Exploring Biotic Approaches in Performance Based Design

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Committee:

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Abstract

Exploring Biotic Approaches in Performance Based Design

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For any building, its façade provides the first layer of interaction with its environment, an optimum design can harness significant synergies while a linear design could considerably increase the energy consumption. As designers, we are required to make informed decisions and educate stakeholders of all potential criteria in selection of the design and engineering approach.

'My thesis goal is to develop such a framework for adaptive façade design based on biomimetic logic and value engineering and test it with parametric modelling. The design subject is a proposed low-income housing project enhanced with biophilic application to provide comfort at low cost.'

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This thesis is best viewed as a two-page spread with this page on left hand side.

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Acknowledgement

I would like to express my sincere gratitude to Prof. Rob Pena and Prof. Chris Meek for their great support, insight and encouragement in completing this thesis.

A big thanks to my parents, family and friends, for their continual encouragement and support.

For,

Ameya

Constant partner, fantastic guide and sharp critic

Exploring Biotic Approaches in Performance Based Design

A framework for adaptive façade design

Introduction

The need for a Framework and Value Optimization:

The 20th century approach in addressing environmental systems issues in building design resulted in built environments that exerted undue influence on ecosystems through reliance on energy intensive systems. This mechanistic technique to achieve optimum comfort conditions within the building system was one of the prime driving factors that led to increased carbon footprint of the real estate industry in the past few decades.

The 21st century awareness of this issue coupled with energy modelling technologies has helped the developed world in reducing its real estate carbon footprint and advance towards sustainable building design. However, for emerging economies around the world, it is not possible for small to medium sized firms to adapt these cost intensive technologies in their design practice. In such a scenario, a framework using easily available parametric tools can guide them for developing envelope systems that harness site positives and eco-friendly strategies to achieve comfort levels while being cost effective.

My thesis provides this framework for adaptive façade design, based on biomimetic logic and value engineering, and helps to test it with parametric modelling, using resources easily available to all design firms.

Chapter 1: Premise

Building Design and Comfort

***The Modern Envelope and Its Impact**: 20th century*

The need to build faster, lighter and aesthetically appealing building forms has been a major driving factor in the construction industry. Nearly 36% of the energy consumed[1] in the developed world today is used to heat, cool and light buildings i.e. to achieve optimum comfort in the built environment.

However, the definition of comfort has changed over the ages and that can be clearly observed in the transition in the way we achieve comfort in our buildings today.

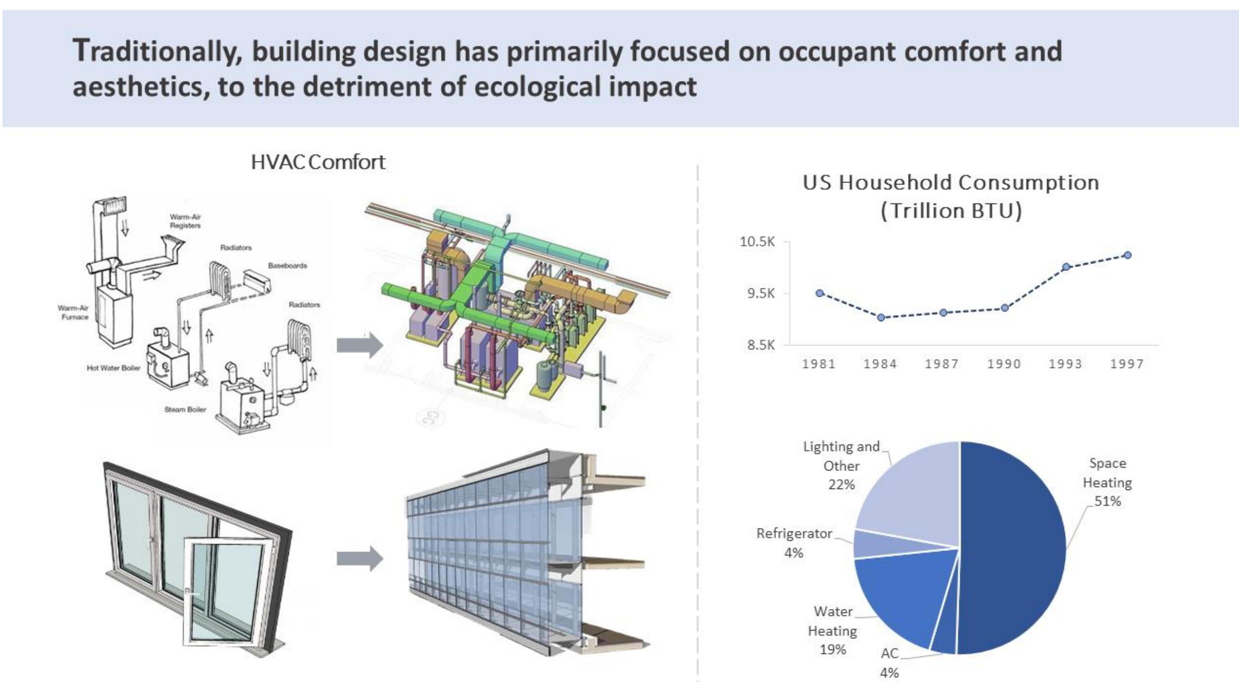

Figure 1: Data showing energy consumption trends from 1981-97 (Source IEA and stock photos)

[1] Source: IEA (international Energy Agency)

The reinvention of the traditional building fascia at the turn of the nineteenth century with new technologies that allowed mass production of glass, led to the widespread use of glazing as a part of the building facade. The use of glass envelope for the first time in the Hallidie[2] building built in 1917 by architect Willis Polk in San Francisco CA, marked the introduction of glazing systems in the US construction industry and reinvented envelope design for decades to come.

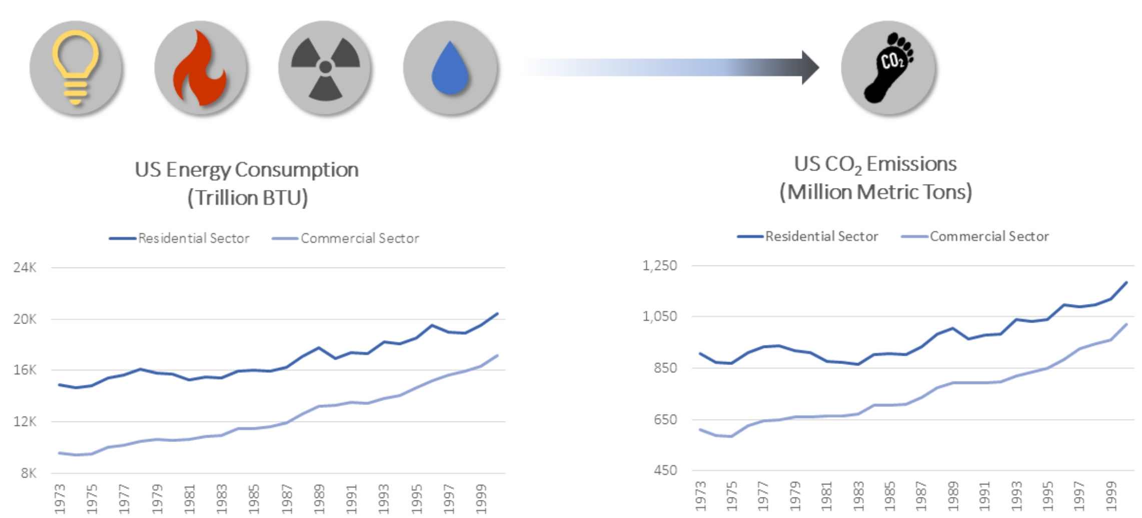

Figure 2: Energy Consumption and Co2 Emissions from 1971-93 (source IEA)

The modern façade meant that the mode of lighting, heating and ventilation underwent a massive transition over the past century. Designers and engineers realized that they were no longer completely dependent on climatic conditions to light and ventilate their buildings. These new systems however were not always adaptable to the local climate and led to overheating / overcooling or undesirable lighting conditions in the building. The need for mitigating these

[2] Sally B. Woodbridge and John M. Woodbridge. Architecture San Francisco—the Guide. San Francisco: 101 Productions, 1982 - referenced from www.greatbuildings.com

issues and to maintain optimum comfort conditions led to the rise of heavy HVAC systems that would often consume entire floorplates and a ton of energy!

The need to achieve optimum environment inside not withstanding what the outer environemnt presented changed the energy and carbon footprint of the construction industry. This *comfort-first* approach however has had a detrimental effect on environment and ecology at large.

IEA on its webpage quotes that '*The buildings and buildings construction sectors combined are responsible for 36% of global final energy consumption and nearly 40% of total direct and indirect CO2 emissions. Energy demand from buildings and buildings construction continues to rise, driven by improved access to energy in developing countries, greater ownership and use of energy-consuming devices, and rapid growth in global buildings floor area, at nearly 3% per year'*.[3]

The Modern Envelope and Its Impact*: 21st century awareness*

The acknowledgement of various implications of construction industry's high energy consumption and its ill-effects on ecology marked a shift in the linear design thinking pattern. The realization about global warming and how rising carbon footprint could be catastrophic led to the emergence of the idea of sustainable design. Change in design thinking commanded change in engineering systems and energy consumption patterns.

As a result, building industry in the developed world today largely focuses on reducing its carbon footprint by constant research and development in energy efficient building design technologies.

[3] Source: IEA (international Energy Agency)

A majority of this has been facilitated by the development of energy modelling technology. By understanding energy usage patterns, we can reduce energy consumption by applying appropriate technologies that address climate and user demands of a site.

