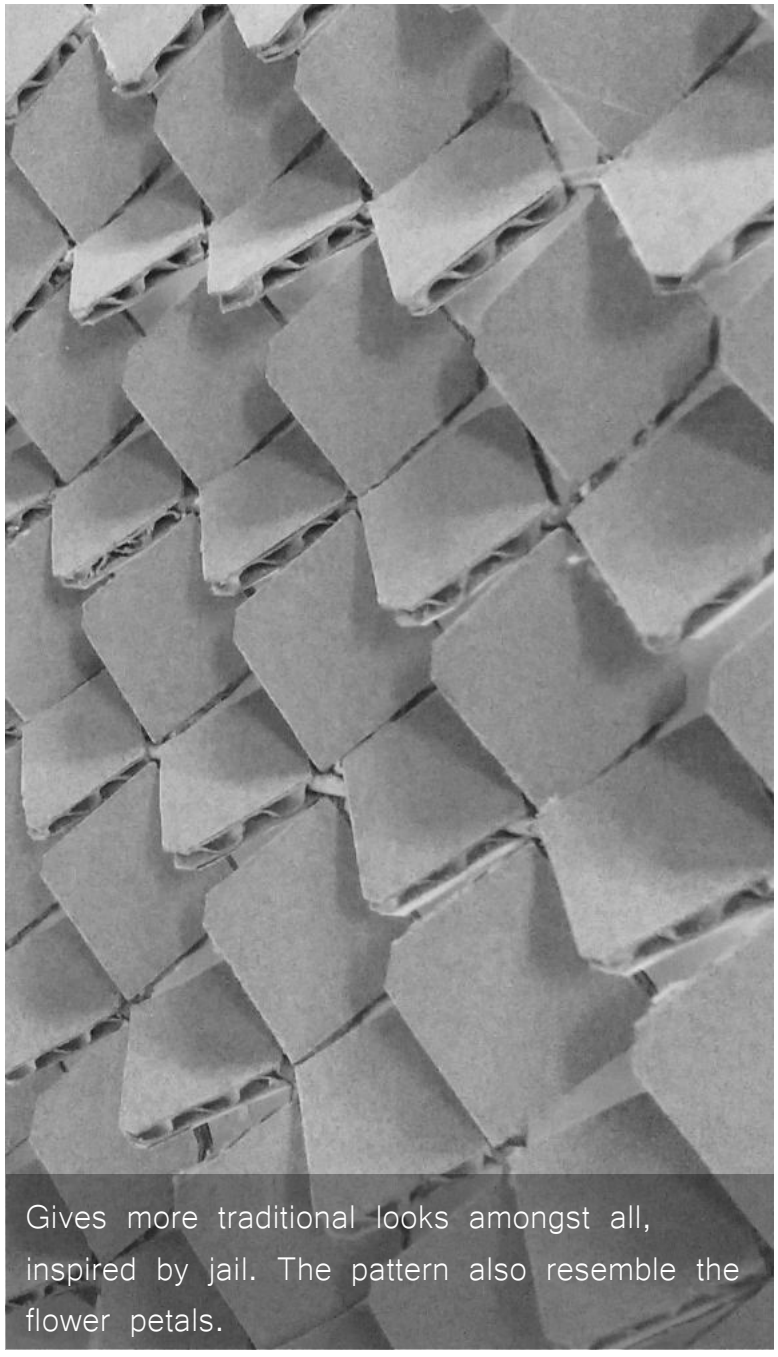
The natural tensegrity of the materials gives an organic looks, which visually connects the building with nature.



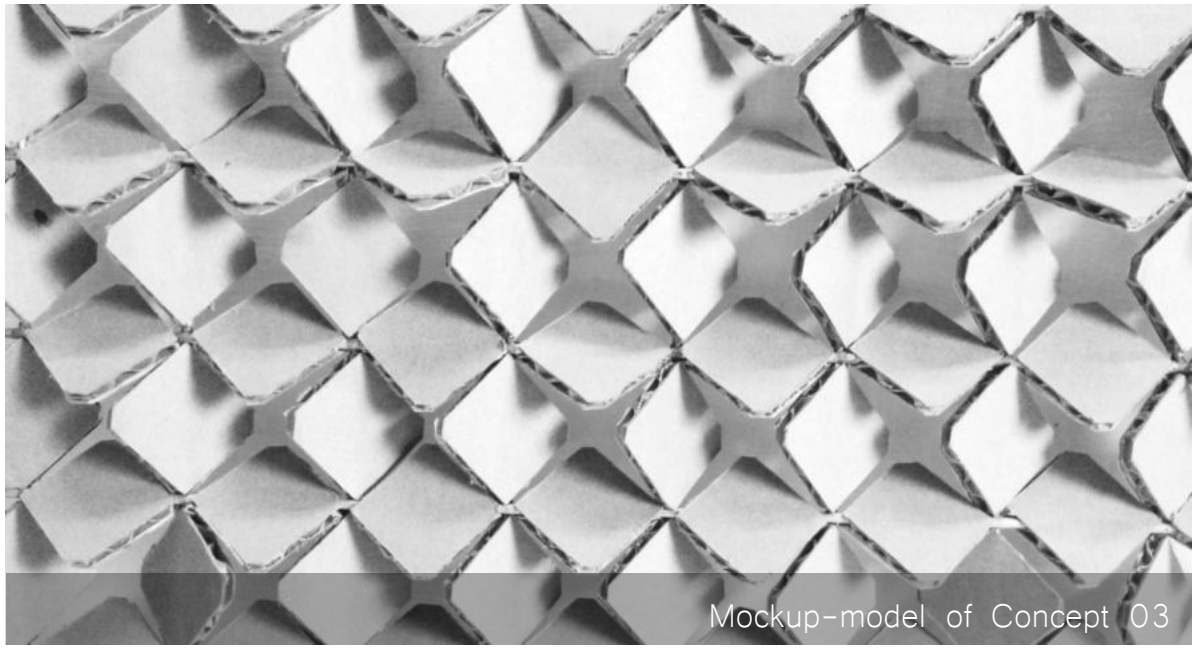
Mockup-model of Concept 02, when the displacement is 0



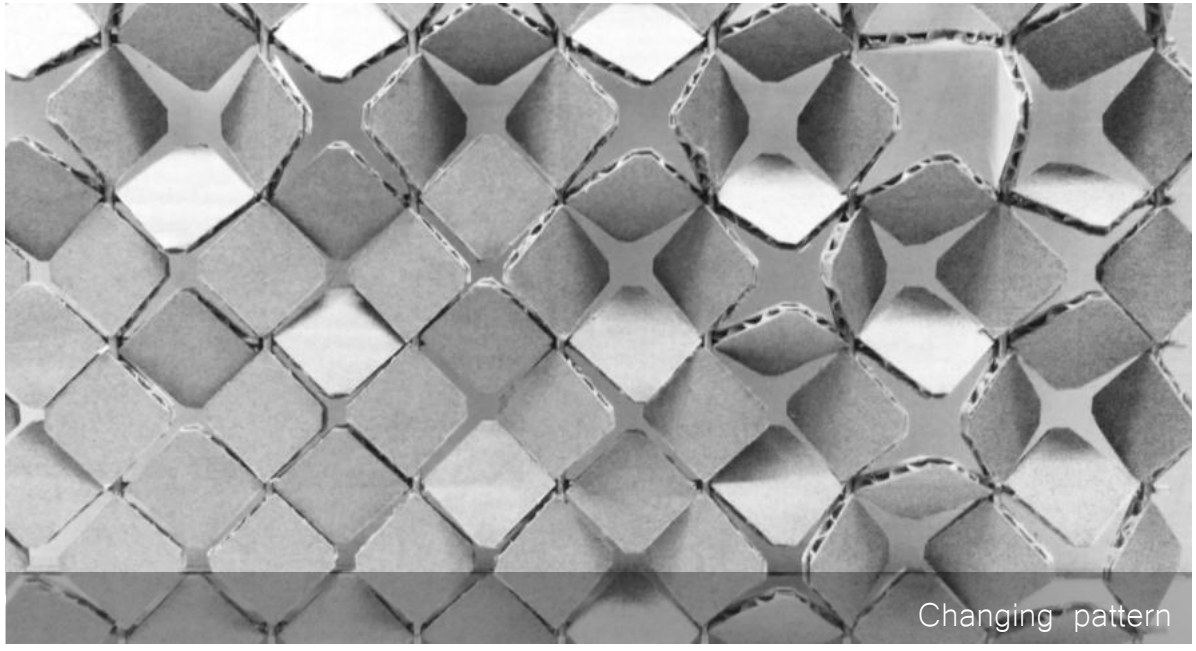
Mockup-model of Concept 02, with maximum displacement



Gives more traditional looks amongst all, inspired by jail. The pattern also resemble the flower petals.



Mockup-model of Concept 03



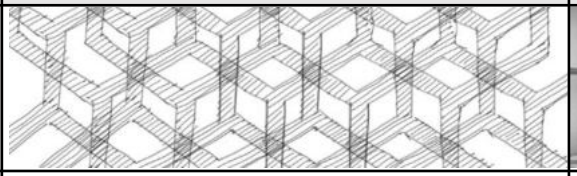
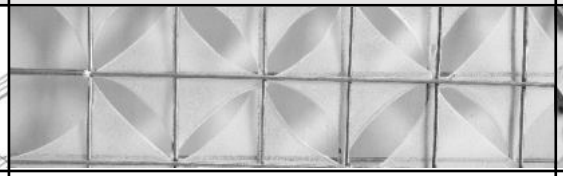
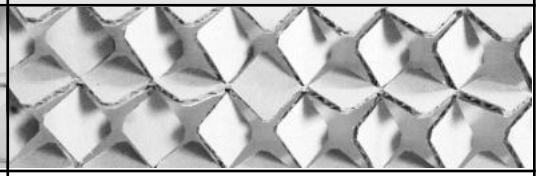
Changing pattern

CHAPTER 08

EVALUATION

EVALUATION

All champion concepts were kept of the table and was analyzed with respect to light, heat and wind control capabilities. And were clustered on the basis of cost, maintenance and aesthetics and then evaluated.

Parameters	Concept #1	Concept #2	Concept #3
			
Materials (panels)	PVC/ACP/Bamboo	PTFE Tensile Fabric	PVC/ACP/Bamboo
Control Factors (40)	15 • No cent percent blockage of glare. • Independent air control • 100% shade every hour.	25 • No cent percent blockage of glare but diffused light due to material opacity • Increase in wind may also increase solar penetration.	35 • 100% blockage of glare and controlled diffused light. • Independent air control • 100% shade every hour.
Cost (40)	15 • PVC-Rs.120/sqft + Structure + Mechanism • ACP-Rs.150/sqft + Structure + Mechanism • Bamboo Flats Panel-Rs.80/sqft • Might have complex mechanism. Hence more cost.	28 PTFE- Rs120/sqft + Structure + Mechanism	35 • PVC-Rs.120/sqft + Structure + Mechanism • ACP-Rs.150/sqft + Structure + Mechanism • Bamboo Flats Panel-Rs.80/sqft
Maintenance (10)	5 High maintenance due to complex mechanism	8 • Durable • Less mechanism.	8 • Durable • Less mechanism
Aesthetics (As per style board)	8 Inspired by lattice structures	7 Natural and organic looks.	8 Light gradients due to angle makes the façade interesting. Resembles flower petals.
Total (100 max)	43	68	86