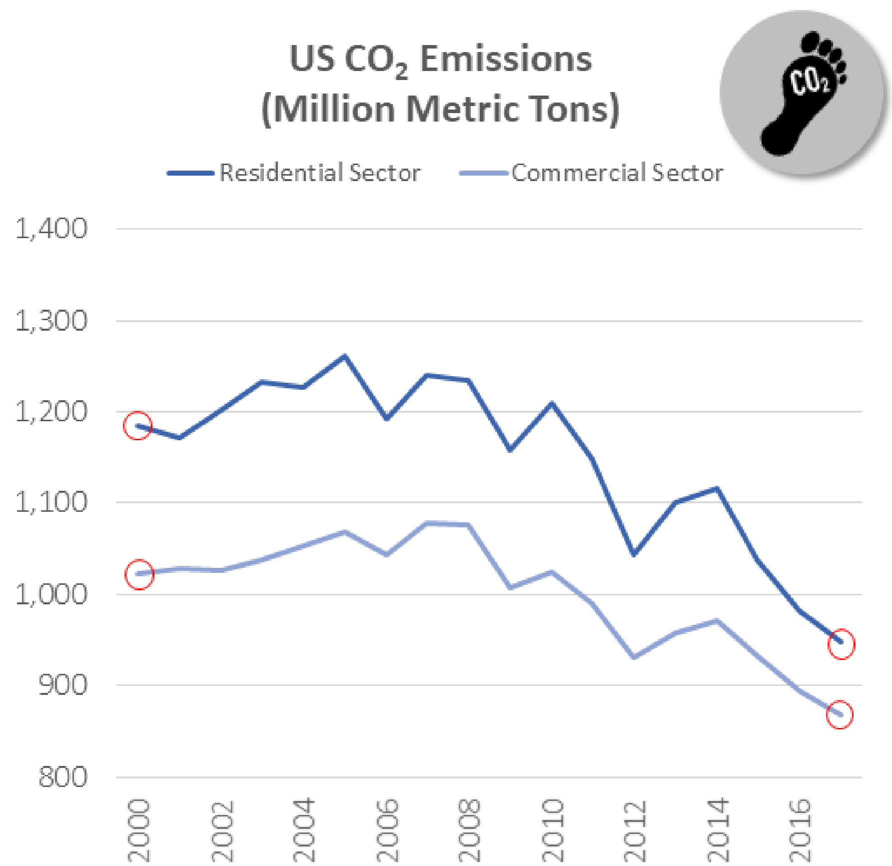

Figure 3: Graph showing steady reduction in carbon emission from year 2000-2016

The above graph[4] is a demonstration to this thinking where we can observe how environmental aware-ness has brought about a shift in carbon emission over a period of 15+ years. The need to adapt to changing climate has been a major driving force that has led to the rise in number of clients seeking sustainable designs and avail technologies that help them lower their building carbon footprint.

[4] Source: IEA

Technology and Façade Design

The 21st century awareness of energy conservation coupled with investment in energy modelling technologies has helped the developed world in developing façade systems that greatly improve the building performance and move towards a sustainable future.

Figure 4: Some Energy modeling software widely used in construction industry today (logos as per brand)

However, for emerging economies around the world, it is not possible for all design practices to adapt these cost intensive technologies in their day to day design practice. Energy modeling requires expensive software and external consulting services, which may not be easily accessible and affordable for small-to-midsize design firms.

As architects it is necessary to understand the implications of aspects that would help achieve the optimum façade design to realize the best possible proportion of function to cost i.e. to design buildings that perform and provide value in terms of Return on Investment.

Savings in EUI[5] (Energy use Intensity) can be translated to savings in cost of operations while reducing the impact on its environment.

[5] A building's EUI is the ratio of the energy consumed in one year to the gross floor area of the building.
EUI = kBtu/sf-yr

Achieving Optimization in Façade Design

Why Façade?

The façade of a building like animal *skin* is its point of interaction with the environment. This envelope has a responsibility to protect its inhabitants and provide comfort and drive energy requirements within the building. This is the first layer of the building which is showcased to the world and as designers we need to make an informed choice when decisions are made so that all stakeholders are aware of all possible criteria for developing an optimum design and the mode of engineering it.

In traditional architectural practice, the building façade trend (where no energy modelling is performed) is usually to achieve the baseline R/U value through market ready facade systems. However, by defining a framework using parametric modelling and value assessment tools (that can help in guiding the decision-making process) an understanding of all possible variations that a design problem can afford in forms of possible solutions can be availed to transition from a 'façade' to 'Performance based envelope' -a high functioning system to achieve the required design intent.

In such a scenario, a framework using easily available parametric tools can guide emerging design practices for developing envelope systems that harness site positives and eco-friendly strategies to achieve comfort levels while being cost effective.

Chapter 2: Biotic Thinking

Man, Nature and the Built Environment

The built environment can be defined as a physical product of social, economic, philosophical and intellectual ideologies of an era[6]. The machinery's main gears are humans and nature, with economics often being the fuel. Each built environment is a creation of varied percentages of the participating elements and the dominance of one participant over other governs the graph for its development.

The modern built environment is thus a product of this complex and dynamic association and has evolved through thousands of years. With the turn of each century it assumes new characteristics pertinent to that age and showcases the technological and intellectual advancement that takes place with time.

[6] King, Anthony, in "Buildings and Society: Essays on Social Development of the Built Environment"

Biotic Thinking

Figure 5: *Nature in the built environment (Image Source-* https://asuevents.asu.edu/content/biophilia*)*

Along with the evolution of the Built environment the relation between its two main pillars- man and nature, has also transitioned consistently. With the passage of time, what began as an association of reverence and fear towards nature progressed steadily to that of respectful stewardship in the middle ages till early eighteenth century and then transitioned to dominance during the industrial revolution, which continues till date.

This transition can be observed through the architectural treatment of nature as noted by Ian McHarg – 'from the early period wild moors of the English country side to the cultivated gardens of the rich colonial estates and Churches during renaissance, the greenhouses built by the Victorian societies to the Glass office buildings commissioned by post-modernists- the inclusion of nature as a part of built environment gradually condensed while man's command and commodification of it steadily amplified, especially with the rise of the modern city'[7].

The 21st century realization, that a built environment is as much dependent on nature as it is on its human component to function successfully led to the rise of ideas like Biophilia[8], Biomimicry, Organic Architecture, Bionic Architecture etc.

The thesis will briefly explore Biomimetics and Biophilic ideologies and applications in architecture. The precedents help to provide an insight into real world applications.

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[7] McHarg, Ian, in "The Essential" chapter 2: 'The place of Nature in the City of Man'
[8] Wilson, Edward in his book- 'The Bio-Philia Hypothesis'

Biomimetics

'Biomimetics is a portmanteau word fabricated from the words biology and mimesis (imitation)'[9]. It is an understanding and application of physiological tactics used by natural systems like plants and animals to adapt to the microclimate. Biomimetics in architecture is a way of applying natural design thinking i.e. Biotic adaptation into architectural design thinking.

Biotic Adaptations in Cactus

Structural Adaptations

modifications in physique/body that aid in adapting to its

Adaptation to thorny leaves help reduce water loss in response to the harsh desert climate

Physiological Adaptations

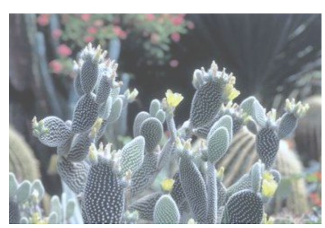
modifications in life processes that aid in adapting to environment

Slow growth rate of desert plants means less energy spent in life processes

The cactus showcases the ultimate example of biotic adaption to its environment. By adapting to its site condition, it thrives even in the harshest climatic conditions.

Behavioral Adaptations

modifications in actions and responses that aid in adapting to environment



Desert flowers remain dormant to conserve energy in hot months

Figure 6: Example | Adaptations in cactus plants in response to desert climate (Image source: stock photos)

[9] G. Pohl, J. Pohl in the chapter 'The role of textiles in providing biomimetic solutions for construction'-, in the book Textiles, Polymers and Composites for Buildings.

Biomimetics| Precedent

Proposed MMAA Office Doha, Qatar | Aesthetics Architects, Bangkok

Figure 7: MMAA Office Building| Bangkok-based Aesthetics Architects GO Group (Image Source: www.Inhabitat.com)

Client: Ministry of Municipal Affairs & Agriculture |Qatar, Doha

Estimated Project Cost: $100M

Date of Completion: Design Competition 2009

Overview:

The MMAA (Ministry of Municipal Affairs & Agriculture) building, dubbed the cactus project[10] has been designed as a net zero energy building.

Figure 8: MMAA building | Proposed interior view (source: Aesthetic Architects)

The design by Aesthetic architects based in Bangkok takes inspiration from local biology of Doha - the Cacti plants. Adopting structural adaptations seen in cactus which helps the plant in thermoregulation and water conservation, the building uses the concepts of dynamic shading and ventilation systems to respond to its microclimate. By opening out the building at night to flush out heat the building achieves energy efficiency.

The dome at the base of the tower will house a botanical garden which could include a garden for visual relief and use plants to clean up waste water.[11]

[10] Sprey, Karen in 'Qatar's giant cactus: a shining example of biomimicry' for New Atlas Magazine
[11] Inhabitat.com

Biophilia

'What if we could experience the same physical, psychological, and emotional benefits moving through an urban landscape that we experience walking through a forest'[12] this premise forms the fundamental crux of the concept of Biophilia. Simply put, Biophilia means the 'the human urge to associate with their natural surroundings'.

As a biological researcher, E. O. Wilson put forth the hypothesis that human beings have a subconscious urge to bond and develop kinship with other life forms. In his book 'The future of life' he maintains that humans are drawn to imageries and objects from primitive nature since they provide familiarity and comfort, a habit formed as a part of our genetic predisposition towards our environment during the process of evolution[13].

Wilson along with socio-ecologist researcher Dr. Stephen Kellert developed the concept of 'Biophilic design', which studied the health benefits of direct association between people and nature in the built environment.[14]

Kellert further proposed that humanity is "*integral to, and not separate from, the natural world*" and was instrumental in introducing the fundamental green design principals.

[12] Sturgeon, Amanda in essay "Creating Biophilic Buildings"
[13] Wilson, Edward in "The future of Life" chapter 6: 'For the Love of Life'
[14] Wilson, Edward and Kellert, Stephen in 'The Biophilia Hypothesis'

Biophilia | Precedent

Amazon Spheres, Seattle WA | NBBJ Architects USA

Figure 9: Seattle Spheres at Amazon Campus, (Source: NBBJ architects)

Client: Amazon |Seattle, WA, USA

Estimated Project Cost: $4.0 B

Date of Completion: Completed 2017

Overview:

Figure 10: Seattle Spheres| Internal Environment (source: NBBJ Architects)

The Spheres: a multi-story, glass-enclosed workplace containing tens of thousands of plants and trees from around the world.[15]

This $4.0 Billion investment by tech giant Amazon into three spheres harboring waterfalls, a river, even treehouse like spaces overlooks tropical gardens with over 25000 plants from all over the world is an adaptation of the Biophilic ideology. This modern greenhouse was designed with an aim to provide employees and their families "*an immersion, an instant connection to nature*[16]," in the dense downtown area of Seattle these spheres were designed to be an office space away from office.

[15] Source: NBBJ Architects (http://www.nbbj.com/work/amazon/)
[16] Source: NBBJ Architects (http://www.nbbj.com/work/amazon/)

Chapter 3: Framework

Framework Design

A building's façade is its point of interface with the immediate surrounding, and an optimum façade design can harness significant synergies while a linear, comfort-only focus could considerably increase the energy consumption. The frame work is inspired from Sim Van der Ryn's philosophy of ecologically sensitive inquiry pertaining to design synthesis:

- What kind of nature exists in a site?
- What will nature allow a designer to build on the site?
- How can nature help the designer achieve his design intent?

By answering these three questions with the help of parametric analysis and applying biotic design thinking, a framework is generated that can help identify the process for optimum façade design for smaller firms who do not have access to complex energy modelling tools and technologies and applying it to a design problem as way of example explanation; which the aim of this thesis is.

'My thesis provides a framework for adaptive façade design, based on biomimetic logic and value engineering, and helps to test it with parametric modelling, using resources easily available to all design firm'

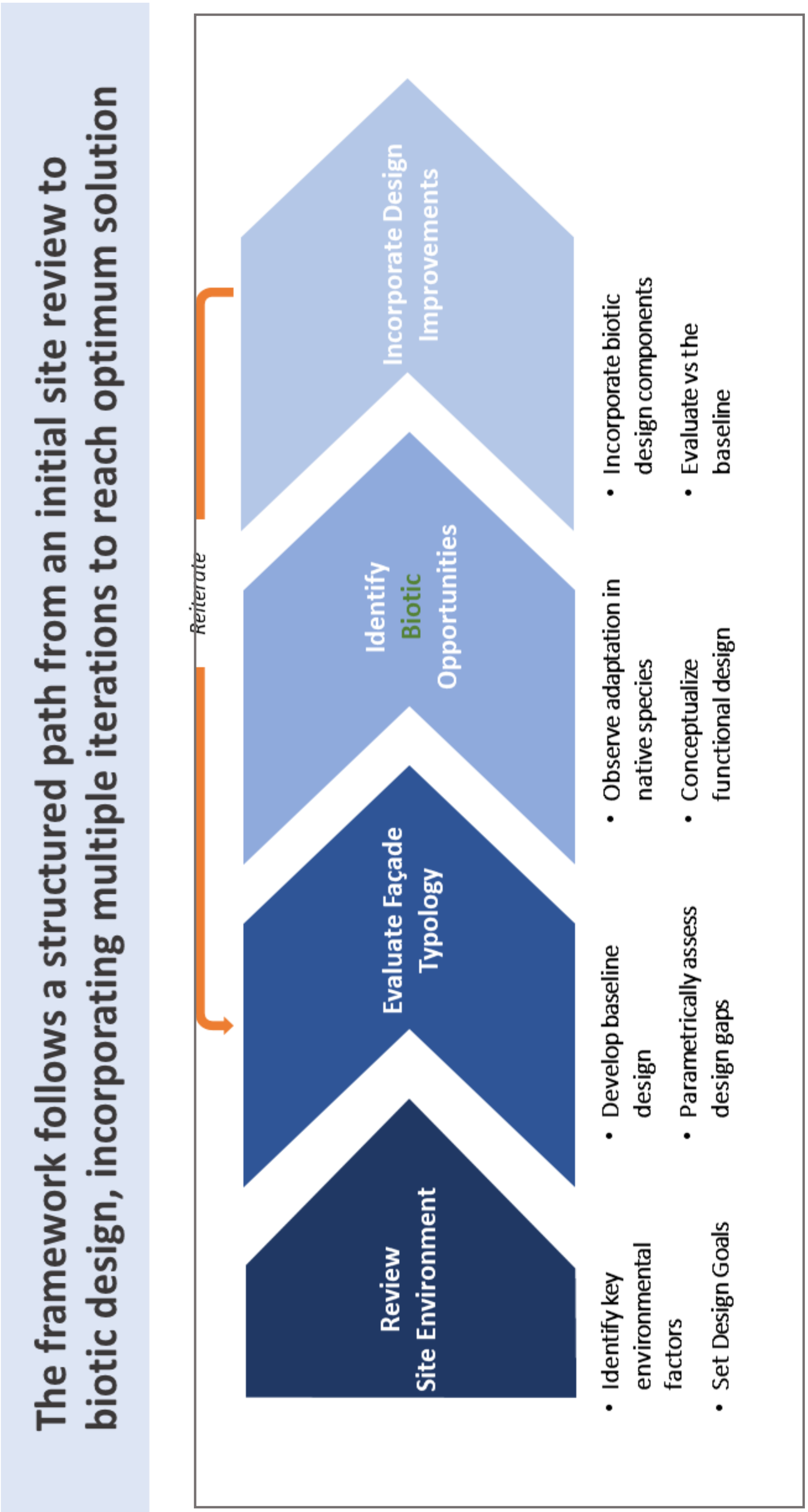


Figure 11: Biotic Design Framework

Design Application

The design application follows the framework to display how it works on an actual project

Design Problem: Neighborhood Revival in Mumbai, India

An existing, self-evolved low-income housing settlement was identified and approved for city funded upgrade by the local governing council. The upgrade required cost effective, thermally comfortable design with high energy efficiency.

Key Design Goals:

- Thermal Comfort
- Visual Comfort
- Cost Efficiency
- Energy Efficiency

The initial design inspiration was based on the principal of 'container city'. Mumbai being a port city has access to shipping yards and unused shipping containers. By utilizing these as the building block-*the skeleton* of each individual house and layering it with energy efficient design decisions using the framework, the existing settlement would be upgraded to provide the families a humanized environment to dwell in.

The design solution proposed a seamless integration of the container city with landscaped multi-purpose community areas that could be used for recreation and movement and incorporate the ideology of Biomimetics and Biophilia

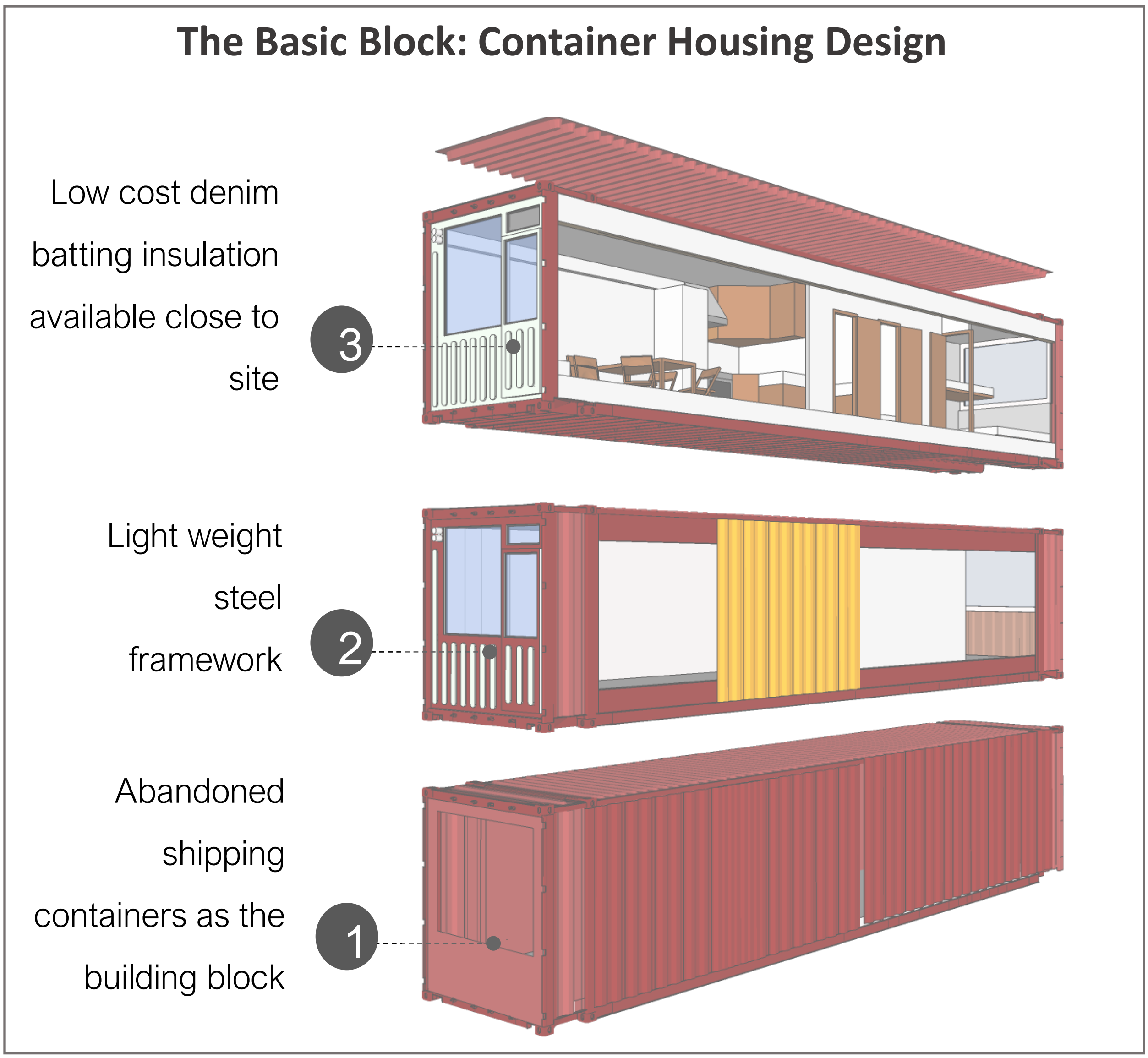
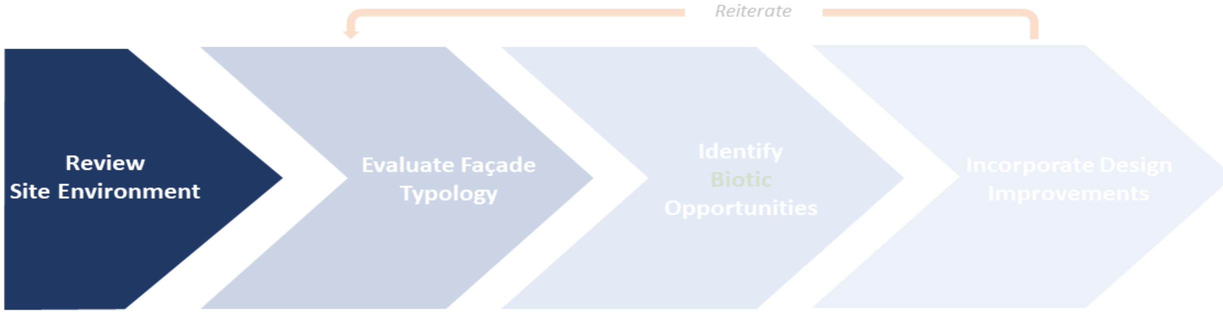