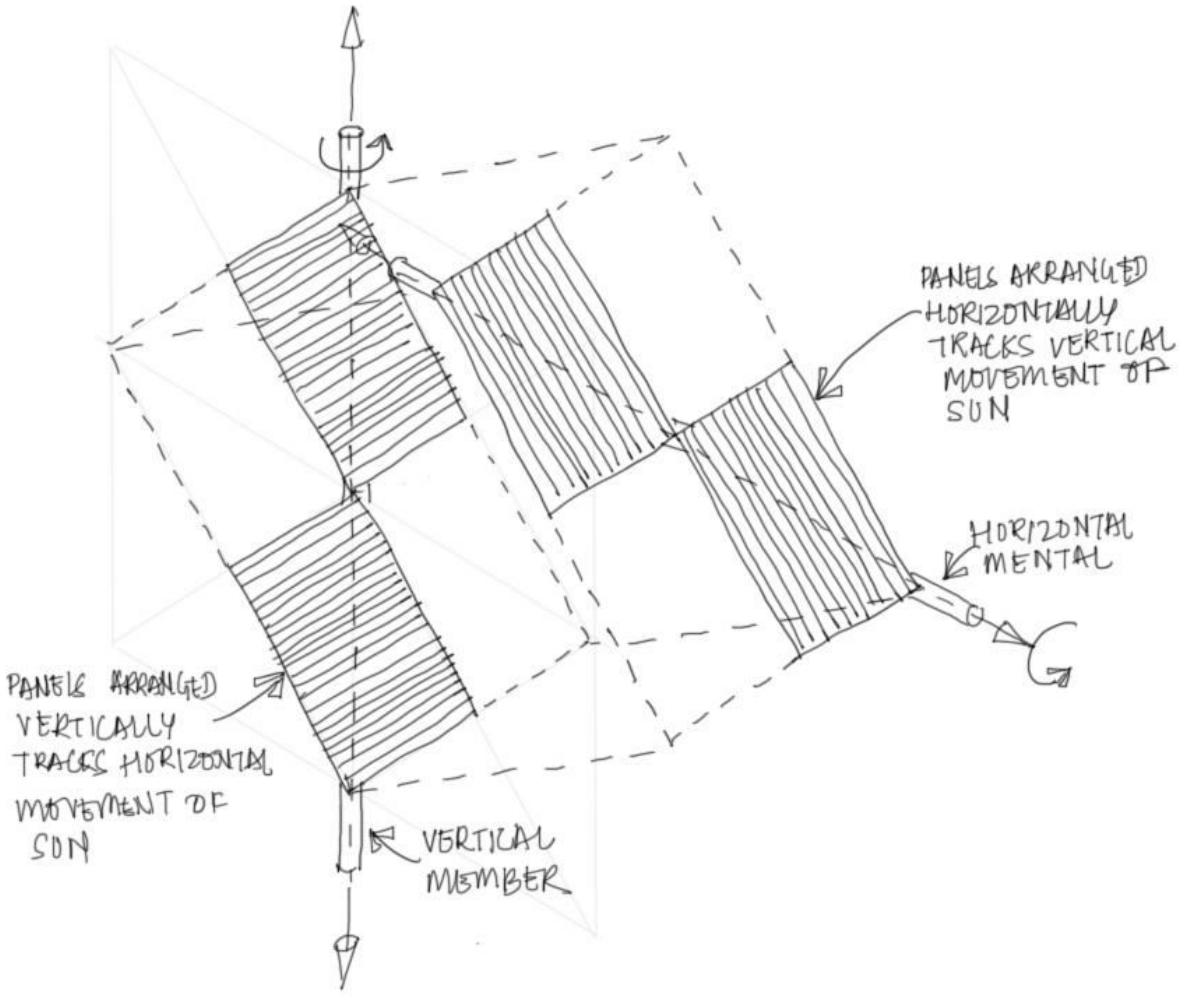
CHAPTER 09

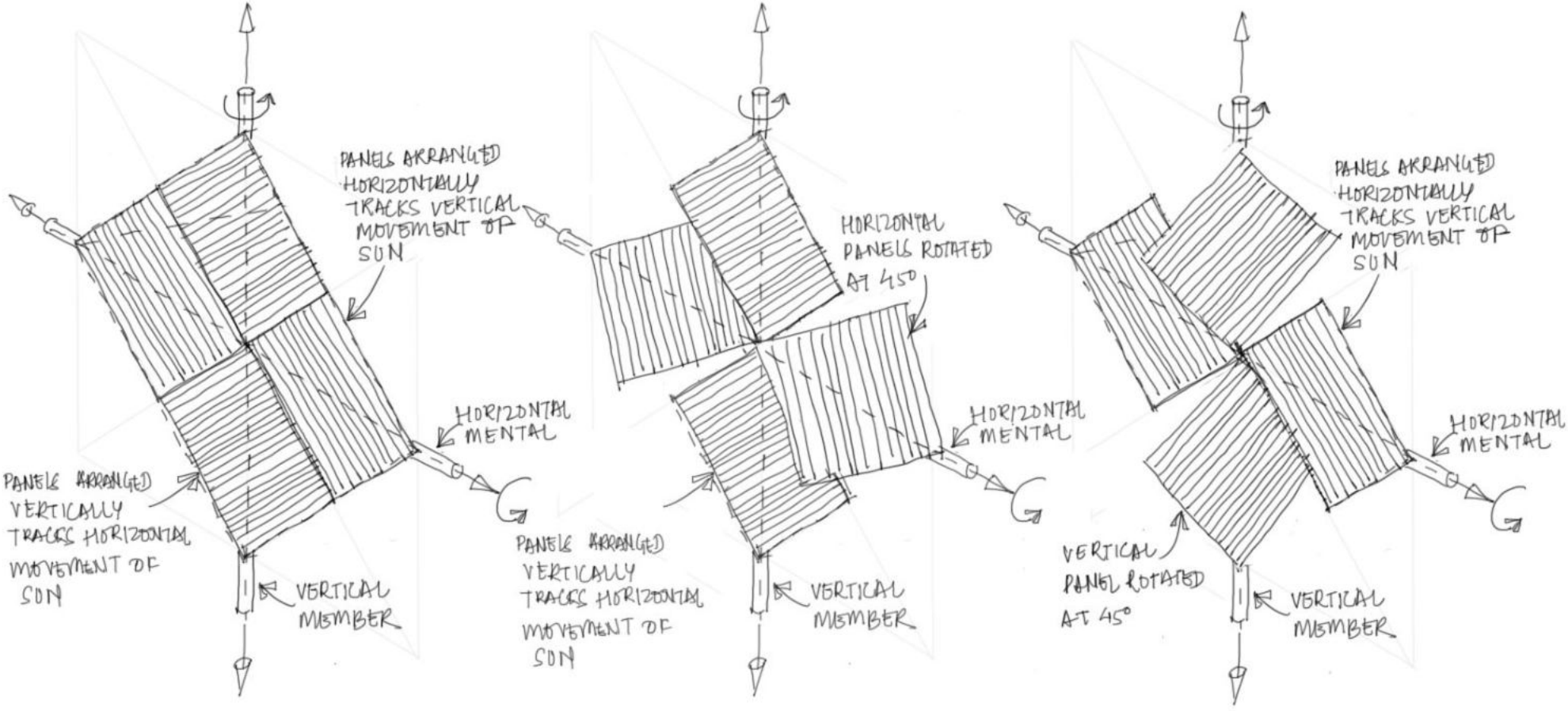
DESIGN DEVELOPMENT

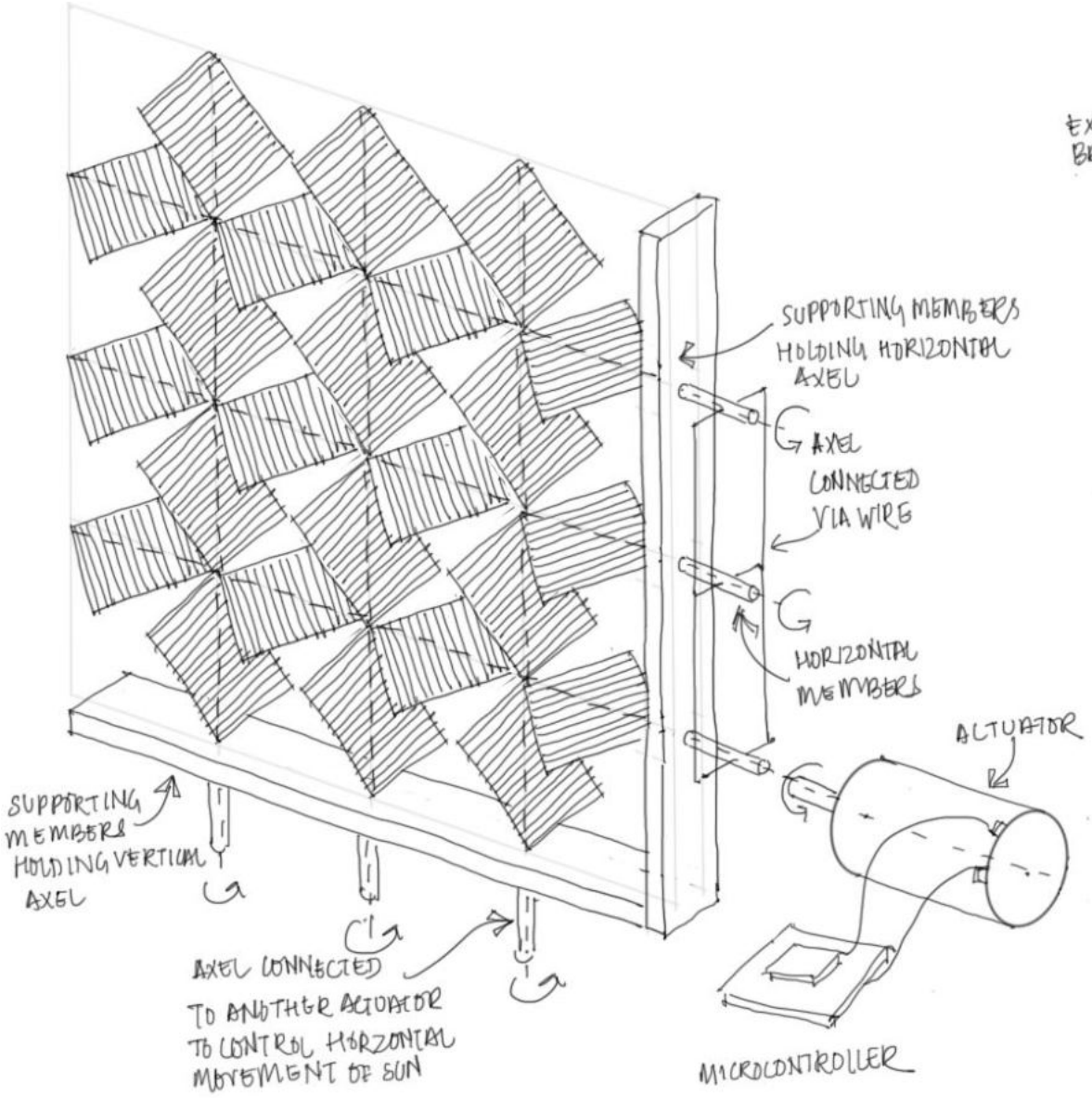
(Under Process)

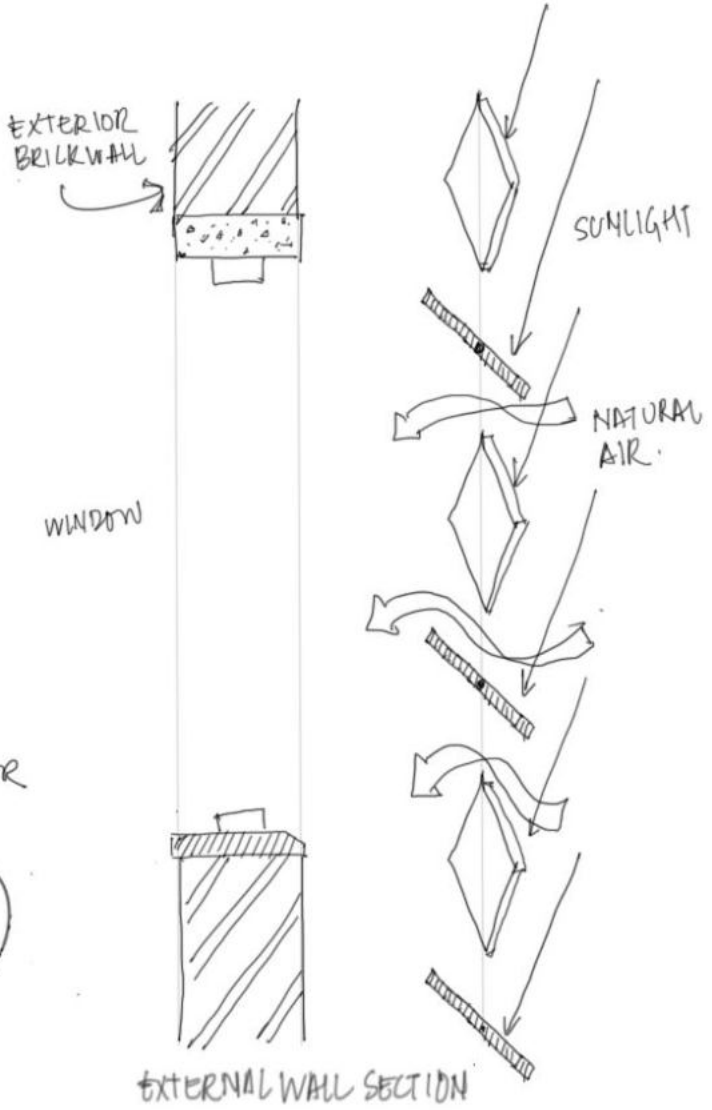
DESIGN DEVELOPMENT

On the basis of evaluation Concept 03 was selected and the details were developed. Each module will consist of two horizontal and two vertical panels each attached to an horizontal and vertical structural members respectively. These horizontal and vertical members rotate in their axis independently tracking the motion of sun and since these members are always be in angle, so there will be always a gap for air to flow.



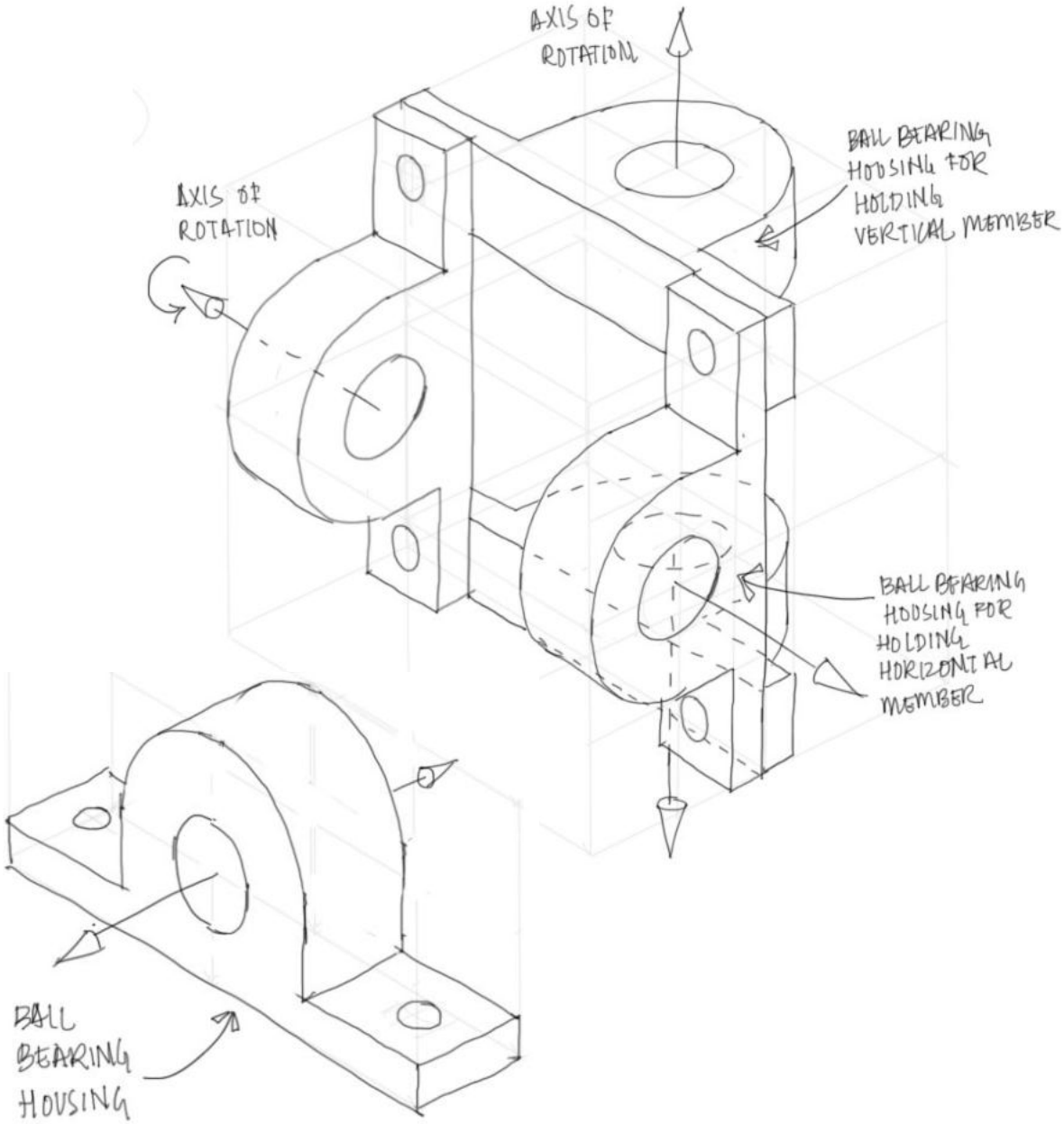

PANELS ARRANGED HORIZONTALLY TRACKS VERTICAL MOVEMENT OF SUN
HORIZONTAL MENTAL
PANEL ARRANGED VERTICALLY TRACKS HORIZONTAL MOVEMENT OF SUN
VERTICAL MEMBER
HORIZONTAL PANELS ROTATED AT 45°
HORIZONTAL MENTAL
PANEL ARRANGED VERTICALLY TRACKS HORIZONTAL MOVEMENT OF SUN
VERTICAL MEMBER
PANELS ARRANGED HORIZONTALLY TRACKS VERTICAL MOVEMENT OF SUN
HORIZONTAL MENTAL
VERTICAL PANEL ROTATED AT 45°
VERTICAL MEMBER


SUPPORTING MEMBERS HOLDING HORIZONTAL AXEL
AXEL CONNECTED VIA WIRE
HORIZONTAL MEMBERS
ACTUATOR
SUPPORTING MEMBERS HOLDING VERTICAL AXEL
AXEL CONNECTED TO ANOTHER ACTUATOR TO CONTROL HORIZONTAL MOVEMENT OF SUN
MICROCONTROLLER


EXTERIOR BRICKWALL
WINDOW
SUNLIGHT
NATURAL AIR
EXTERNAL WALL SECTION

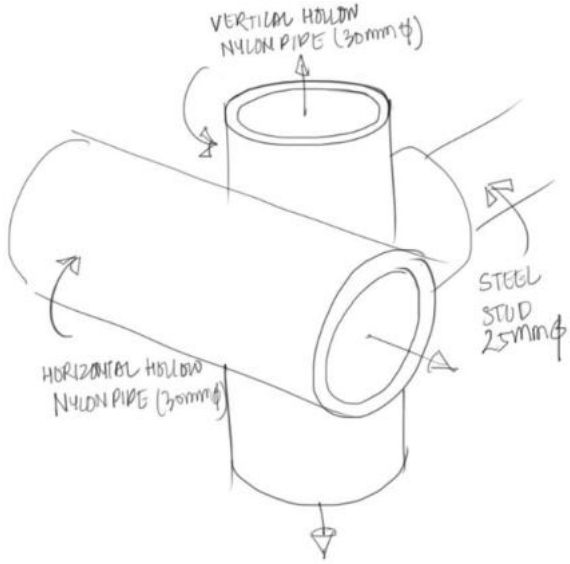
Stud Design

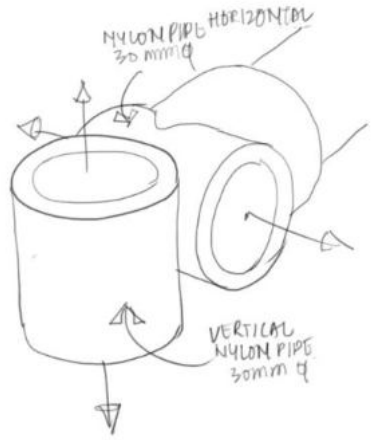
A simple Ideation with ball bearings for the stud design such that it allows two axis movement which was the requirement of the design and should also hold the framework.

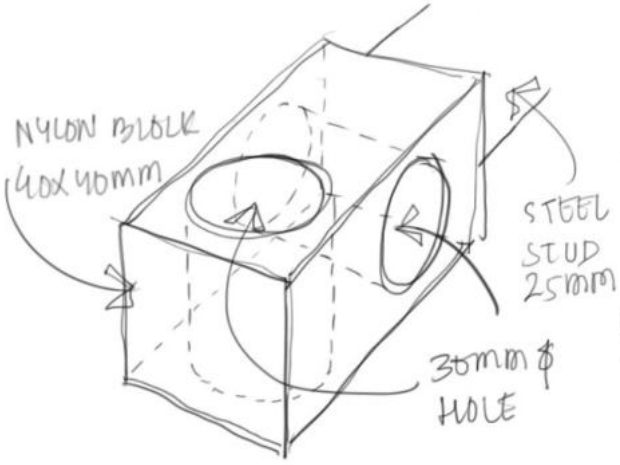


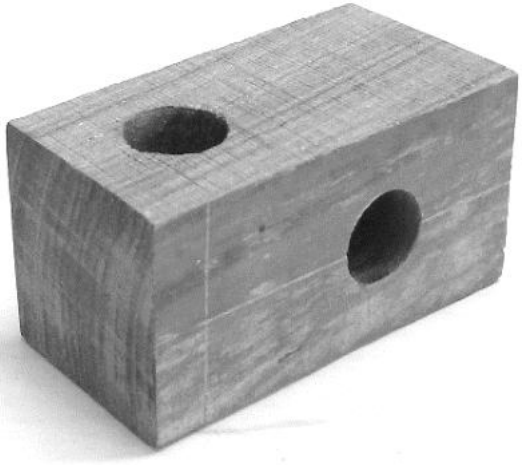
Stud Design

When I was making the mock-up of the system, I came up with a more simpler solution. So I needed something which supports and holds two axis movement, I made a two plastic bushes and oriented them in two way axis, Since the doesn't require high speed movement and something which is light weight, I developed this.