Figure 12: The container house

01: Review Site Environment



Tools: Climate Consultant[17] or Blogspot by Dr. Andrew Marsh[18]

The framework proposes that *nature* should be the foremost line of inquiry. By analyzing the site, its physical parameters and local climate it is possible to guage the environmental factors that potentially affect the façade design.

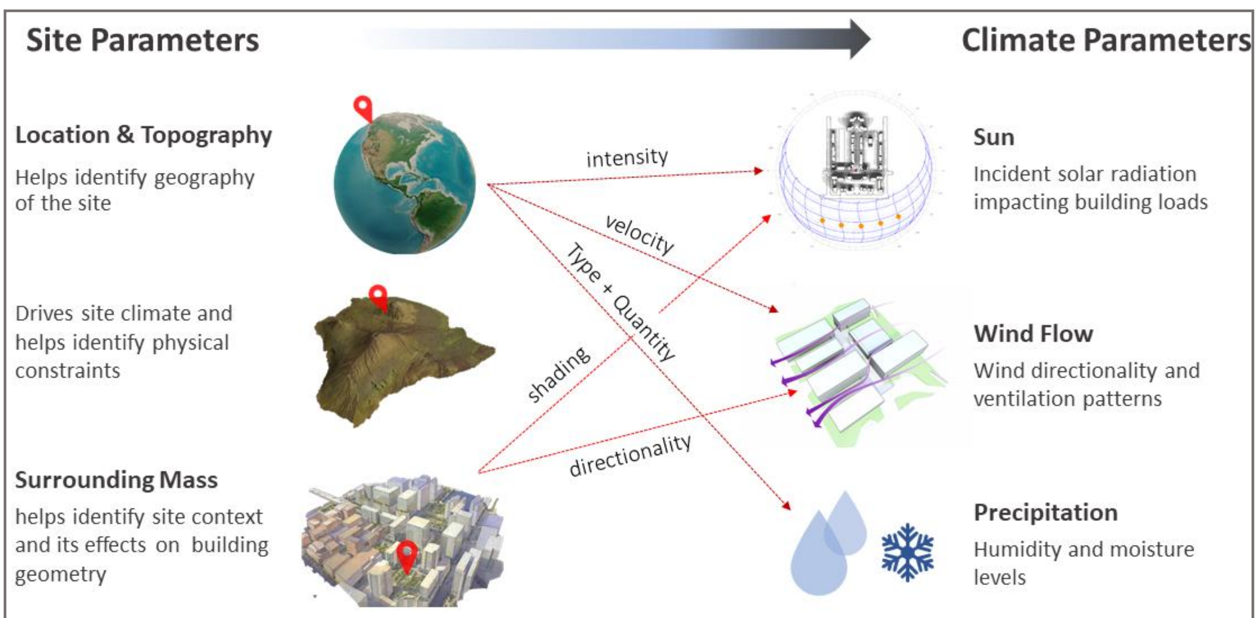


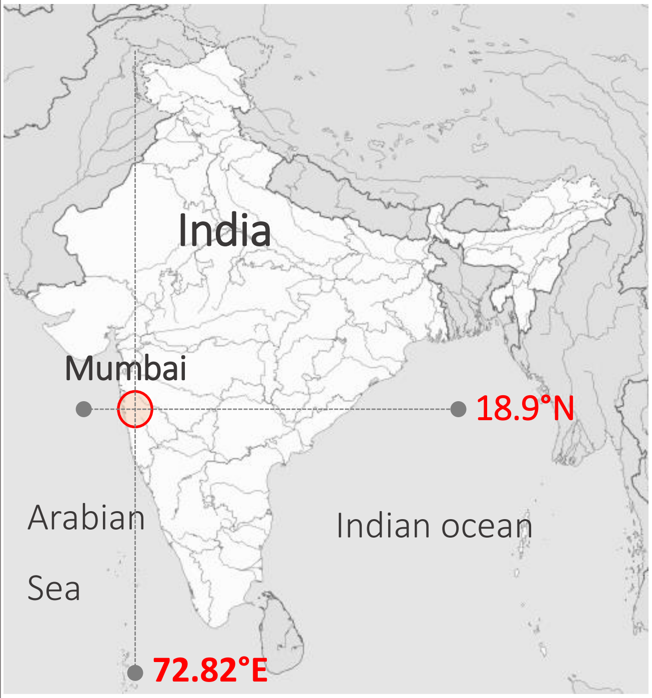
Figure 13: Nature as the first line of inquiry

[17] Climate Consultant is a graphic tool to understand and interpret local climate data. (Developed by UCLA Energy Design Tool group)

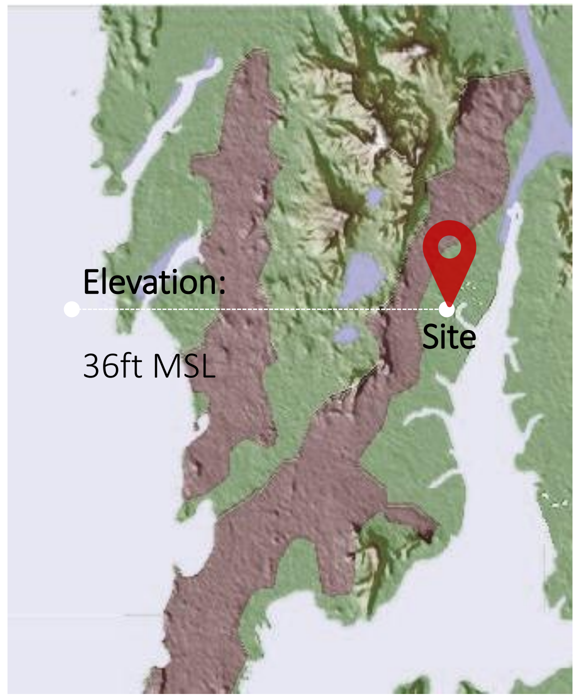
[18] Online tool that helps in assessing climate and site data (Copyright Dr. Andrew Marsh and Ref: http://andrewmarsh.com/software/)

01: Review Site Environment: Low income housing site in Mumbai

Location:_Mumbai, India



Mumbai Topography Map (NTS)



Site Massing

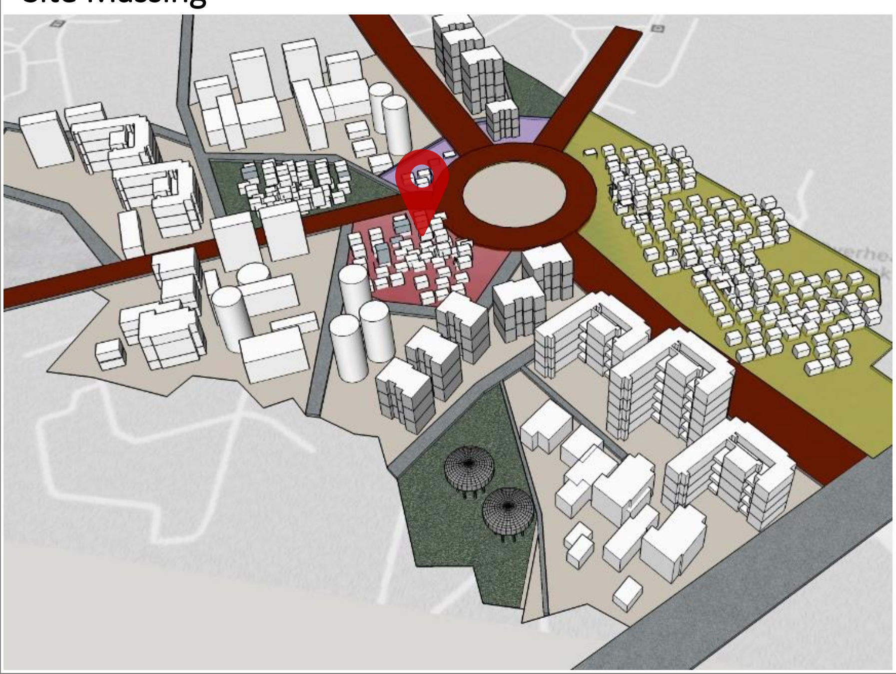


Figure 14:

The three images shown here depict the location, mean elevation and site massing for design problem.

The data shows that the site is located on a relatively flat mass close to the sea with proximity to freeway along its NE boundary.

(Data+Maps: Gov/Survey of

01: Review Site Environment: Low income housing site in Mumbai

Deriving Climate data using Climate Consultant as tool.

Data Analysis: Mumbai has tropical wet and dry climate, a high sun angle with seven months of dryness and peak of rains in July with wind directionality from SW to NE. (analyzed using Köppen climate classification)

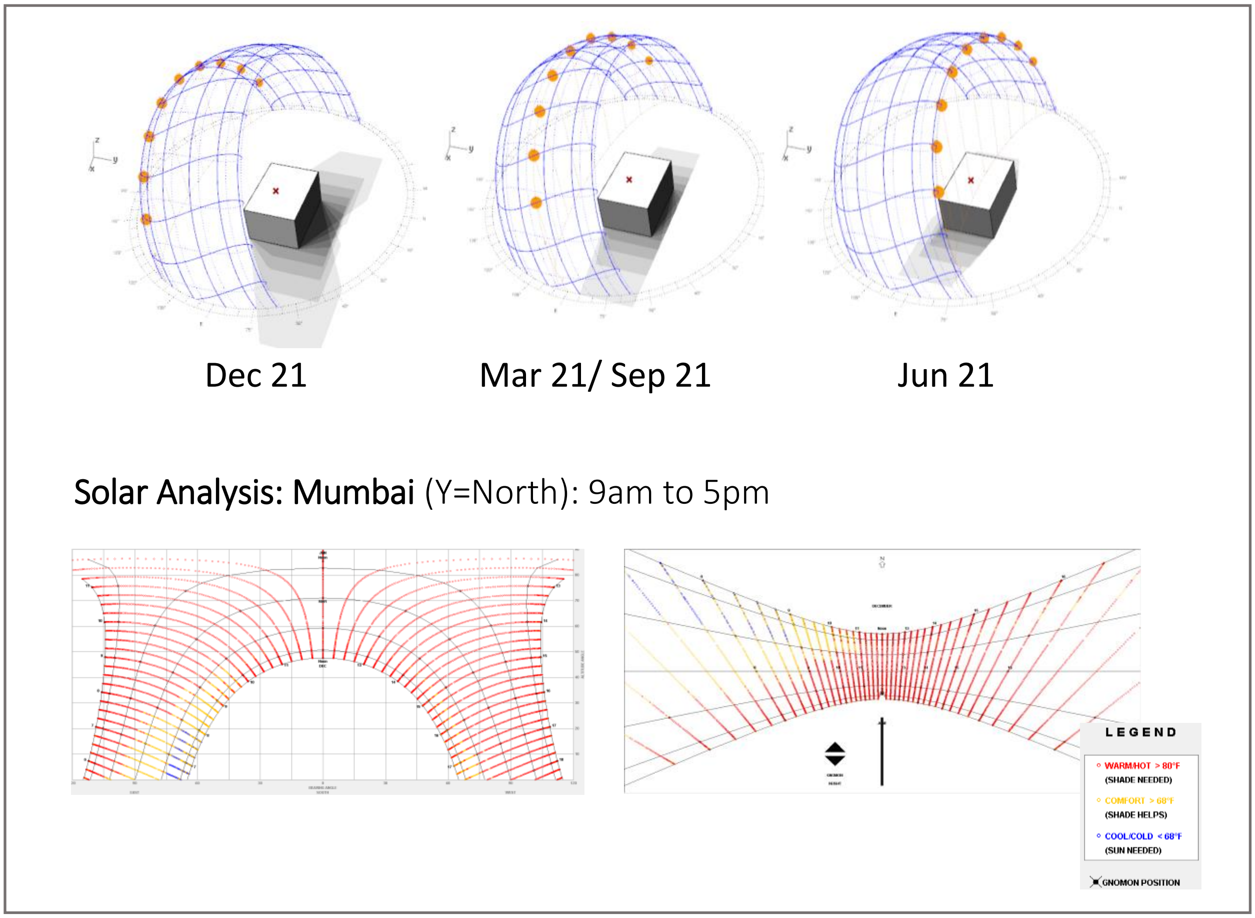
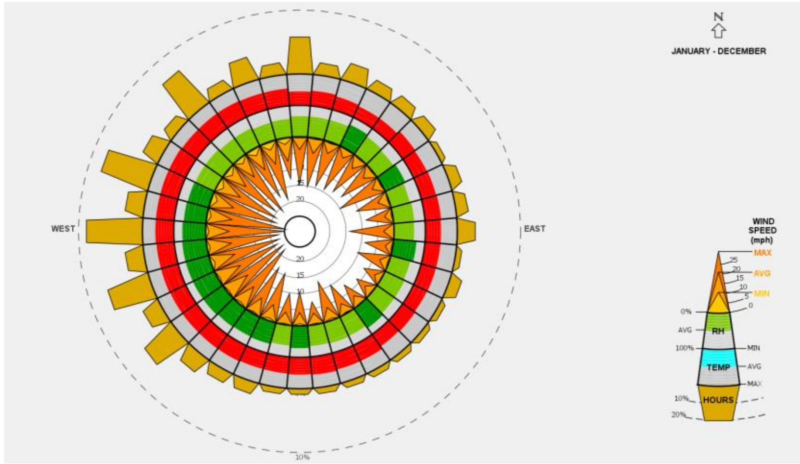


Figure 15: Sun Shading Diagram



Wind Rose

Climate data for Mumbai (Chhatrapati Shivaji International Airport) [hide]													
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C (°F)	37.1 (98.8)	39.6 (103.3)	41.7 (107.1)	42.2 (108)	41.0 (105.8)	37.1 (98.8)	34.8 (94.6)	33.5 (92.3)	36.4 (97.5)	37.9 (100.2)	37.4 (99.3)	39.8 (103.6)	42.2 (108)
Average high °C (°F)	30.7 (87.3)	31.2 (88.2)	32.5 (90.5)	33.0 (91.4)	33.3 (91.9)	32.1 (89.8)	30.0 (86)	29.6 (85.3)	30.4 (86.7)	33.2 (91.8)	33.5 (92.3)	32.0 (89.6)	31.8 (89.2)
Average low °C (°F)	16.8 (62.2)	17.8 (64)	21.0 (69.8)	23.9 (75)	26.3 (79.3)	26.0 (78.8)	24.9 (76.8)	24.7 (76.5)	24.3 (75.7)	23.4 (74.1)	20.9 (69.6)	18.6 (65.5)	22.4 (72.3)
Record low °C (°F)	7.4 (45.3)	8.5 (47.3)	13.8 (56.8)	16.9 (62.4)	20.2 (68.4)	19.8 (67.6)	21.2 (70.2)	19.4 (66.9)	20.7 (69.3)	16.7 (62.1)	13.3 (55.9)	10.6 (51.1)	7.4 (45.3)
Average rainfall mm (inches)	0.6 (0.024)	1.3 (0.051)	0.2 (0.008)	0.7 (0.028)	12.5 (0.492)	523.1 (20.594)	799.7 (31.484)	529.7 (20.854)	312.3 (12.295)	55.8 (2.197)	16.8 (0.661)	5.3 (0.209)	2,258 (88.898)
Average rainy days	0.1	0.1	0.0	0.1	0.7	14.5	23.2	21.4	14.4	3.0	1.0	0.4	78.9
Average relative humidity (%)	69	67	69	71	70	80	86	86	83	78	71	69	75
Mean monthly sunshine hours	269.5	257.6	274.3	283.7	296.2	148.6	73.4	75.9	165.1	240.2	245.8	253.2	2,583.5
Source #1: India Meteorological Department (Period 1961–1990, record high and low up to 2010)[2][3]													
Source #2: NOAA (humidity, sun 1971–1990) [4]													

Precipitation & Temperature Range Table

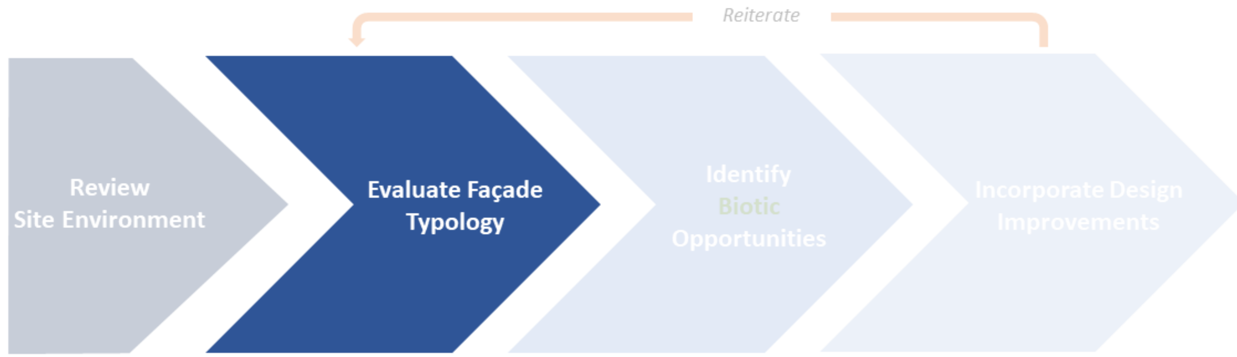
Figure 16: Temperature and Wind Flow analysis

Analysis:

The difference in precipitation between the driest month and the wettest month is 835 mm. The variation in annual temperature is around 6.0 °C with monsoon being characterized by heavy westerly winds.[19]