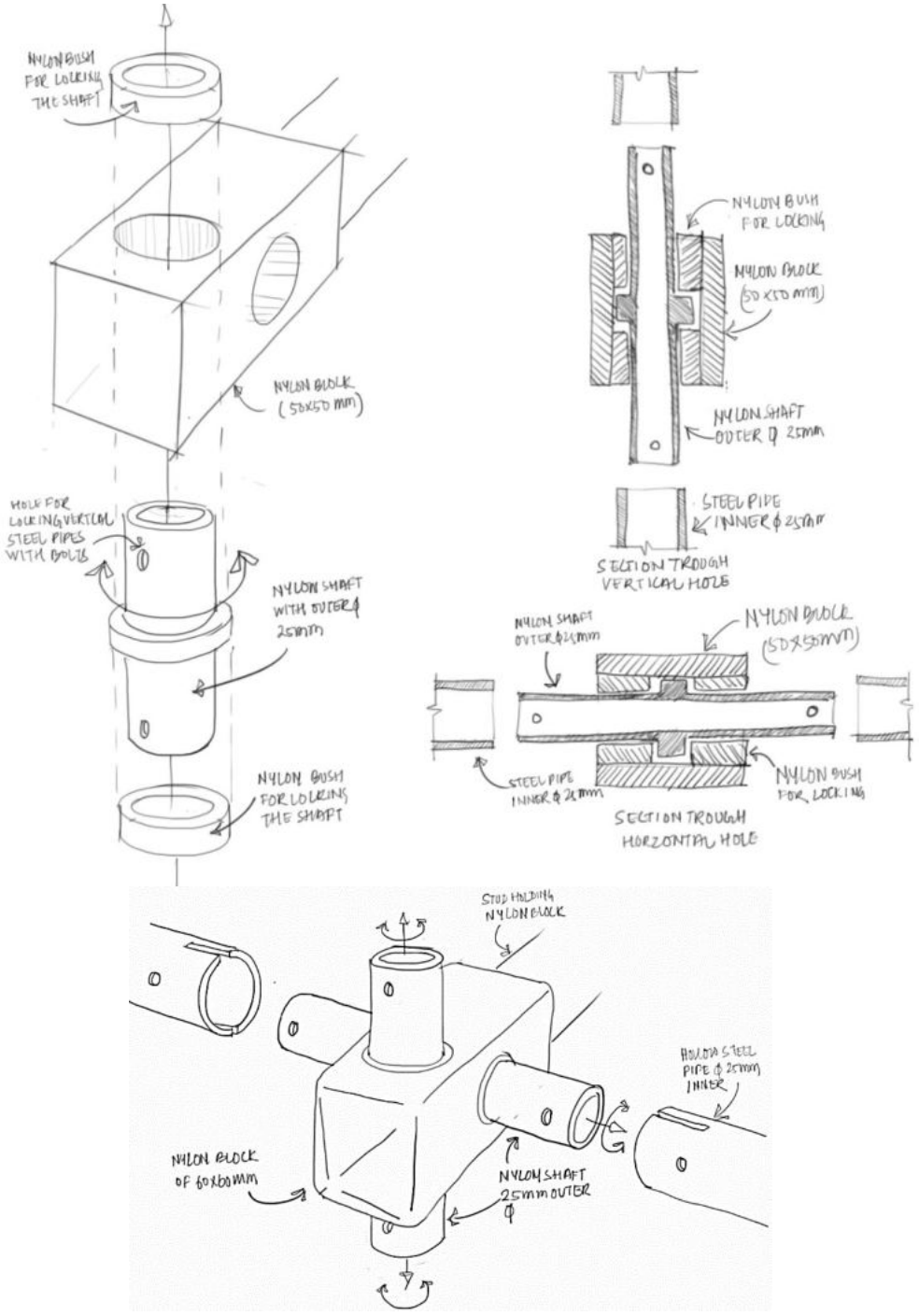




Stud Design

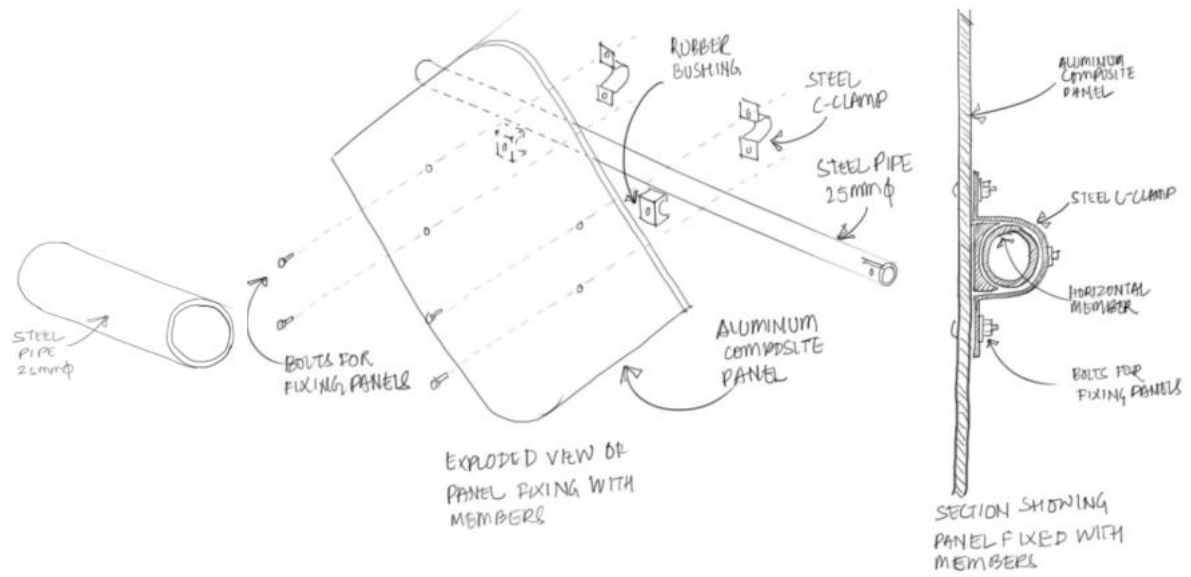
Since there was a need of modular design, so that it can multiply itself to any number, so I came up with a detail which can be easily manufactured and assembled.

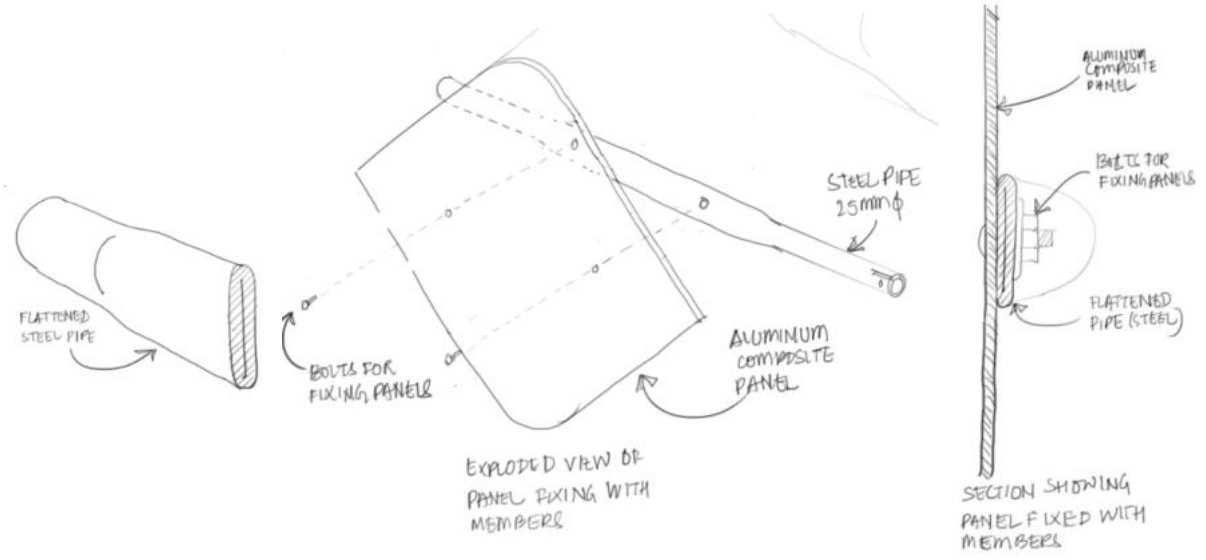
Now these shafts can be rotated freely in their own axis, and to restrict vertical or lateral movement these are locked into the shell through tight fitting nylon bushes. Now these shaft can be attached to the steel pipes and can be locked with bolts which will make the framework on which the panels are going to installed.



Aluminum Composite Panel Fixing

The panels are fixed by clamping it with the members and is locked by adding a screw which passes through the pipe restricting the panel to move along with pipe. A rubber bush is added to increase the contact surface between the clamp and the pipe.





Size of the Panel

The size of the panel was decide upon various factors.

Material availability

Standard size of ACP panels available are:

- 915X1830
- 1220X2440
- 1500X3000
- 1500X3600

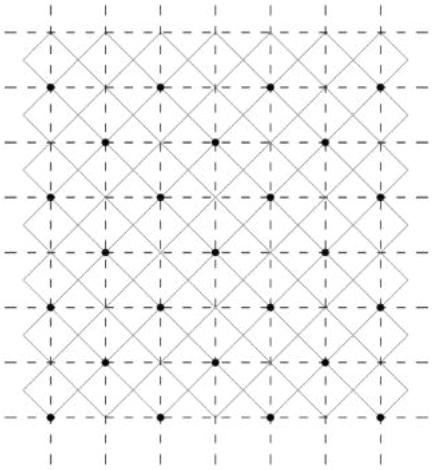
The size of the building openings

A typical size of a naturally ventilated building opening will have a window height of 1200mm and the width may vary in according to the amount of light they want to let in.

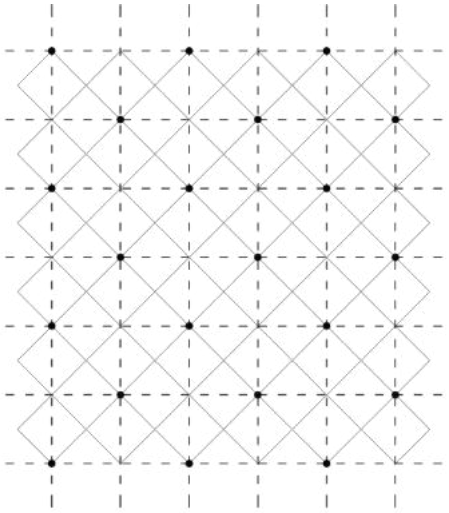
Material Optimization

More the grid size less will be the framework and more the allowance of building openings.

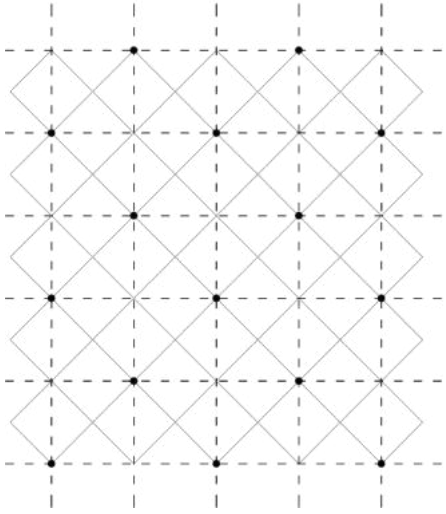
But since the ACP is supported by only one member running diagonally, its better to choose an option which allows standard building openings and also remain strong when there are wind loads. Hence panel size 915X915 was chosen, which has grid size of 1200X1200 which can be a standard window opening.



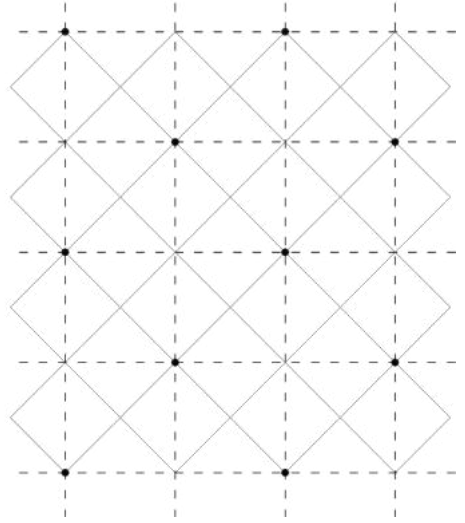
PANEL SIZE: 610X610
GRID SIZE: 850X850



PANEL SIZE: 750X750
GRID SIZE: 1050X1050



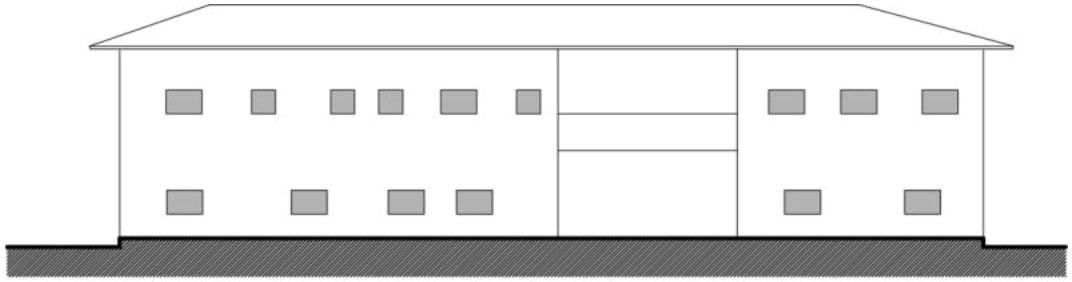
PANEL SIZE: 915X915
GRID SIZE: 1250X1250



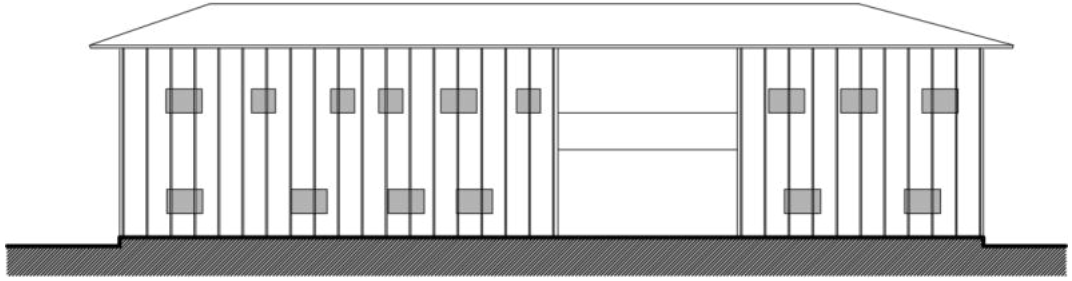
PANEL SIZE: 1220X1220
GRID SIZE: 1700X1700

Structural Framework

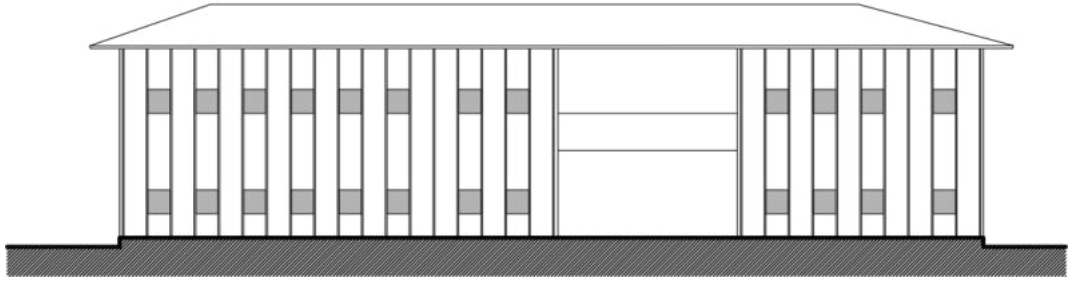
The total system has to be fixed with the building and there should be a structural framework which holds the structure and also adheres the system to the building.
Since the system was based on 1.2mX1.2m framework, vertical members can be fixed on to the structural components of the building.
And after arranging the members in 1.2m array, I found the windows were intersecting with the framework.
So, in accordance to the architectural drawings, I rearranged and standardized the wall openings without affecting the internal layout.



South Side Elevation
Workshop Block



South Side Elevation with structural framework
Workshop Block



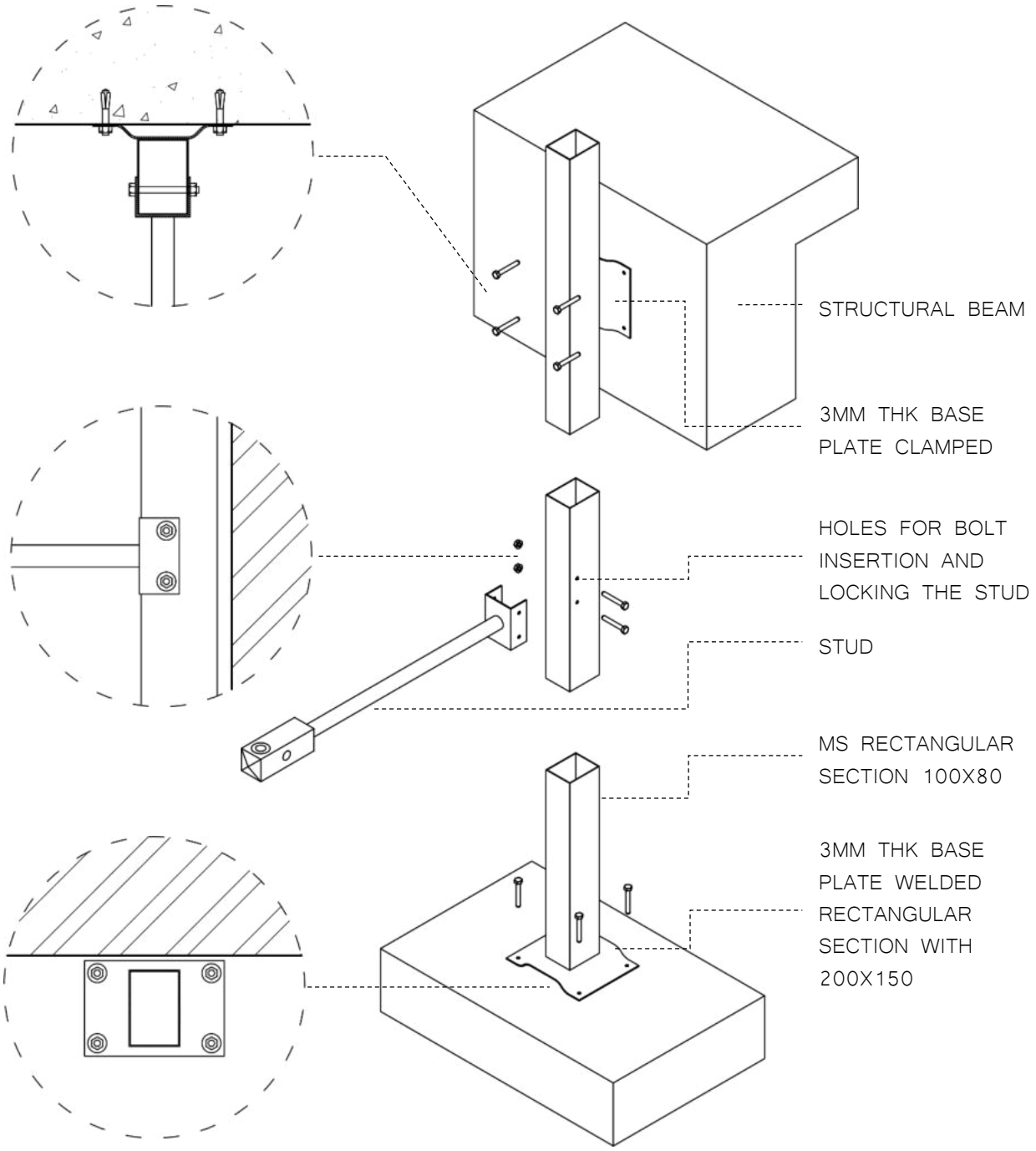
South Side Elevation with structural framework and rearranging the openings
Workshop Block

CHAPTER 10

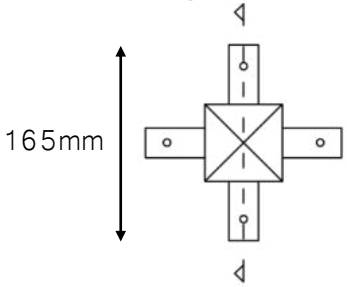
FINAL DESIGN

Structural Frame

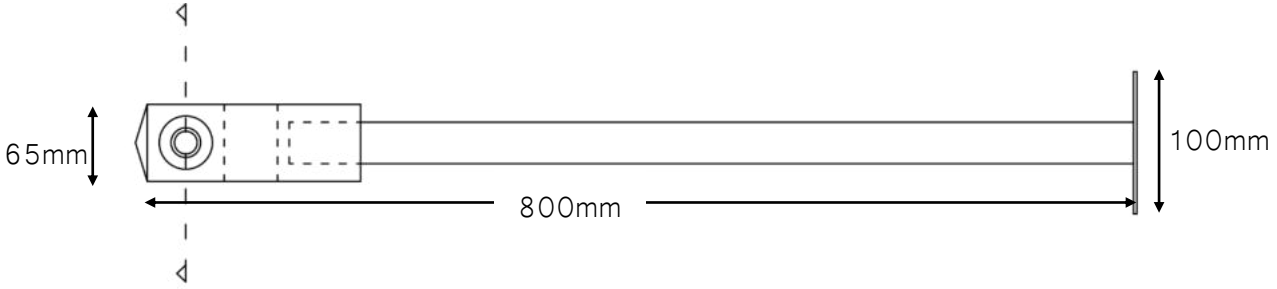
The vertical members used are rectangular section. These members are fixed to the ground to bear the vertical load of the system. The members are also rested and clamped with the building structural component(beams). Now the studs can be clamped on to the vertical members making the structural framework of the system.



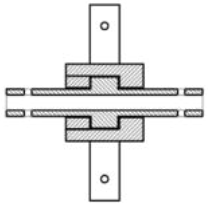
Detailed Drawings of Stud



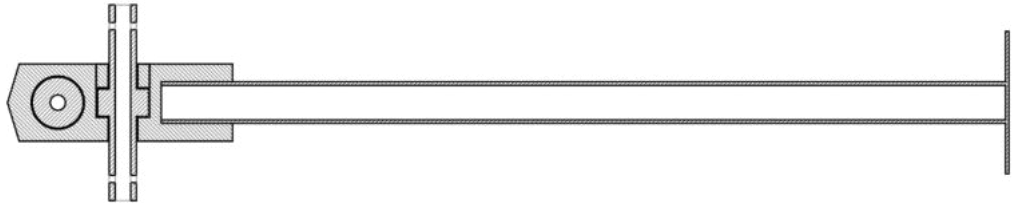
Front View



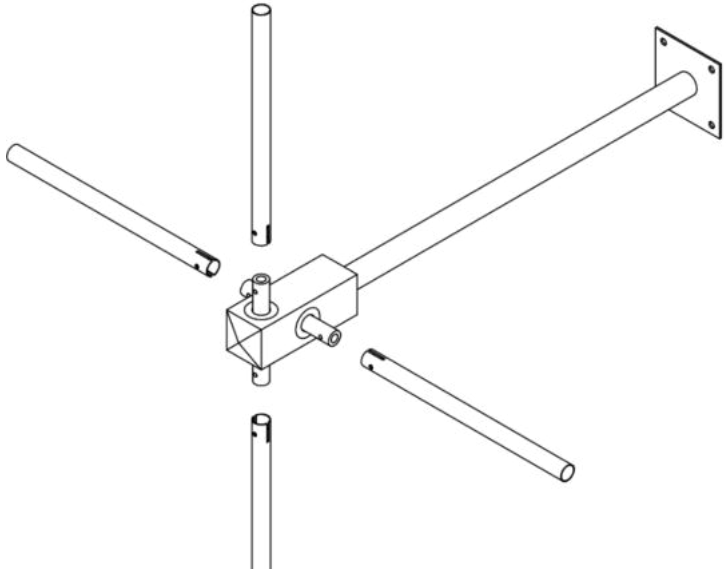
Side View



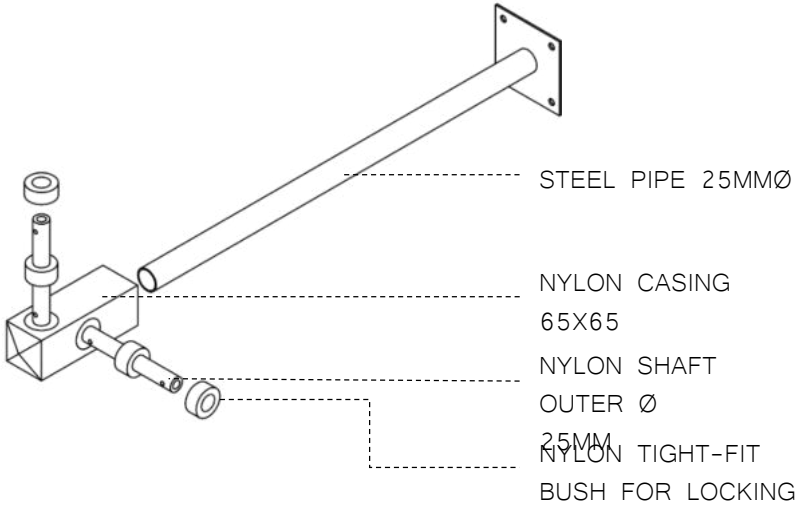
Section BB'



Section AA'

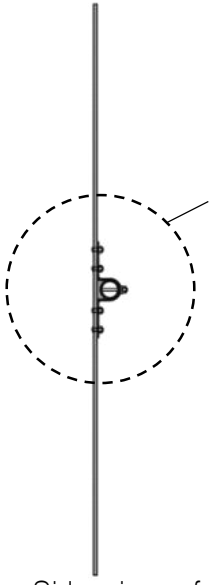


Exploded view of stud getting fixed with steel members

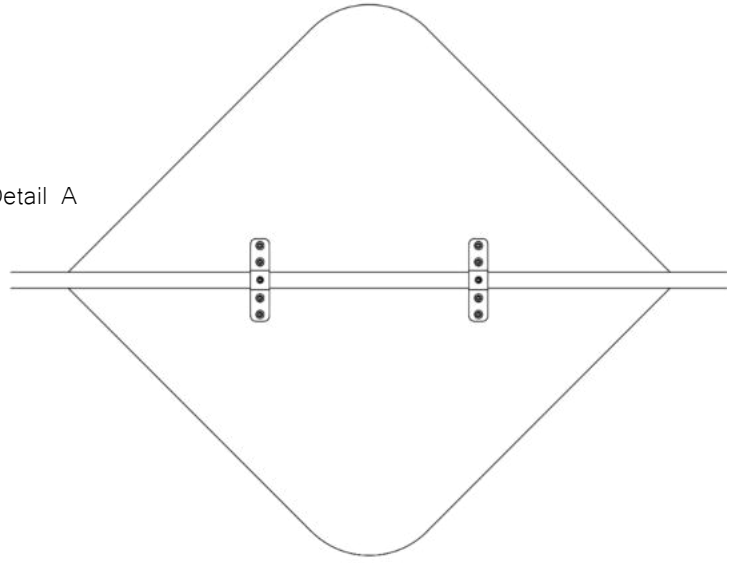


Exploded view of stud.

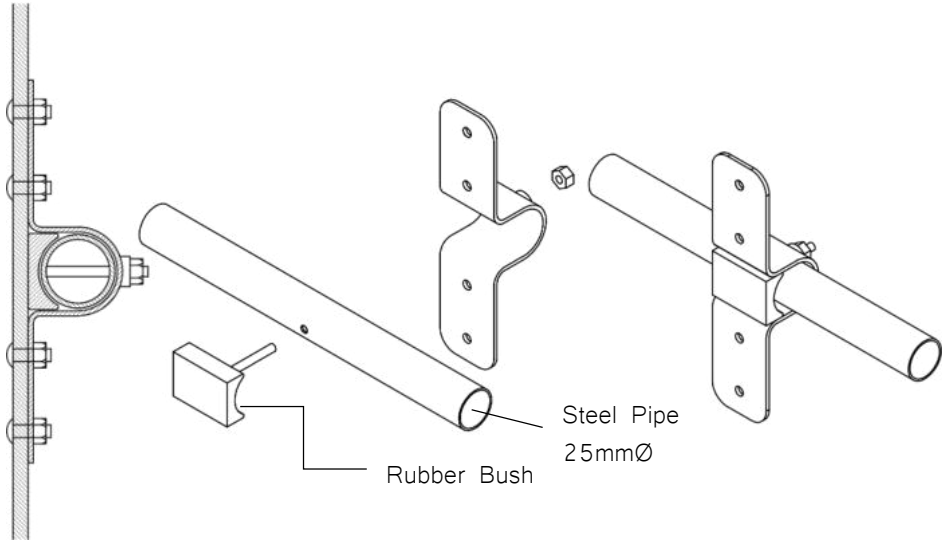
Detailed Drawings of Panel



Side view of ACP panels

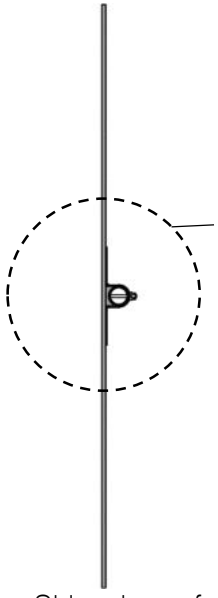


Back view of clamp fixing with ACP panels

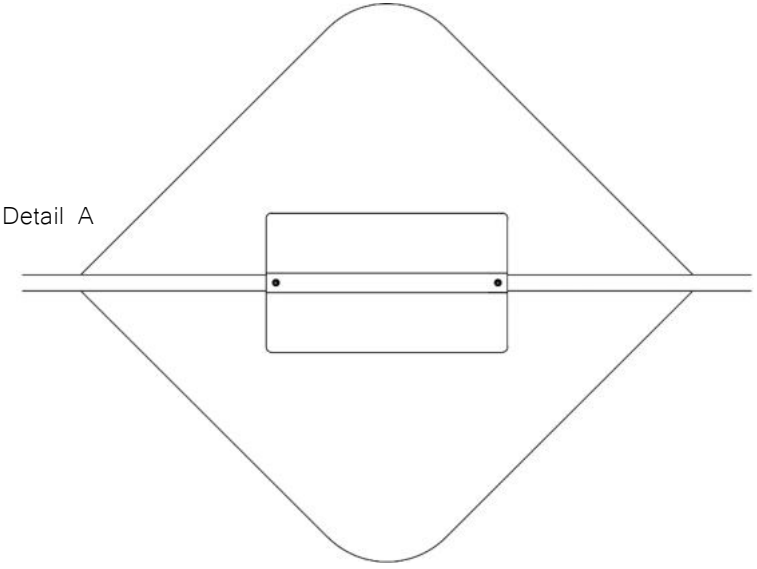


Detail A

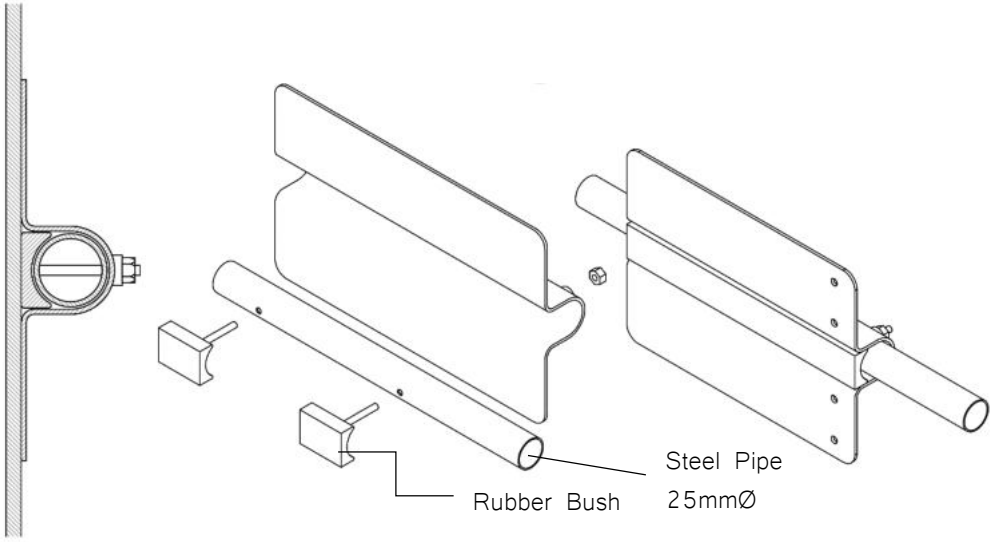
Exploded view of clamp fixing with steel pipe



Side view of ACP panels



Back view of clamp fixing with ACP panels

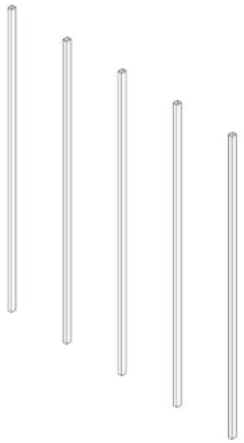


Detail A

Exploded view of clamp fixing with steel pipe

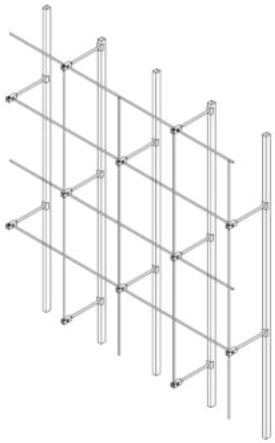
Easy Modular Installation and Maintenance

The whole system can be transported assembled in-situ. The structural members are clamped to the structure of the building and the studs is fixed to the vertical members in diagonal grid pattern. Then horizontal and vertical framework is fixed with studs and the panels are clamped with the steel framework. If something goes wrong then each part can be removed separately without affecting the overall system and can be replaced.

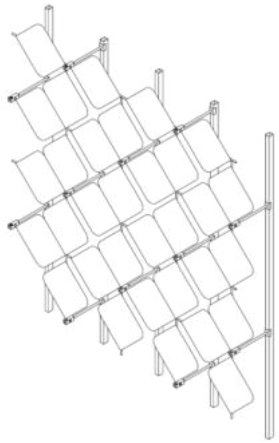


First the structural members are fixed to the structural components of the building.

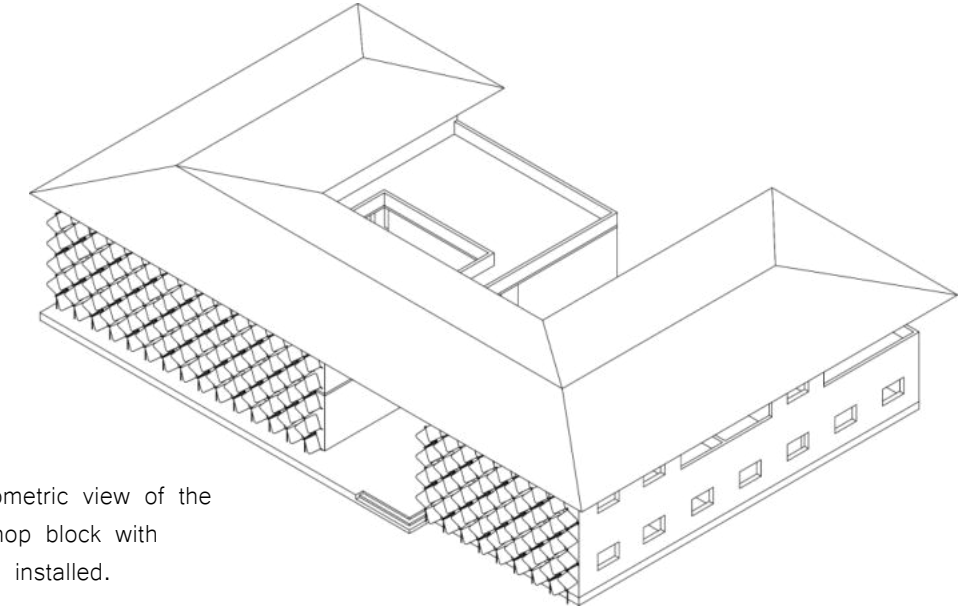
Then the studs are clamped to the structural framework.



Then horizontal and vertical framework is fixed with studs.



Now the panels are clamped with the steel framework.

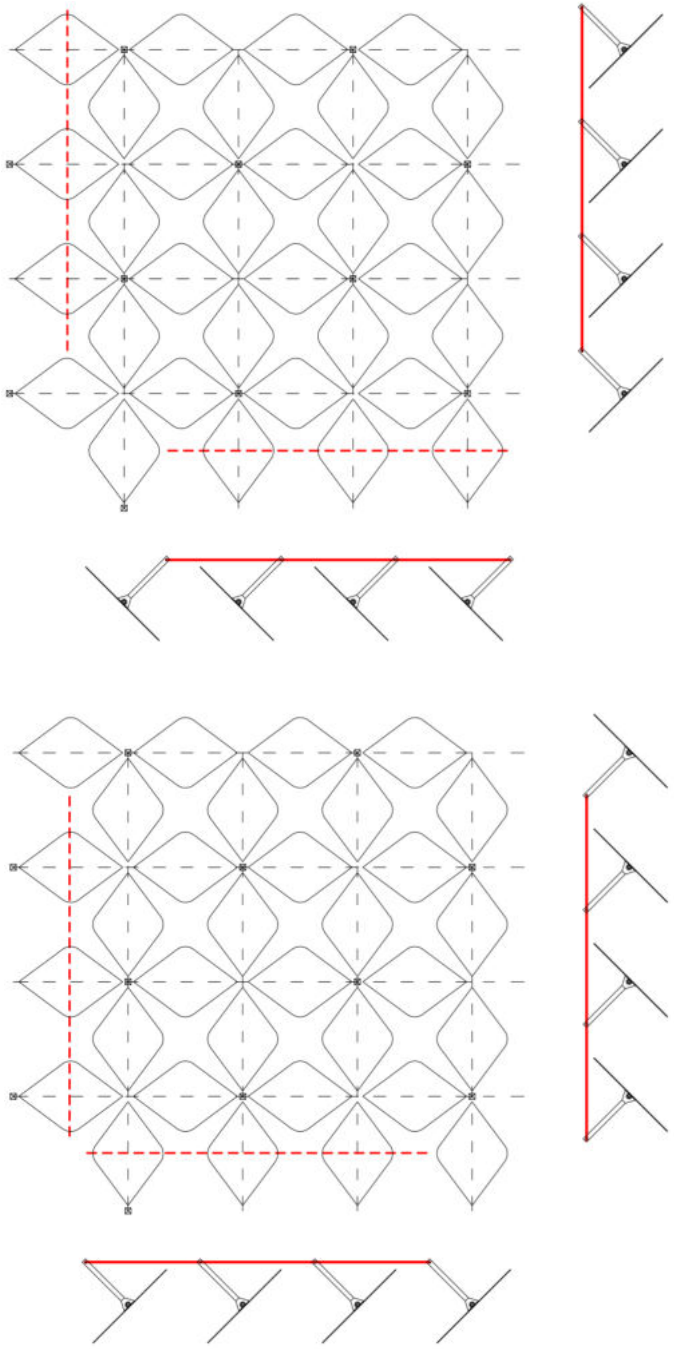


An isometric view of the workshop block with façade installed.