[19] Source: Tata institute of Fundamental Research, Mumbai, India

02: Evaluate Façade Typology



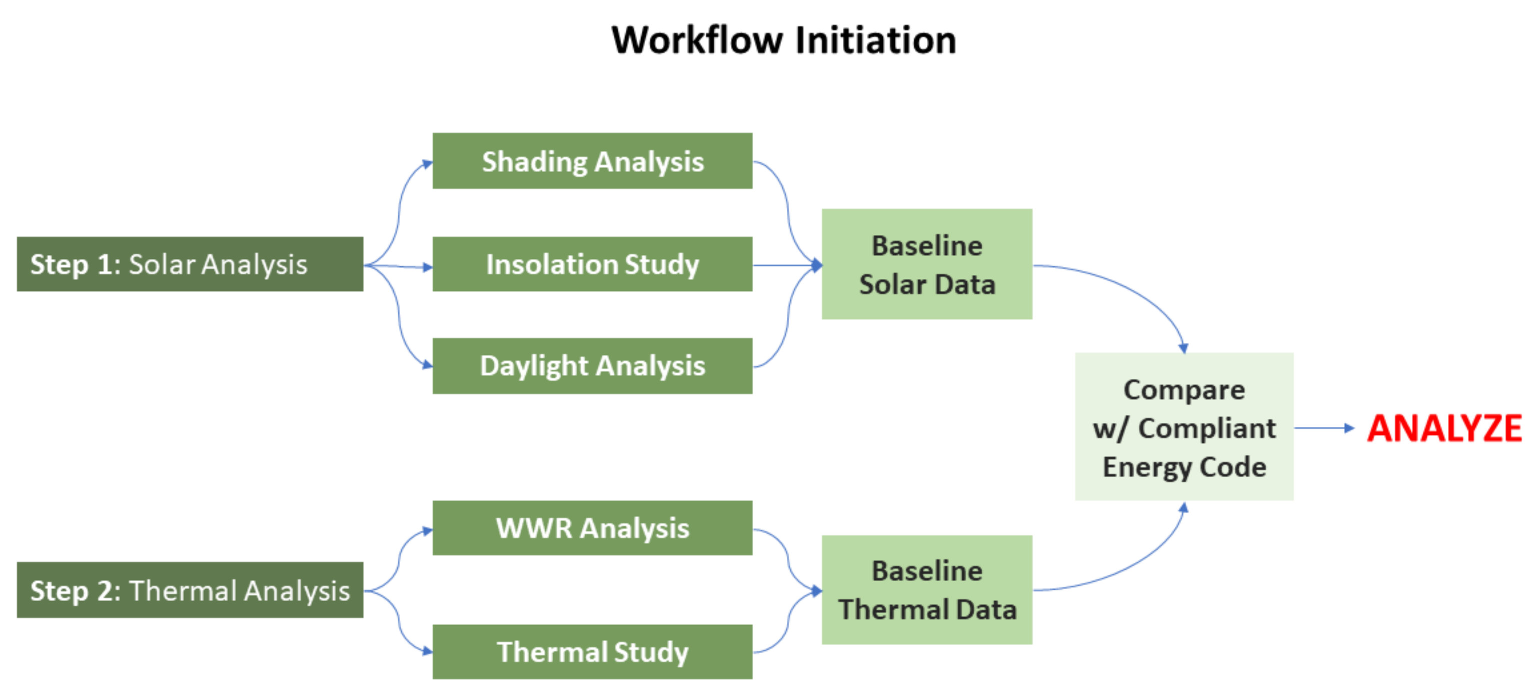
Tools: Rhino (Diva/Grasshopper) + Andrew Marsh

Environmental Factors and Load Design

Adopting *Environmental factors* as first line of inquiry in design thinking helps in maintaining a balance between daylight and ventilation, overheating and heat control, passive solar gain and energy efficiency by capitalizing on the incident solar and wind energy while providing an environment which safeguards the building system against impact damage, vandalism and fire hazard.

Environmental factors help understand the type of load a façade must balance. For example, if the incident solar radiation and heat gain is high the type of load would be cooling load whereas if the design is heating dominated the type of loads would be heating loads. Type of load can help dictate the parameters a façade should achieve to achieve optimum comfort condition within the building.

❷ Evaluate Façade Typology: Establish baseline building design for each façade component to identify strategies



Workflow Initiation

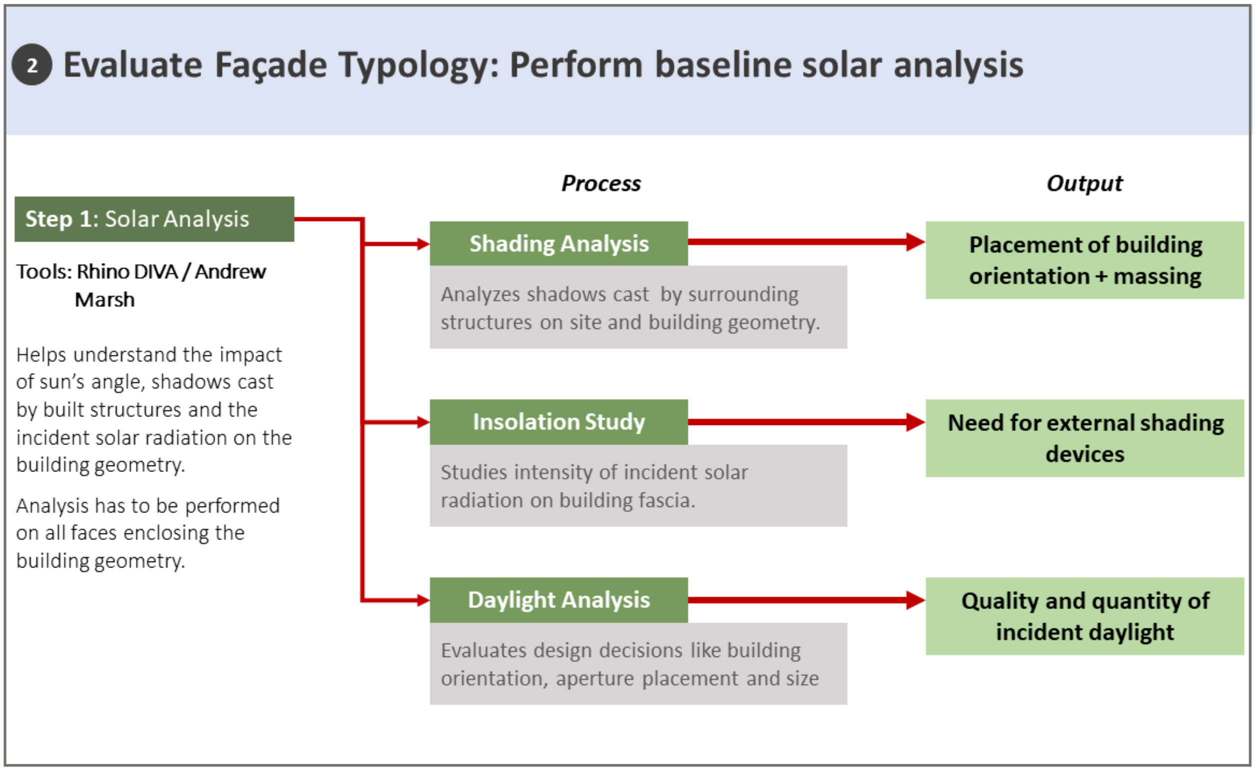


Figure 17: Step 01-Solar Analysis

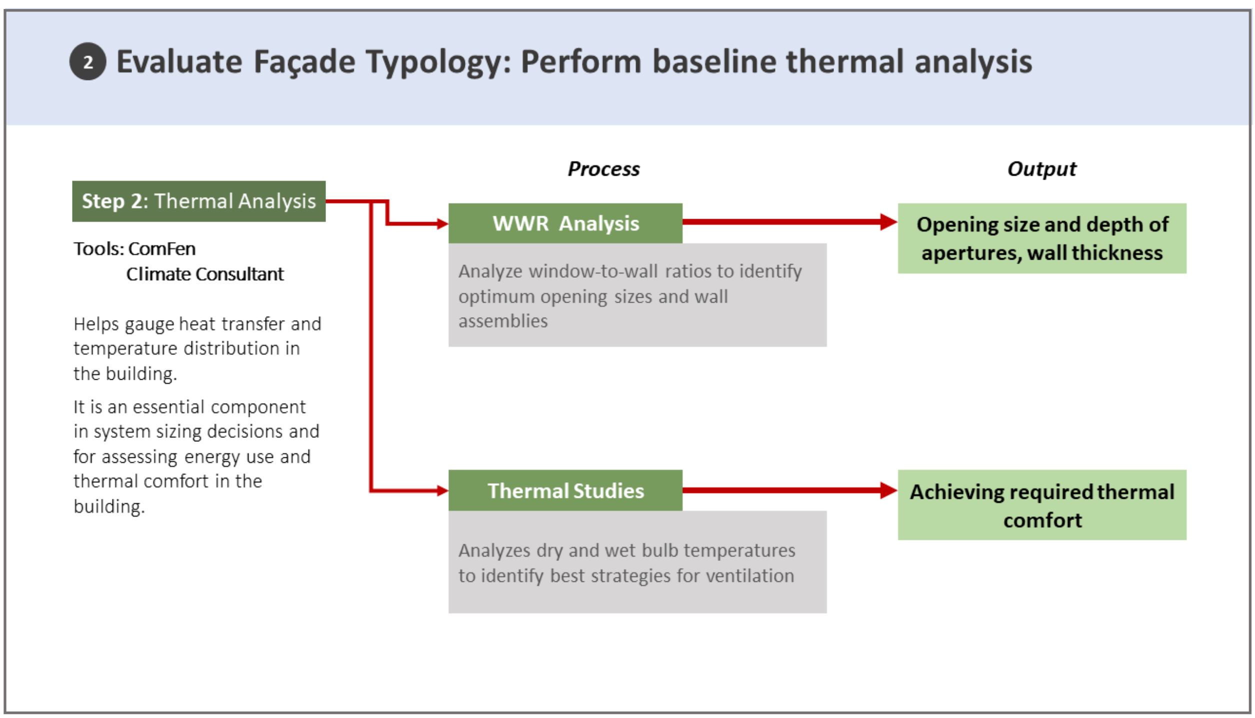


Figure 18: Step 2 Thermal Analysis

02: Evaluate Façade Typology: Low income housing site in Mumbai

Design Goals:

The aim of the solar analysis is to evaluate how design decisions like building orientation, aperture placement and selection of finishes help or hinder daylighting within the housing module. The main objective of the design is to provide a humanized and comfortable environment of around 24-28 degree C for the inhabitants while reducing the need for supplemental electric lighting by achieving 70% UDI and 300-500lux Illumination level.