Actuation and Sun-tracking

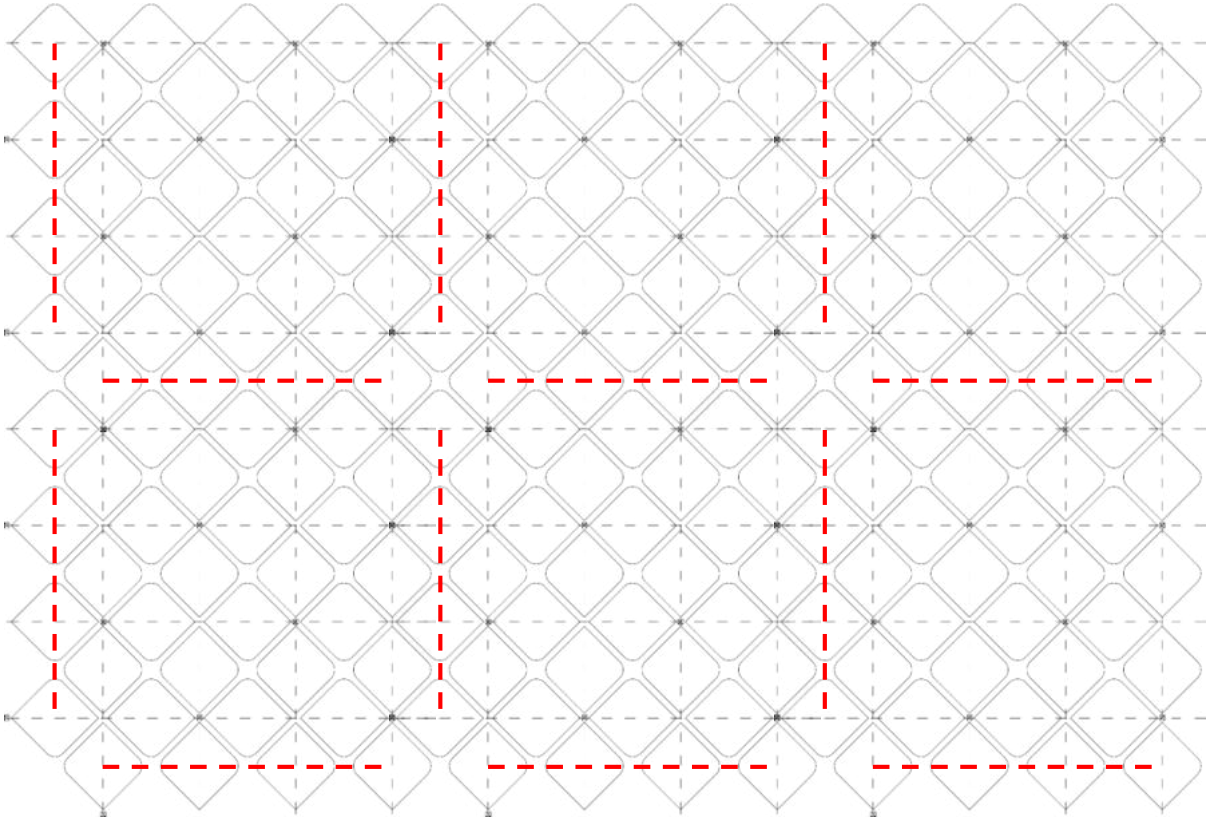
Each row in a module has a master panel which is again connected, so that the other panels in rows will move in-tandem, tracing the vertical movement of sun. And the same mechanism happens in panels arranged in rows, tracking the horizontal movement of sun.

The panel tracks and blocks the radiation of the sun giving 100% shade on the primary skin of the building without blocking the natural ventilation. This reduces the heat gain of walls which surrounds the interior space, resulting less conduction and convection.



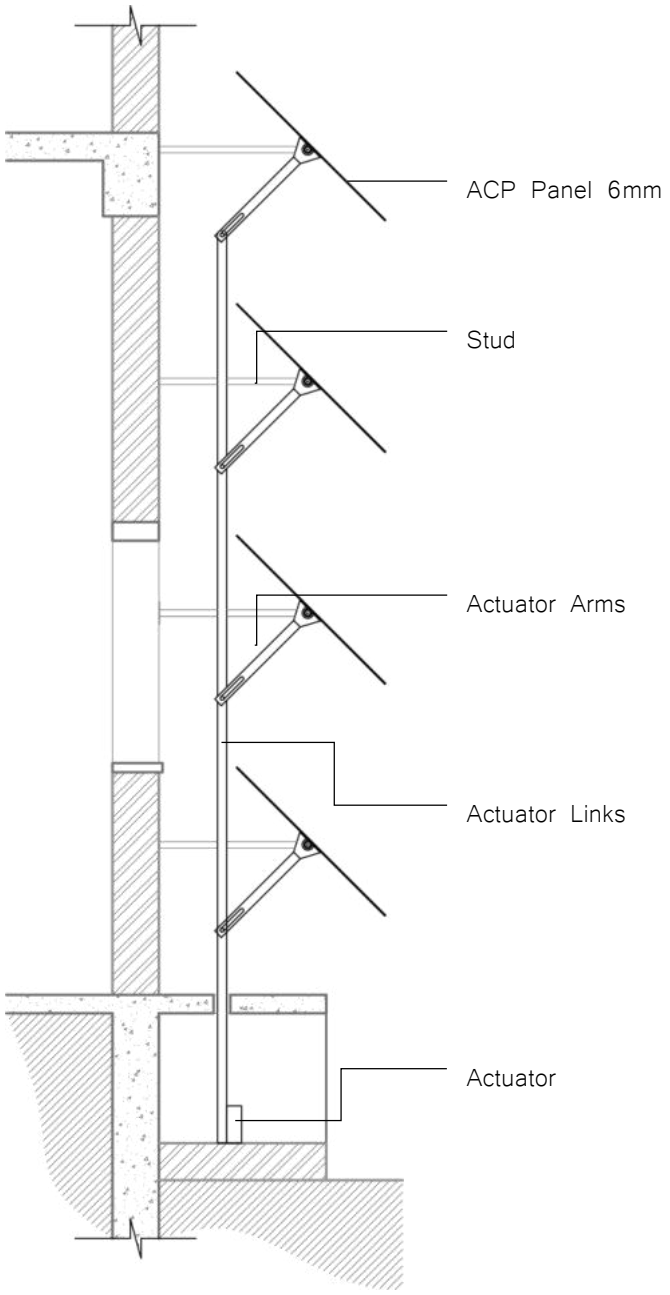
Modularity

The modules can be repeated and installed on the entire façade of the building. The size of each module can ne customized depending upon the requirements.



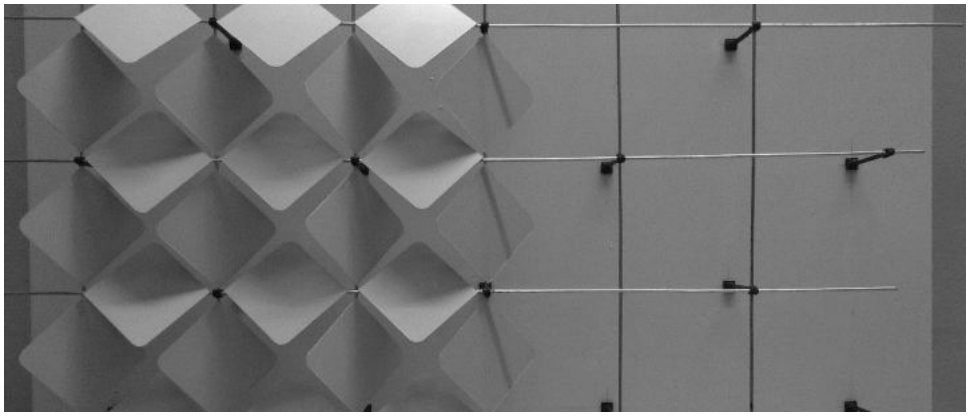
External Wall Section

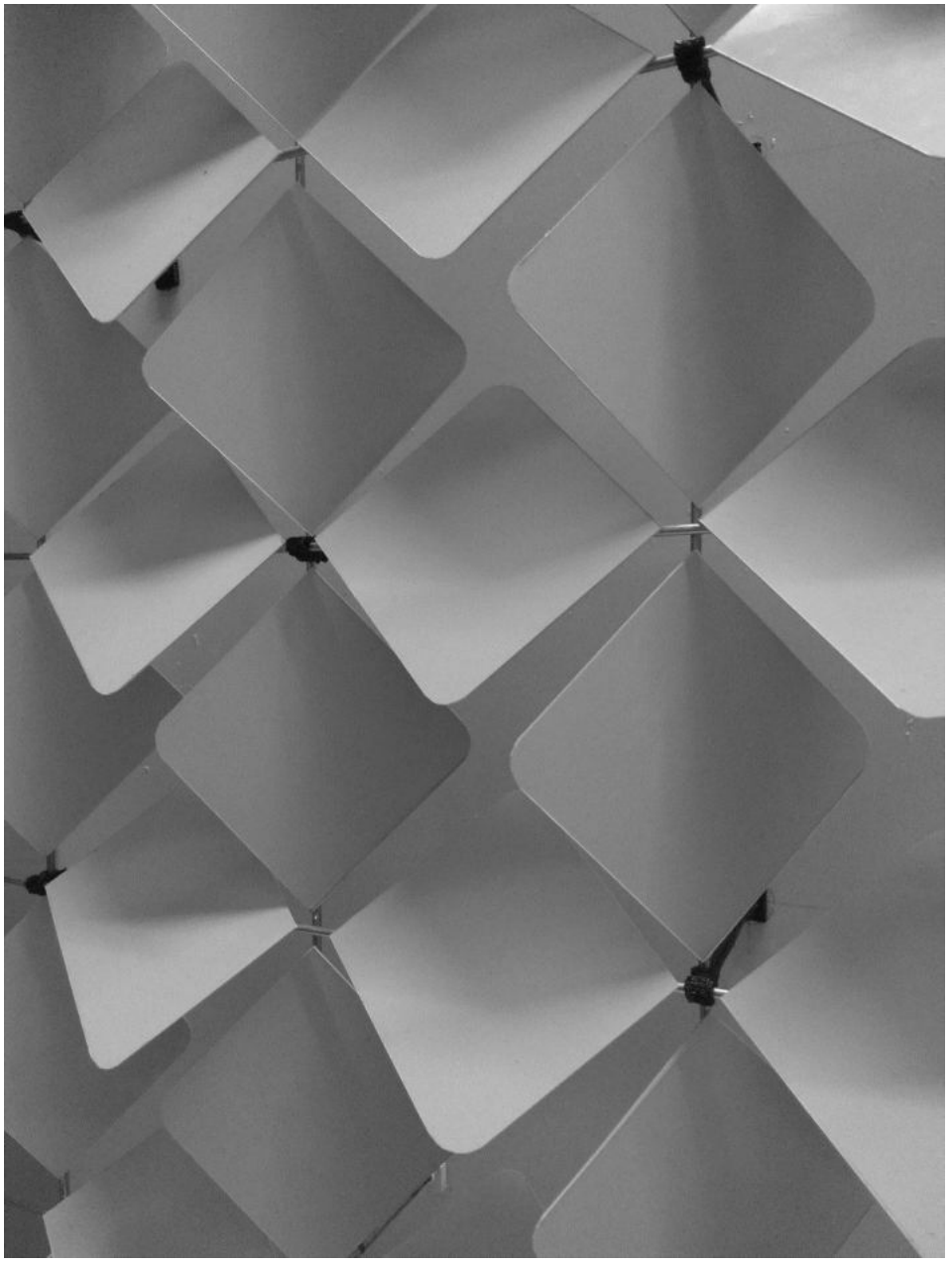
In the current context the Actuator is installed right below the system, Guarded by the cabinet made of RCC, and can be accessed from out side.

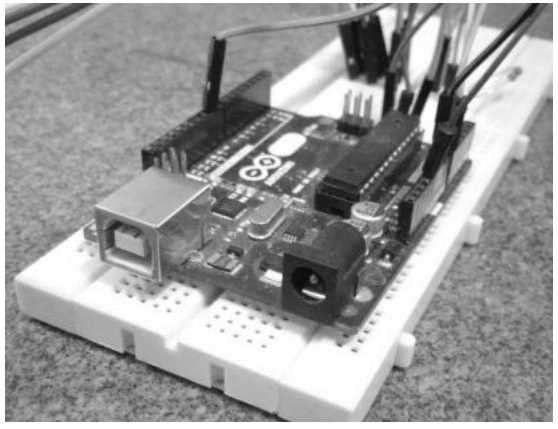


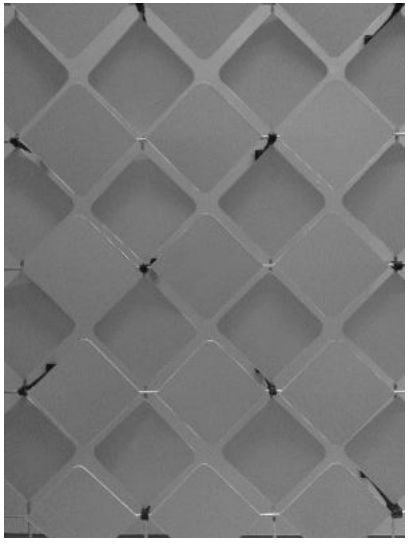
External Wall Section

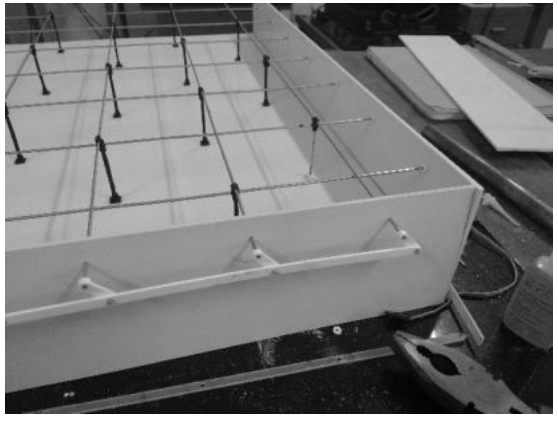
Working Mock-Up Development











Cost

The design has been done with conventional material and processes. And the mechanism has been optimized for its easy maintenance and affordability. Depending upon the cost, the system can be operated manually or can be upgraded by installing more sensors and actuators giving more flexibility of customization.

	Items	Dimensions	Weight (gms)	Material cost/kg	Price of each piece	No. of pieces /module	Weight /module in kg.	Cost in each module	Price of item/sqft.
STUDS	Box Section (MS)	120X80X7500	88704	65	748	5	443.52	28828	68.5
	Steel pipe	700	430	220	94	15	6.45	1419	3.37
	Mounting plate	100X100	128	220	28	15	1.92	422	1
	Nylon casing	65X65X180	450	230	103	15	6.75	1552	3.7
	Shaft	165X25Ø	80	230	20	30	2.4	552	1.31
PANELS	ACP	900X900	5796/ panel	130/ sqft	1170	45	260.82	52650	125.2
	Steel Pipe	1250	750	220	165	45	33.75	7425	17.65
	Clamps	5			4	90		360	0.85
ACTUATOR	Actuation links	50X25	1580	200	316	2	3.16	632	1.5
	Actuator				2000	2		4000	14.86
	Total						226.48 kg	97288	**237.94**

CHAPTER 11

REAL-TIME SIMULATION

(Work In Progress)

Interior Simulation

Image showing the light intensity inside the building without the system being installed. One can see the amount of glare inside.

1st Floor Plan

Interior Simulation

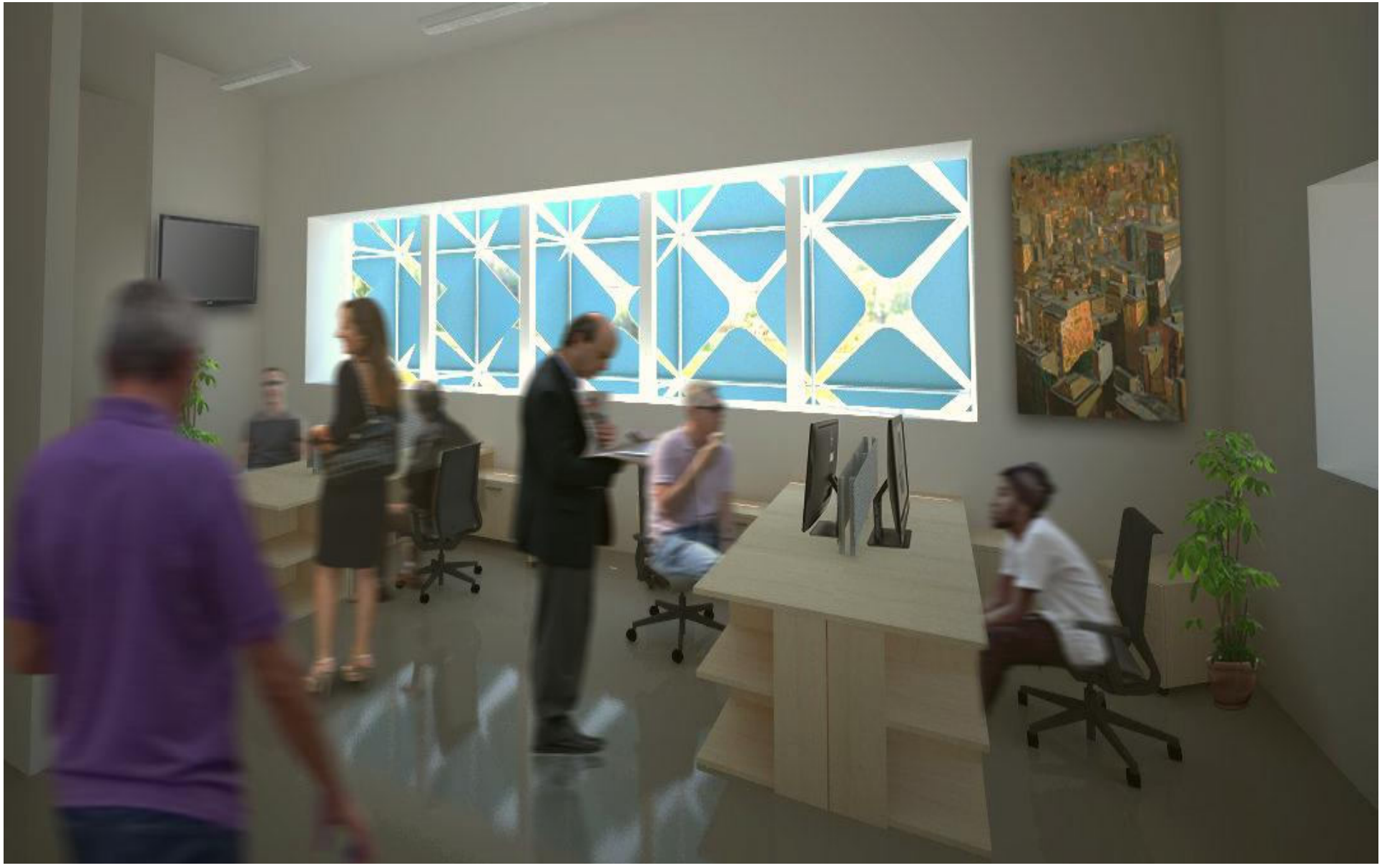
Image showing the light intensity inside the building when the system is installed. Now the glare is reduced and also the light intensity.

1st Floor Plan

Interior Simulation

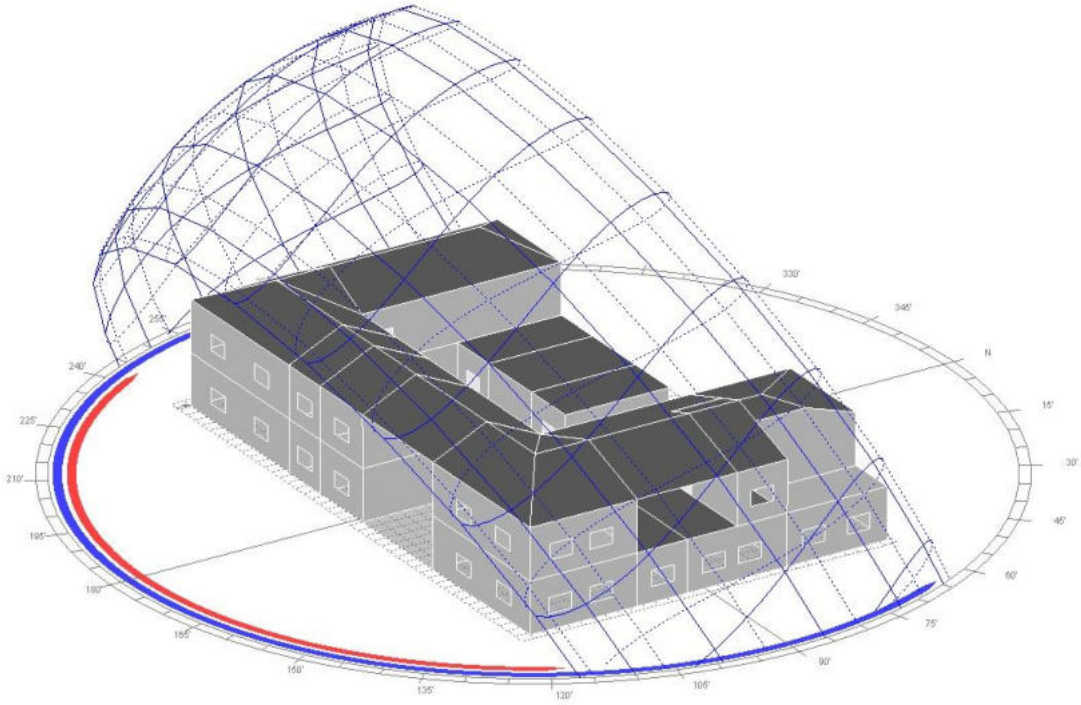
Image showing the light intensity inside the building when the system is installed. This time the size of the openings were increase for better the air exchange and light intensity.

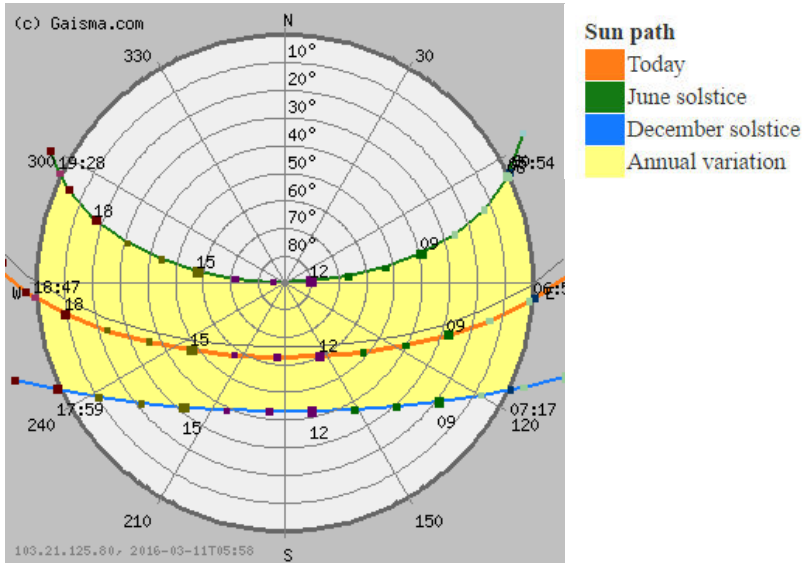
1st Floor Plan



Sun-path Diagram

The diagram shows the annual sun movement range. Since the location is situated on the northern hemisphere of the earth, the south and the west facing façade will always be exposed to the sun.

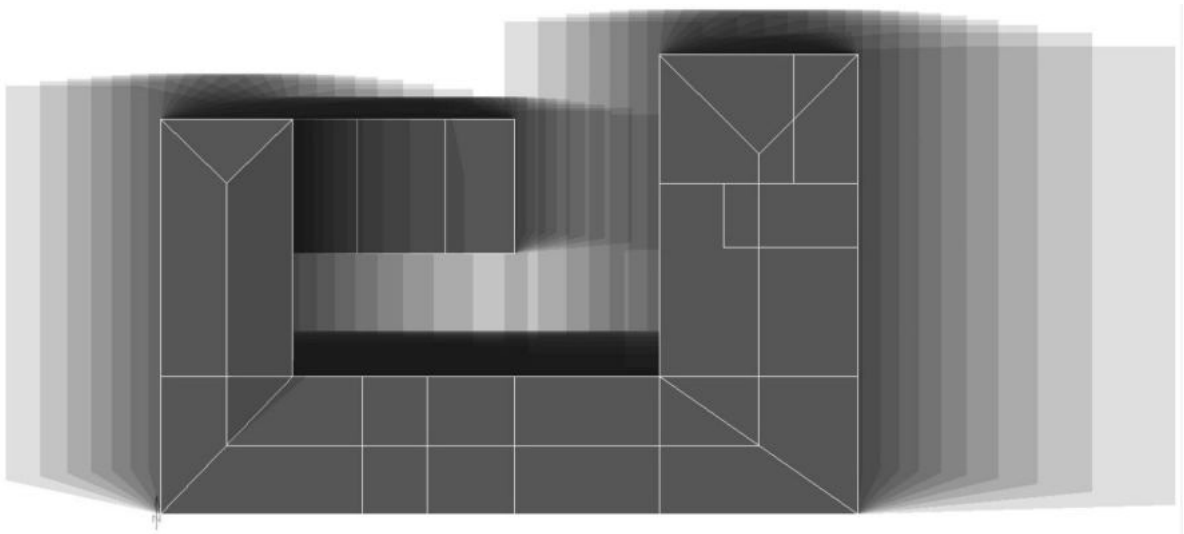




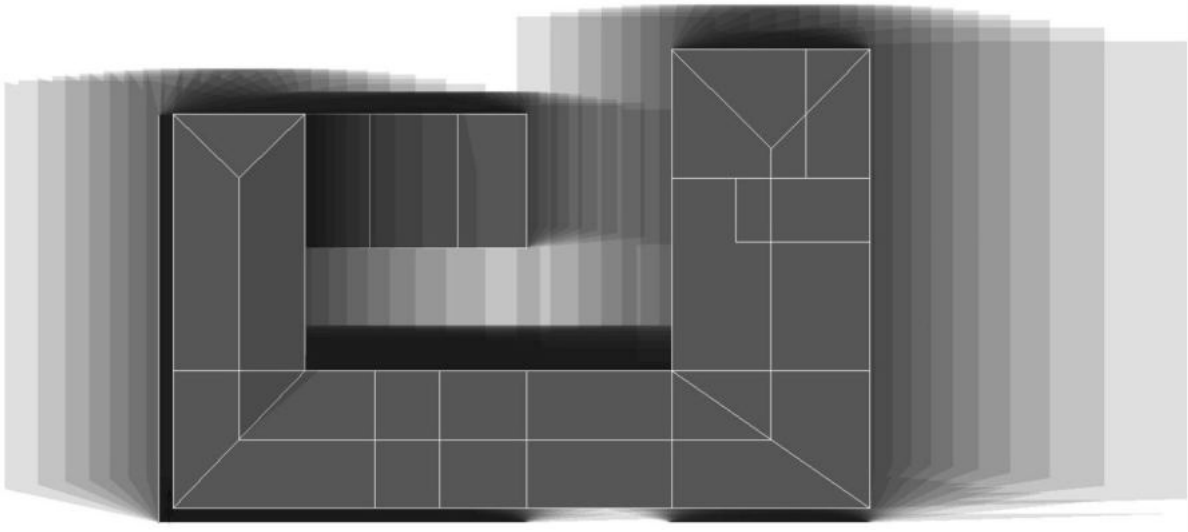
Shadow Range Diagram

This diagram shows the range of shadows throughout the day on peak summer. In both the diagrams the black patches are the areas where there's shadow throughout the day and the air use to be cooler than the air compared to the region which are not in shade.

After installing the façade we can see the dark regions appearing on the south and west face of the building this helps the air to cool at those region and these cooler air will circulate through the to the courtyard.



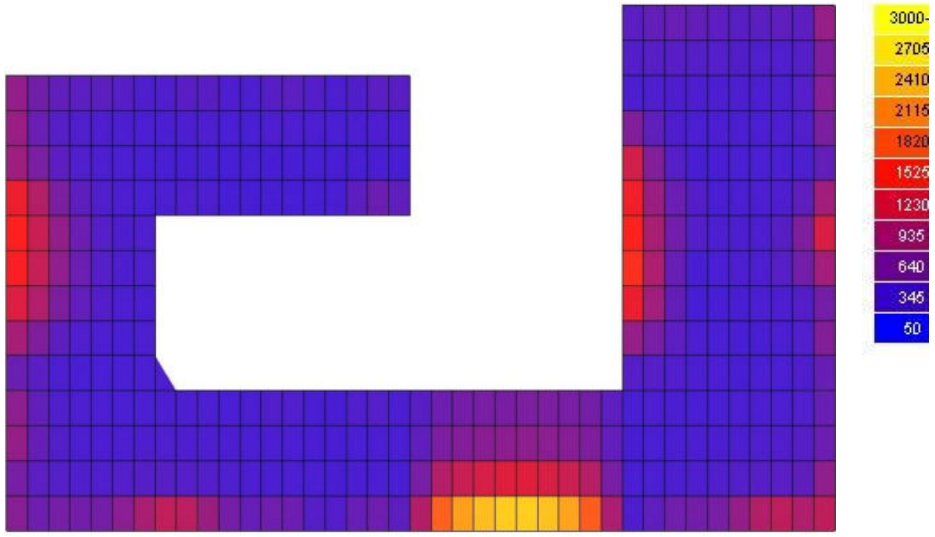
Without Facade



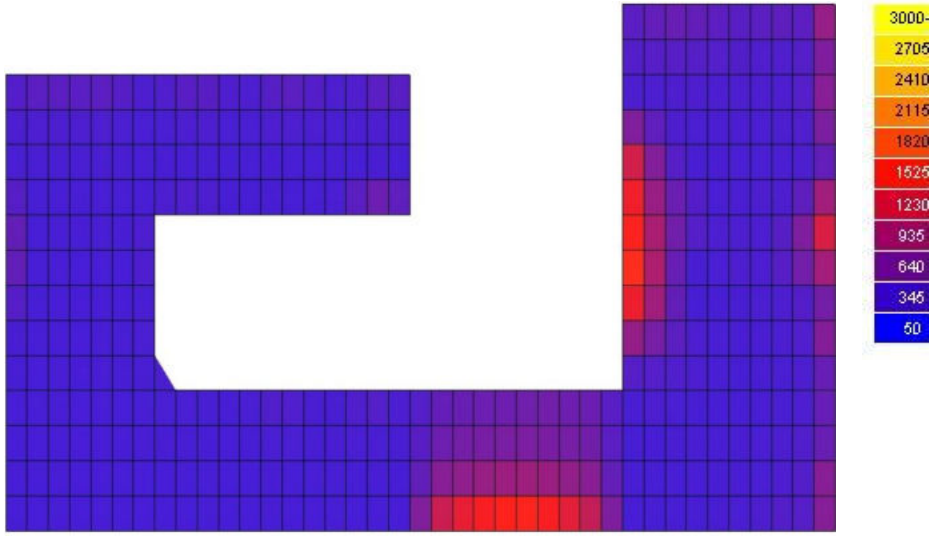
With Facade

Solar Gain Analysis

The analysis is done on the average values on the peak hottest days in summer. One can see the difference when the facade is installed, the solar gain has been reduced by 1000 watt-hr, this helps to reduce the thermal mass of the building hence reducing the heating through convection by walls floors and other building components.



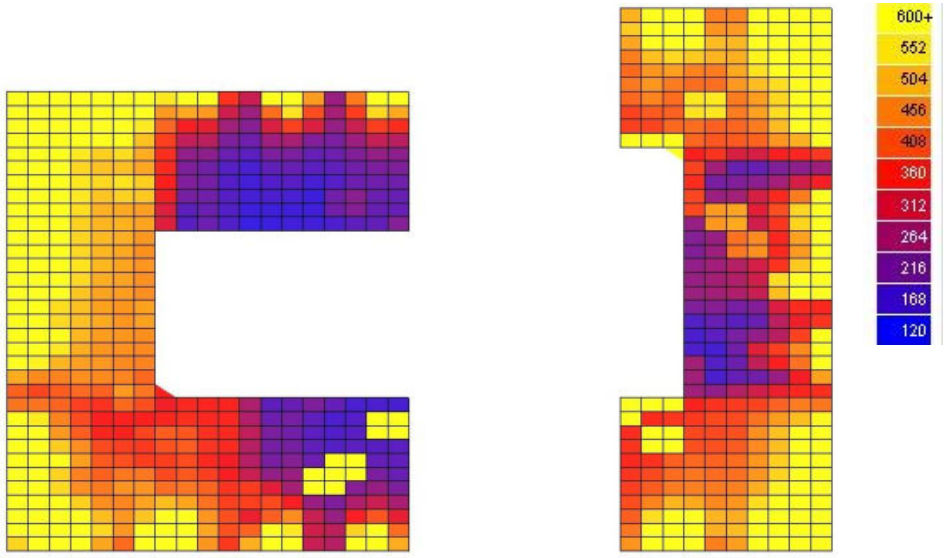
Without Facade



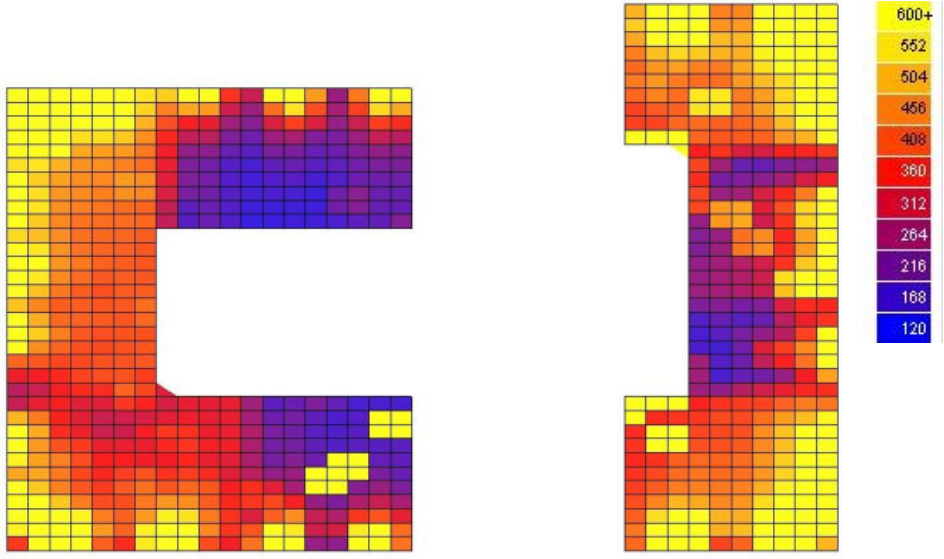
With Facade

Natural Light Intensity Analysis

The analysis is done on the average light intensity values on the peak hottest days in summer. One can see the difference when the facade is installed, along with the light quality turned to diffused, the light intensity has also been brought down to 250 to 500 lux which is ideal for office and classroom environment.