<u>Step 01</u>

<u>A. Shading Analysis: </u>(Tool - Andrew Marsh)

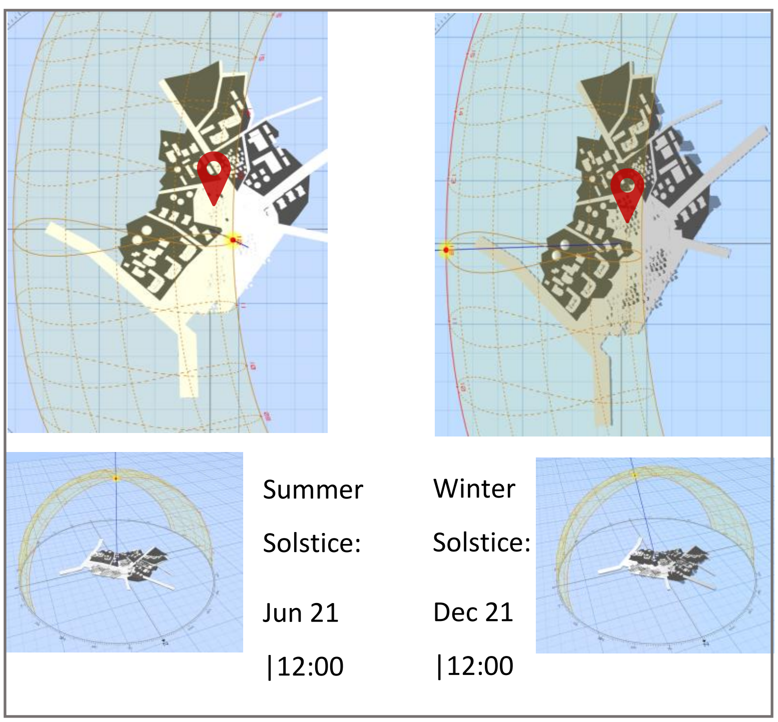
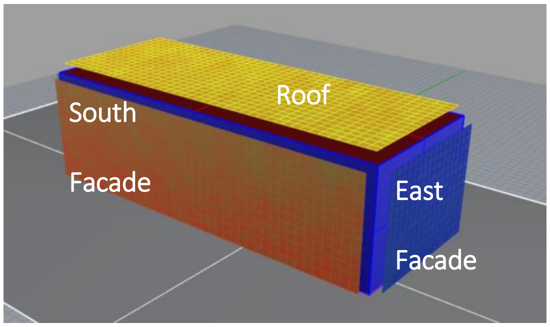


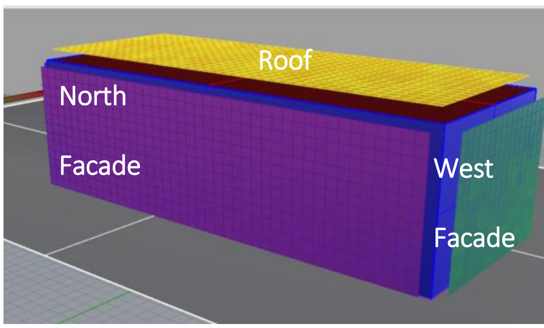
Figure 19: Shading Analysis using Andrew Marsh Tool

For the given site- Mumbai Shadows cast on the summer solstice are relatively shorter compared to winter solstice or spring equinox, since the sun is at higher altitude in summer while the winter sun being at the lowest altitude casts the longest shadows**.**

B. Insolation Study: (Tool – Rhino| Diva)



Surface	Angle of inclination	Incident Radiation
	(Degree to horizontal)	(kwh/m2)
North	90	239.72
South	90	856.86
East	90	489.57
West	90	609.16
ROOF	0	1171.74



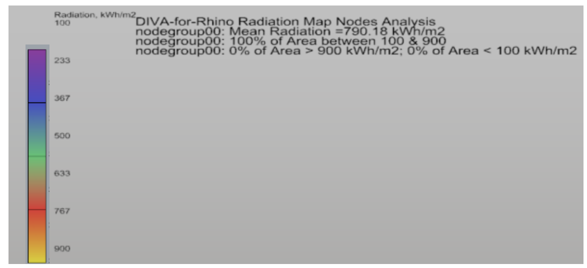
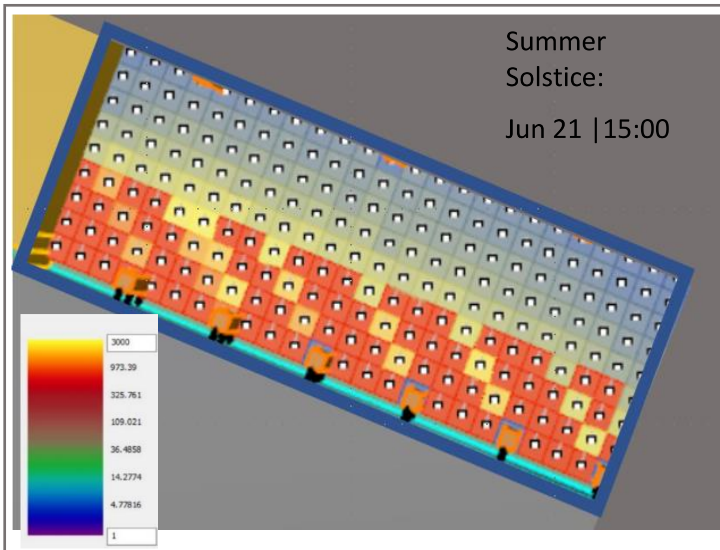


Figure 19: Insolation Study on the container Block using Rhino Diva Tool

Diva Radiation analysis of the building shows that currently the mean radiation on the middle floor window without any shading device is about 790.18 kWh/sqm which exceeds the prescribed value of up to 150kWh/m2.

C Daylight Analysis: (Tool – Rhino| Diva)



The map shows that the required illuminance level is exceeded by almost 3 times.

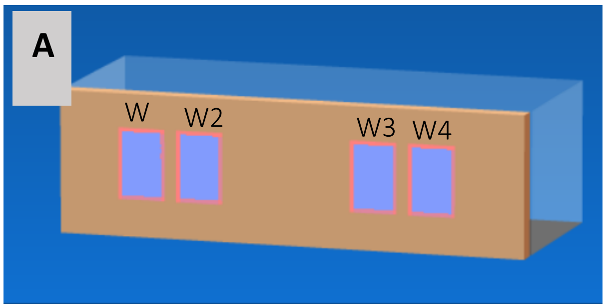
The floorplate is over lit and has conditions of glare along the south and south west facade. The low angle of winter sun can cause this.

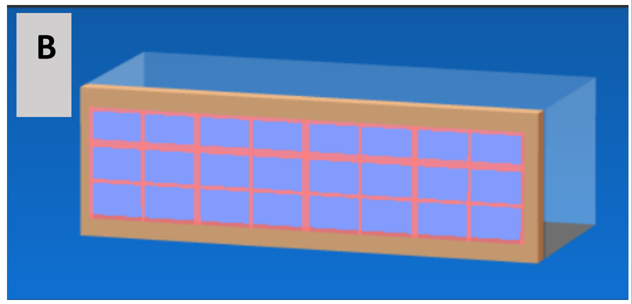
Figure 20: Daylight Analysis showing Illumination Range from South facade

Step 02

A. WWR Analysis: (Tool Comfen)

Window-to-wall ratio designed at 20% and 70% to study the impact of contrasting ratios on solar heat gain, view quality and thermal comfort and its effect on energy requirement.





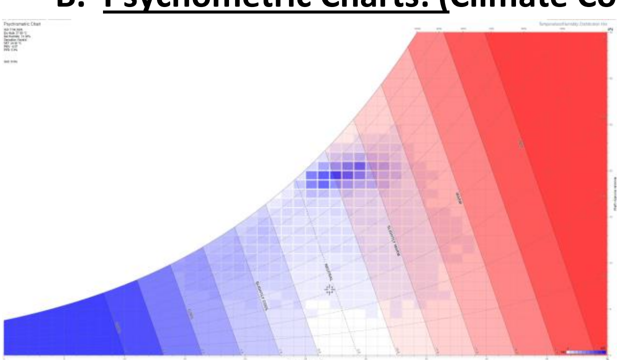
Height	Width	Sill heigh	Dist. left	Window ar	Vision ar	Setbac	Frame type
6.00	4.00	3.00	5.00	24.00	20.39	0.50	Al w/break
6.00	4.00	3.00	10.00	24.00	20.39	0.50	Al w/break
6.00	4.00	3.00	25.00	24.00	20.39	0.50	Al w/break
6.00	4.00	3.00	30.00	24.00	20.39	0.50	Al w/break

	A	B
Heating	5.09	7.66
Cooling (source)	6.66	5.45
Fan (source)	7.53	7.02
Lighting (source)	4.19	4.63
Total Energy (source)	23.47	24.76
Peak Demand Electricity	4.63	4.36
Peak Demand Electricity Date	AUG 28 09:30 AM	JUN 8 03:30 PM
Peak Demand Natural Gas	10.74	10.81
Peak Demand Natural Gas Date	JAN 27 06:15 AM	JAN 7 06:15 AM
Avg. Daylight Illum.	46.46	35.10
Avg. Discomfort Glare	10.19	9.57
Avg. Thermal comfort	86.60	84.48
CO2 emissions	6.85	6.73
Hours setpoint unmet	225.00	170.00

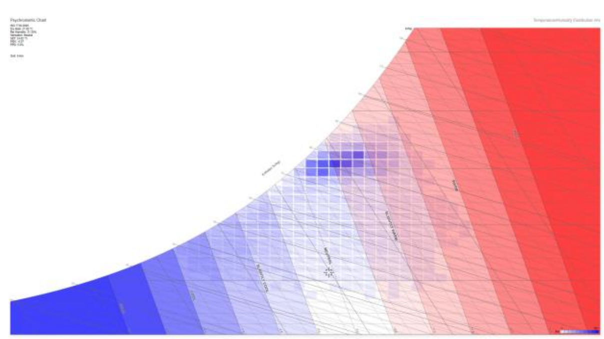
Higher WWR leads to solar heat gain from the south façade and can lead to glare conditions during low sun angle. This leads to higher energy demand and would require solar radiation control.