Without Facade



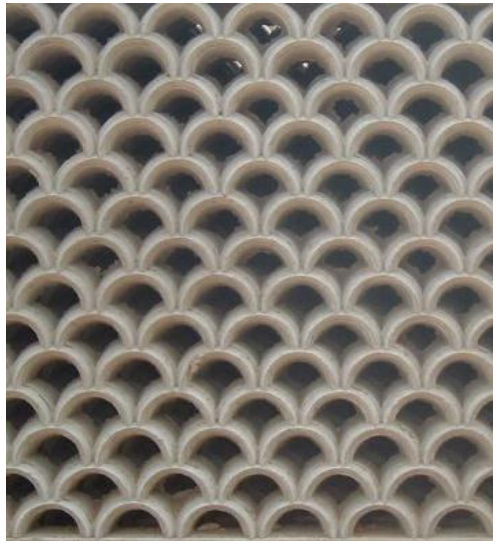
With Facade

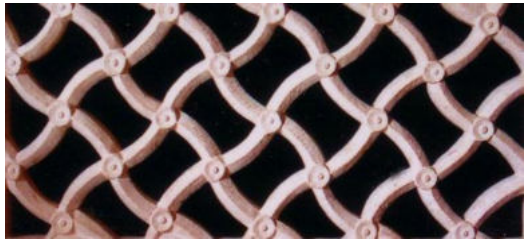
CHAPTER 12

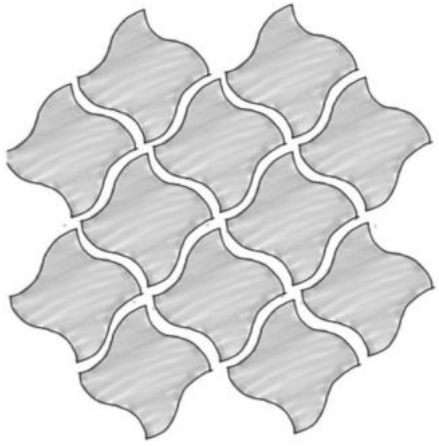
COLOR
SHAPE
PATTERN

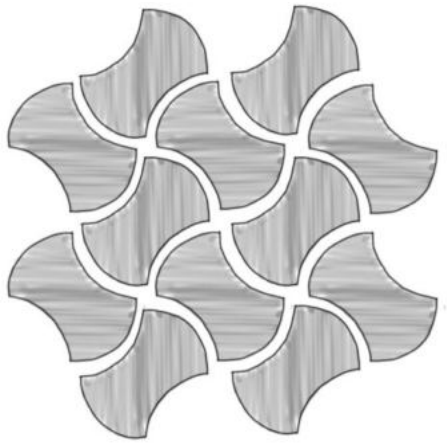
Shape Derivation

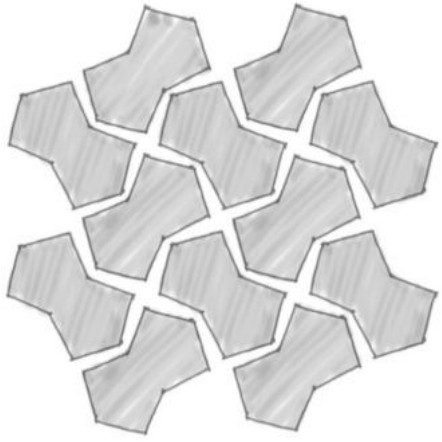
Few shapes were derived from the style-board and conventional jaalis and they were simplified.

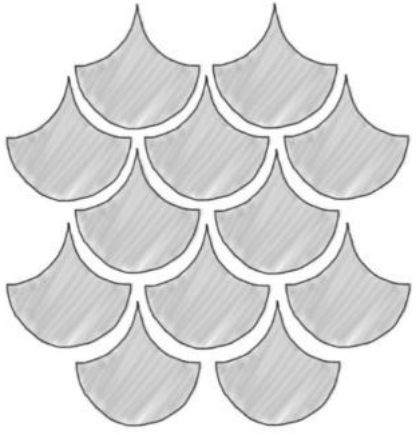


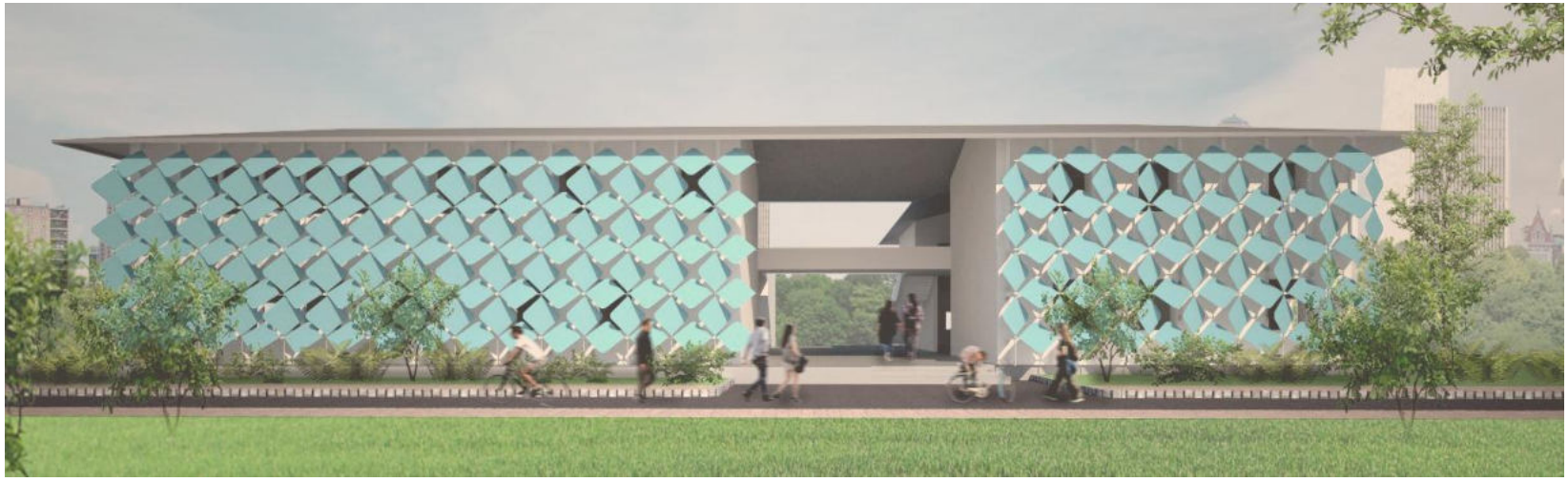


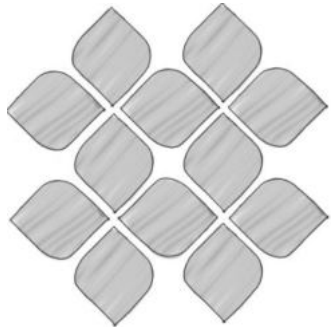




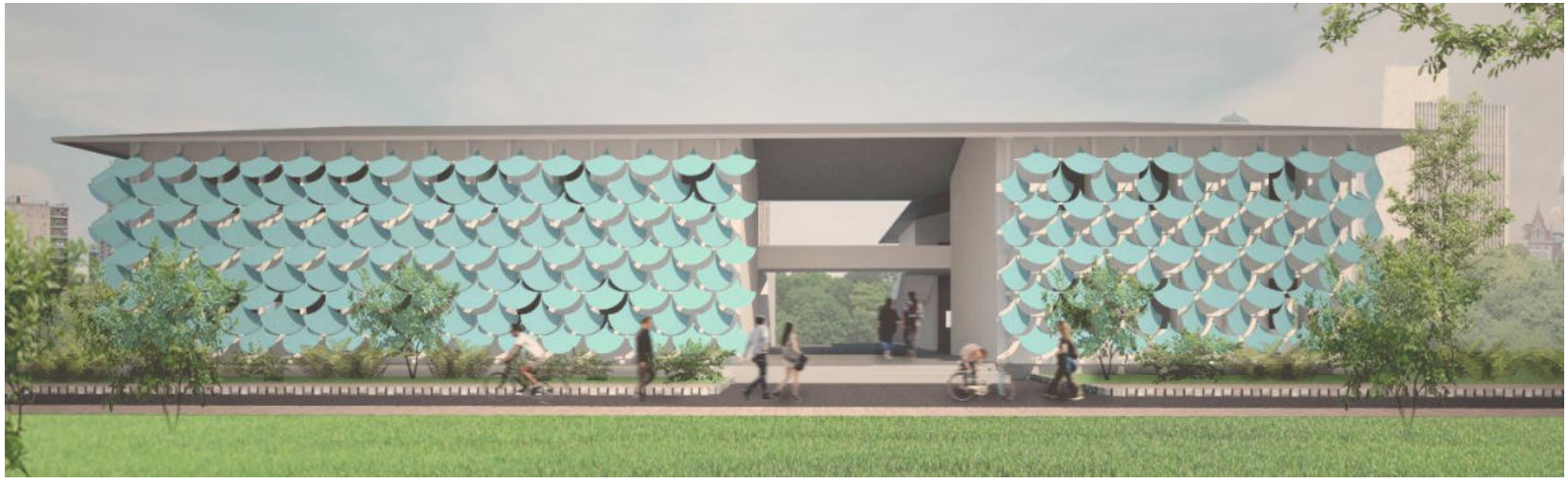


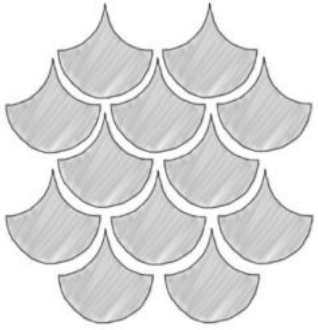




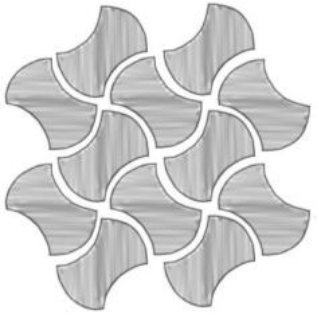


Shape 1

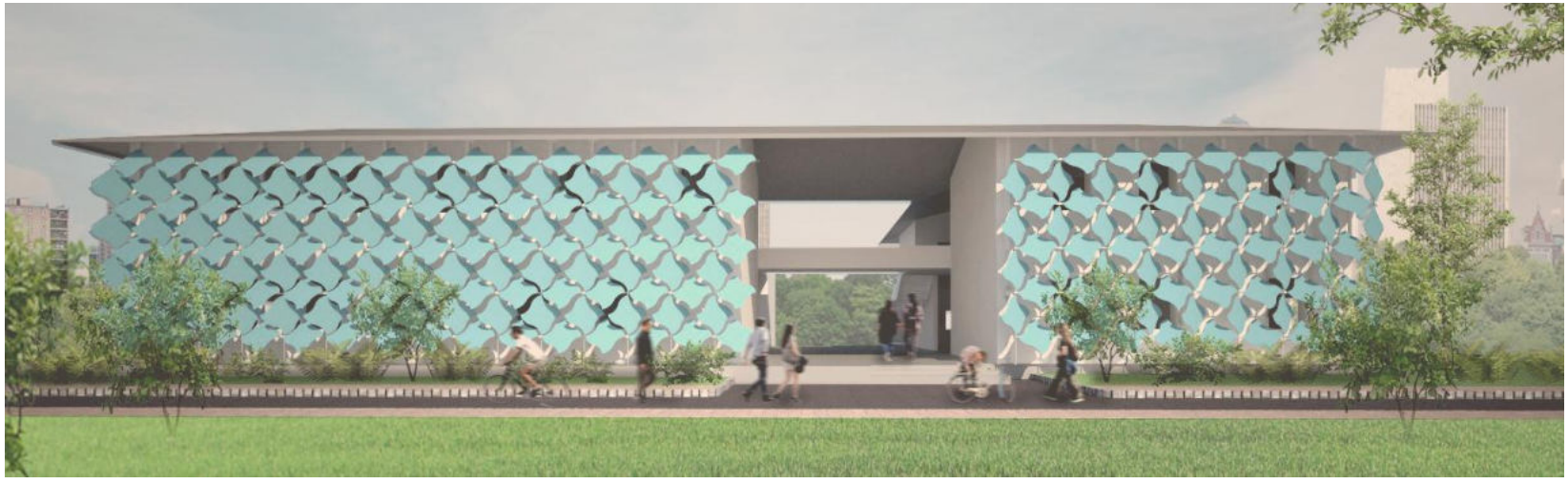


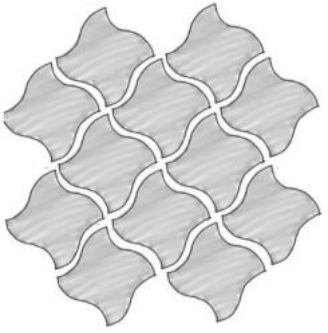


Shape 2



Shape 3



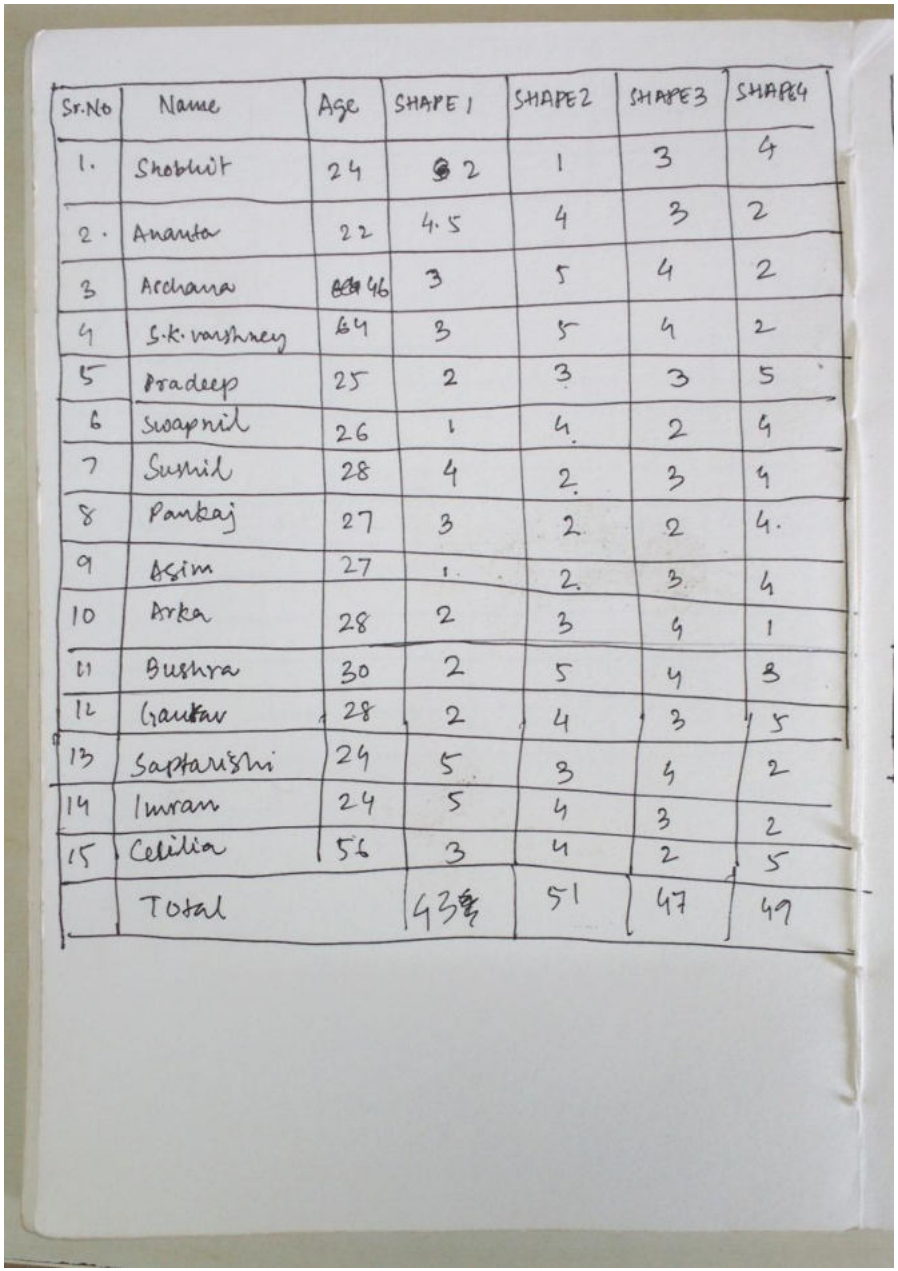


Shape 4

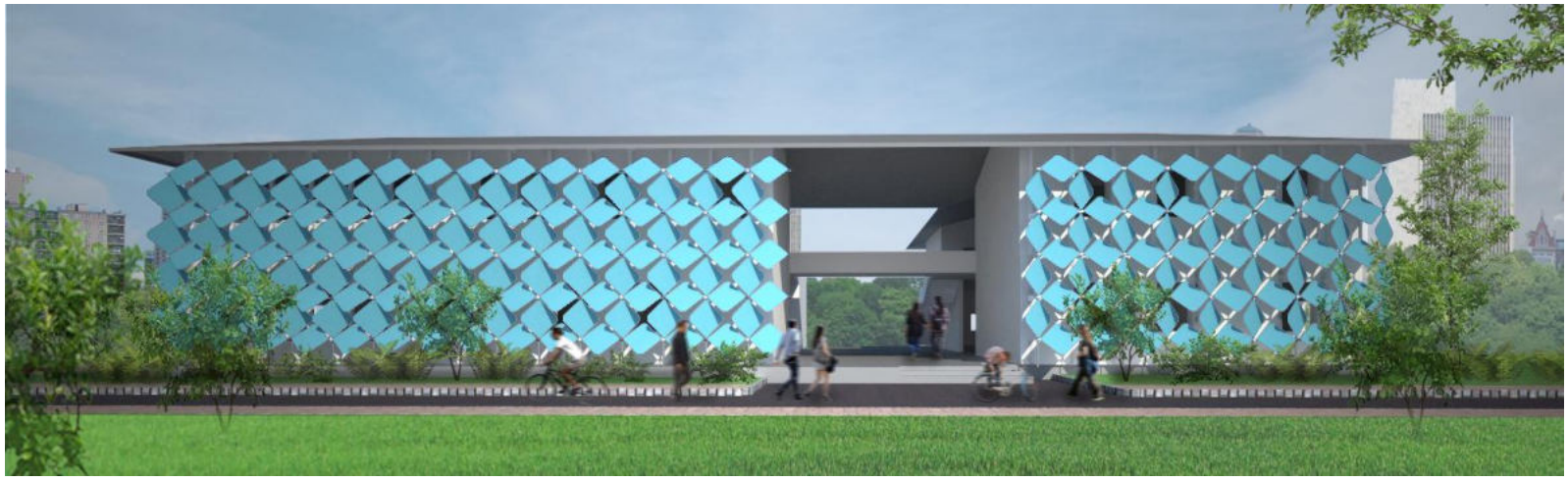
Shape Evaluation

Since the building was an NGO, different simple shapes which derived from the conventional Indian Jaalis were tried on the façade of the building and then evaluated by 15 people.

Shape 4 was considered after the evaluation.



Sr.No	Name	Age	SHAPE 1	SHAPE 2	SHAPE 3	SHAPE 4
1.	Shobhit	24	2	1	3	4
2.	Ananta	22	4.5	4	3	2
3	Archana	46	3	5	4	2
4	S.K. varshney	64	3	5	4	2
5	Pradeep	25	2	3	3	5
6	Swapnil	26	1	4	2	4
7	Sumit	28	4	2	3	4
8	Pankaj	27	3	2	2	4
9	Asim	27	1	2	3	4
10	Arka	28	2	3	4	1
11	Bushra	30	2	5	4	3
12	Gautav	28	2	4	3	5
13	Saptarishi	24	5	3	4	2
14	Imran	24	5	4	3	2
15	Celilia	56	3	4	2	5
	Total		43	51	47	49

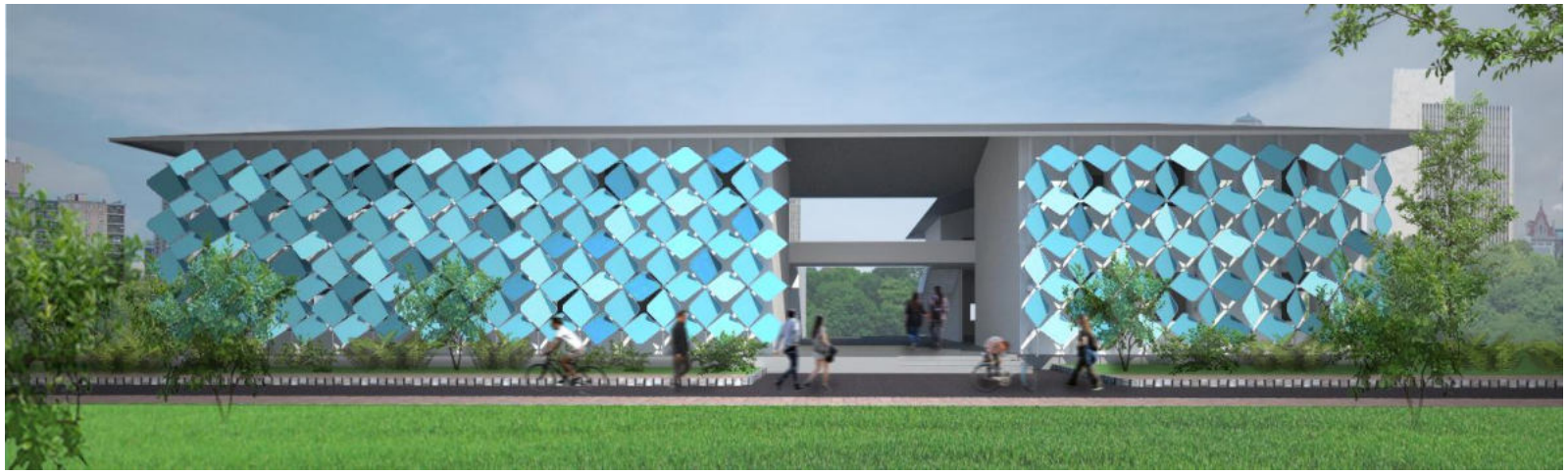


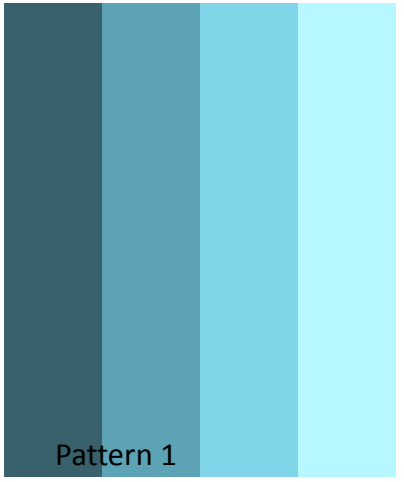
Color 1

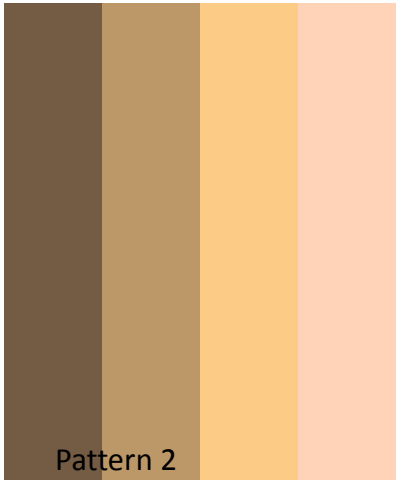
Color 2

Color 3

Color 4




Pattern 1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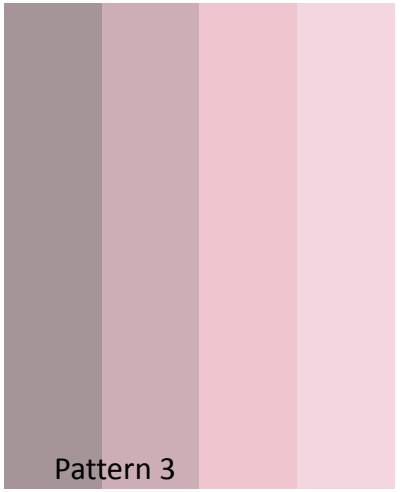
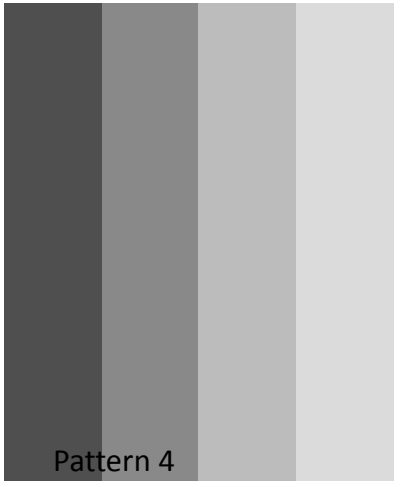
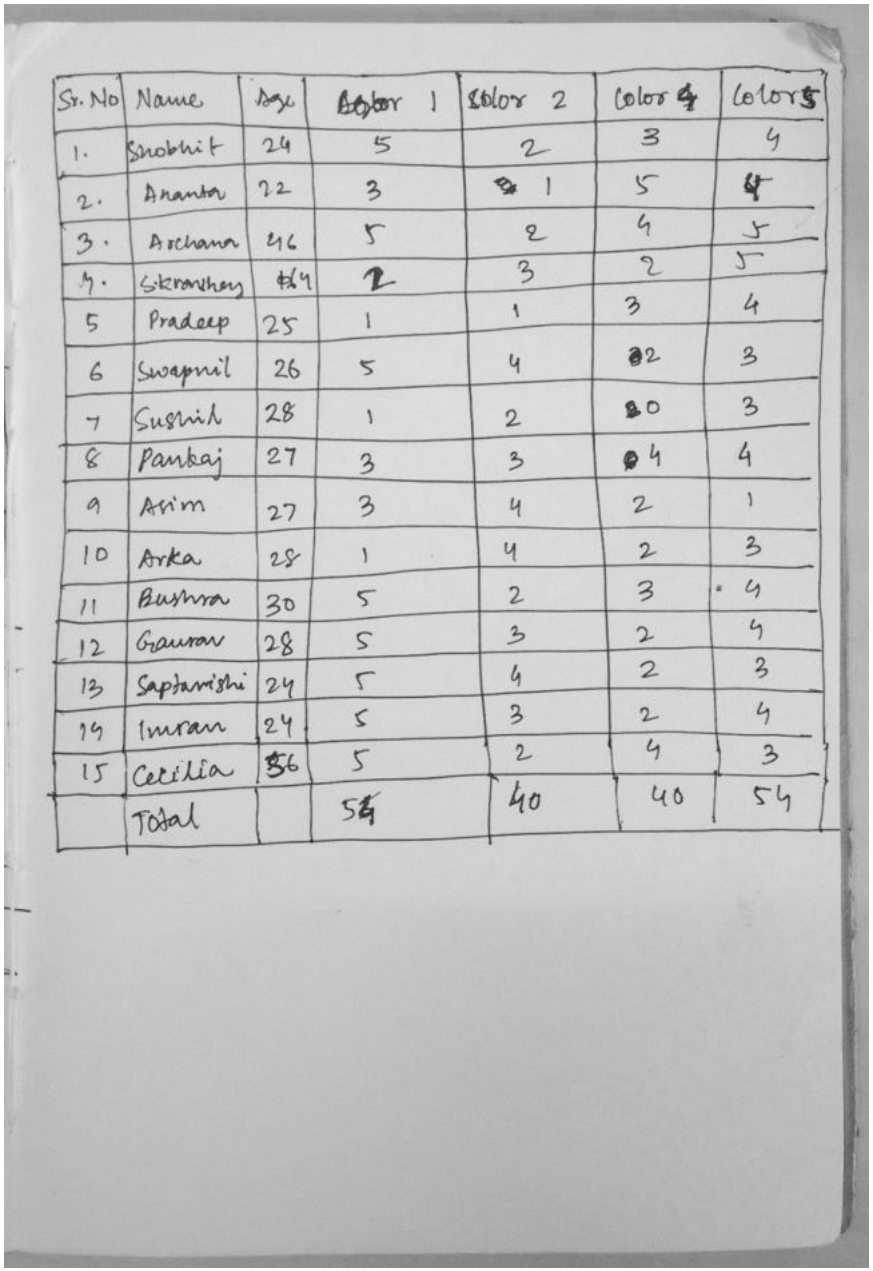

Pattern 3


Pattern 4

Color Evaluation

Different colors were also tried on the façade of the building and then evaluated by 15 people. Since it was an NGO and signifies the symbol of love and generosity, I chose more pastel like color as options. Then I also tried to put different gradients to make it more interesting to look.

Color 1 was considered after the evaluation.



Sr. No	Name	Age	Color 1	Color 2	Color 4	Color 5
1.	Shobhit	24	5	2	3	4
2.	Ananta	22	3	1	5	4
3.	Archana	46	5	2	4	5
4.	Sikrawhey	44	2	3	2	5
5	Pradeep	25	1	1	3	4
6	Swapnil	26	5	4	2	3
7	Sushil	28	1	2	0	3
8	Pankaj	27	3	3	4	4
9	Arim	27	3	4	2	1
10	Arka	28	1	4	2	3
11	Bushra	30	5	2	3	4
12	Gaurav	28	5	3	2	4
13	Saptarishi	24	5	4	2	3
14	Imran	24	5	3	2	4
15	Cecilia	56	5	2	4	3
	Total		54	40	40	54

Rendered view of the workshop block with the system.

CHAPTER 13

FUTURE POSSIBILITIES

Enterprise Model

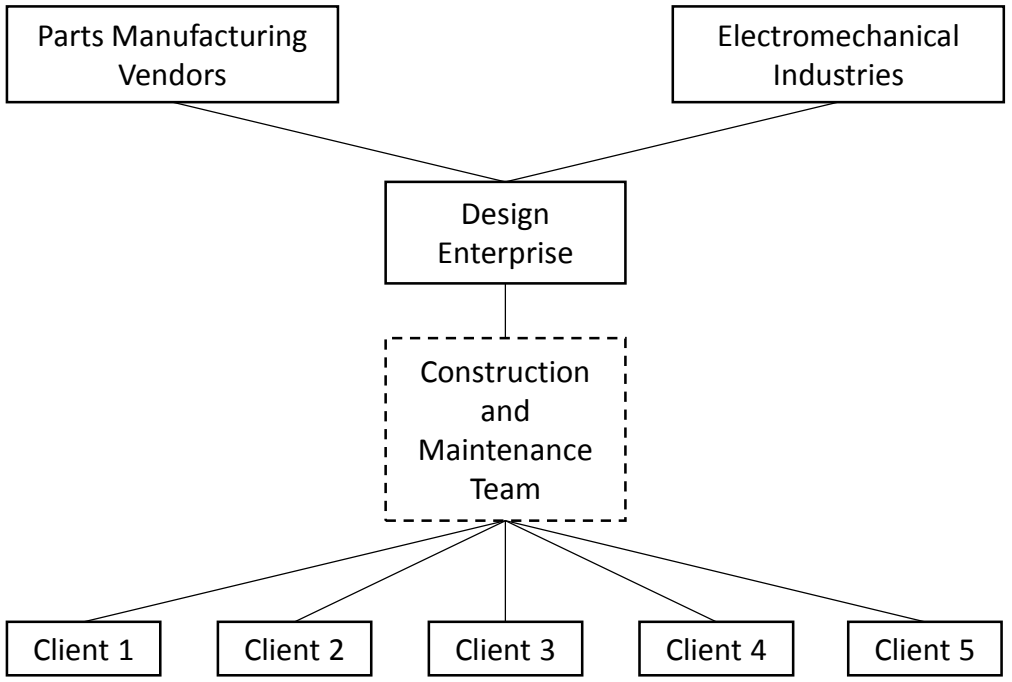
Further I realize that the product has also the potential to develop as an enterprise model which can be customized and developed according to the building requirements.

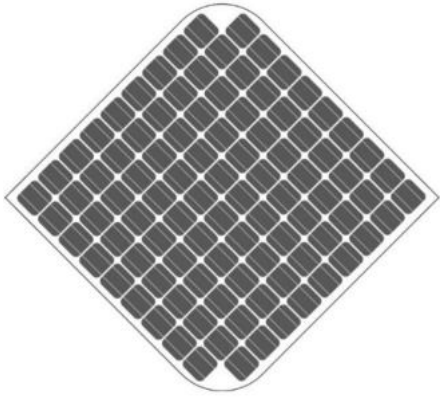
What is an Enterprise Model?

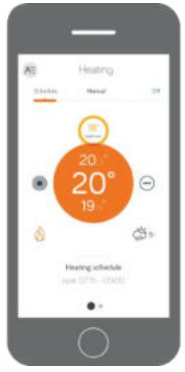
A business organization which work on a certain domain and follows a purposeful systematic method for its development and implementation.

Why the enterprise model?

- Since the design is modular, it has the potential to be replicated in a larger scale in any kind of commercial or institutional building but with certain restrictions.
- Since India has a summer dominated climate through most part year. The scope of the product increases since it can be used in many other geographical locations with similar conditions.
- The parts are mass producible. It can be easily transported and assembled on-site.
- The materials used are conventional and readily available throughout the country.
- The design is aimed at affordability.
- Customization- A number of choices for panel design would be provided. This would include the choices in color, shape and control of personal internal environment.







CHAPTER 14

FEEDBACK

Saw your Design….was really impressive…congratulation for the effort and this opens up a lot of possibilities in responsive architecture especially in naturally ventilated buildings I see potential of exploring it further…just a few quick comments…what about wind loads…what about horizontal surfaces say over a plaza, etc. can it will be equally effective?…can it store solar?

-Ar. Arka Banerjee
Halfbrick Architects
Kolkata

इस शोधपत्र में वर्तमान समय की एक महत्वपूर्ण चुनौती को गहराई से समझते हुए अपनी परिकल्पना (hypothesis) का एक सार्थक समाधान ढूँढने का प्रयास किया गया है। विशेष बात यह है की इस पूरी प्रक्रिया में स्थानीय परिदृश्य (local context) और सततपोषिता (sustainability) के सिद्धान्तों का भी ध्यान रखा गया है। विवरणिका में प्रस्तुत चित्रमुद्रण अत्यंत ही प्रभावशाली है।

-Prof. Nishant Bharadhwaj
McGAN's Ooty School Of Architecture

The art of heliotropism has greatly been explored through the design process, and learning through traditional systems. But a justified implication is rudimentary, as the designer is greatly influenced by self enforced preconceived notion of building in low cost. Apart from this the designer deserves a great appreciation for showing us that zoomorphism can also be achieved at such a low cost and with so much ease and simplicity. The beauty lies in its simplicity and open ends of exploration.

-Ar. Asim Bikash
Principal@Halfbrick

It was a wonderful effort seeing your project. Climate responsive building is the call of the day and the outcome that you have provided is definitely very welcoming.
Having said this, I would like to say that general people needs to be more aware of climate responsive buildings and this awareness may be attained through mass-scale programs.
Also, climate responsive buildings can be looked upon with low-cost so that it can be able to cater to all strata of the population.
Once again, I'll like to congratulate and thank you for this brilliant step forward towards this new horizon of architecture. Have a great future.

-Ar. Aritra Sardar
Principal@ASAR

Rendered view of the workshop block with the system.

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