Figure 21: Comfen Analysis of WWR

B. Psychometric Charts: (Climate Consultant / Andrew Marsh)



Analyzing: Dry Bulb temperatures



Analyzing: Wet Bulb temperatures

Façade Typology Analysis

From the analysis, façade design typologies can be defined in three simplistic ways based on two main governing factors

A. Site (Location | surrounding context) + B. Building facade orientation (N/E/W/S facing):

1. **Shaded façade**: when incident solar radiation causes heat gain and needs to be shaded.

2. **Daylighting Façade**: when incident solar radiation is lesser that required to achieve baseline Daylight Autonomy.

3. **Combination façade**: when incident solar radiation is dynamic in range requiring both shading and daylighting at different times of day or month

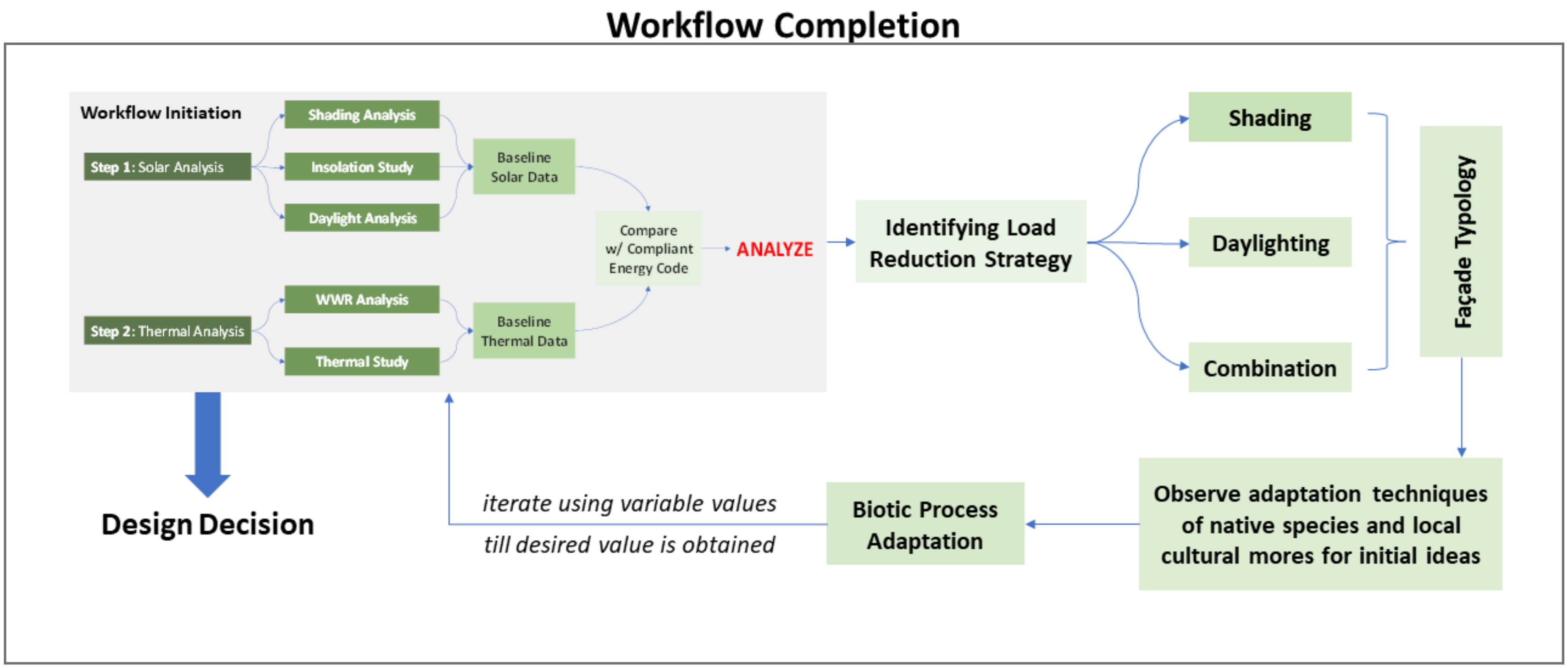
Parameters	Target Values/ Compliant Energy Code	Project Hits	% Variable
Annual Radiation Range	150	790	526.67%
Useful daylight Index	75	72	96.00%
Target Illuminance levels	300	483	161.00%
R Value (Wall Assembly)	30	30	100.00%
Peak Heating Load	NA	NA	0.00%
Peak Cooling Loads	NA	NA	0.00%
EUI	NA	NA	0.00%
Cost	NA	NA	0.00%

Figure 22: Tabular comparison of Data obtained post parametric analysis with target values or code compliance

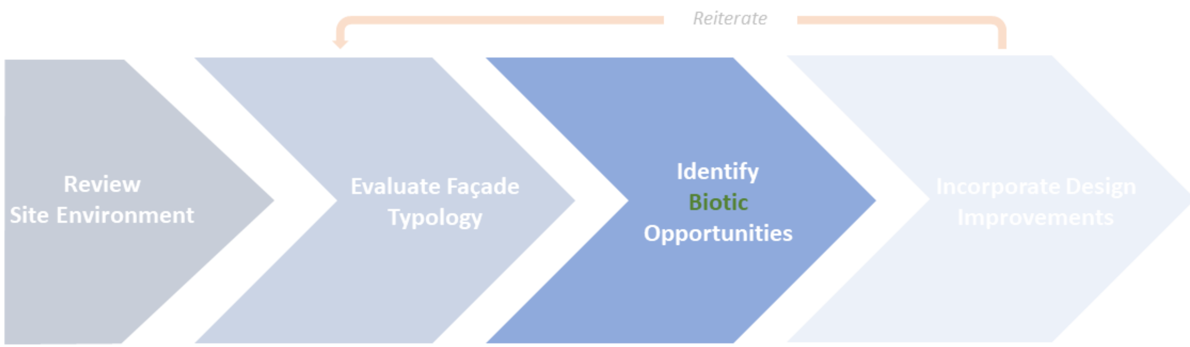
Data Indications:

- Parametric analysis and comparison identify the need for south and southwest façade to be treated thermally to achieve comfort
- Diva analysis shows mean radiation of 217.27 kWh/sqm between 9:00 am and 5:00 pm on the south façade which denotes that Shading can help achieve comfort conditions on south and west facade.
- Comfen analysis indicates that for a high window-to-wall ratio to optimize daylight, a high shading factor would have to be provided to safeguard against rain and heat
- *A deep shade on southwest would help reduce radiation impact and help achieve thermal comfort.*

❸ Identify Biotic Opportunities: Workflow Process



Workflow Completion



Identify shading strategy for the project

Key Workflow Design Observations:

- **South /West are Shaded Facades**

Treat the south façade to reduce heat gain and allow daylight to enter the block, to maintain thermal balance and protect from heavy rainfall. Site constraints require dictate closed faces on north / northeast due to freeway location.

- This being the south façade, without any development in front of the block, an overhang or a shading device would be suitable with louvers or deep projection which would help in maintaining occupant comfort and providing visual relief.

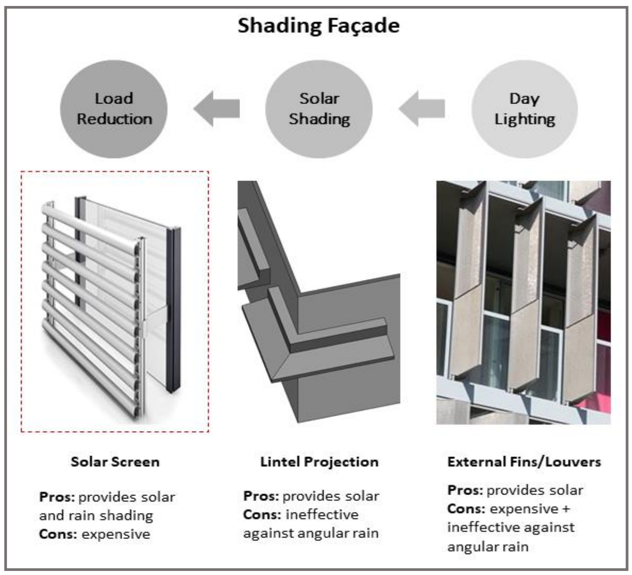


Figure 23: Widely available shading systems: Solar Screen as chosen medium (Source: Stock Images)

Solar Screen

Solar screen is a window shading system that provides an additional layer of thermal envelop for the building. In cases where the angle of sun is low and radiation levels are high solar screen can help mitigate the effects of overheating and help in reducing building cooling load. Hence the solar screen is chosen as a mode of shading.

Traditionally solar screens have been widely used across Asia and middle east as shading devices. By playing with aperture sizes and shapes solar screens can help create a beautiful effect of shadow and light providing playful movement in a dull environment while protecting against incoming radiation

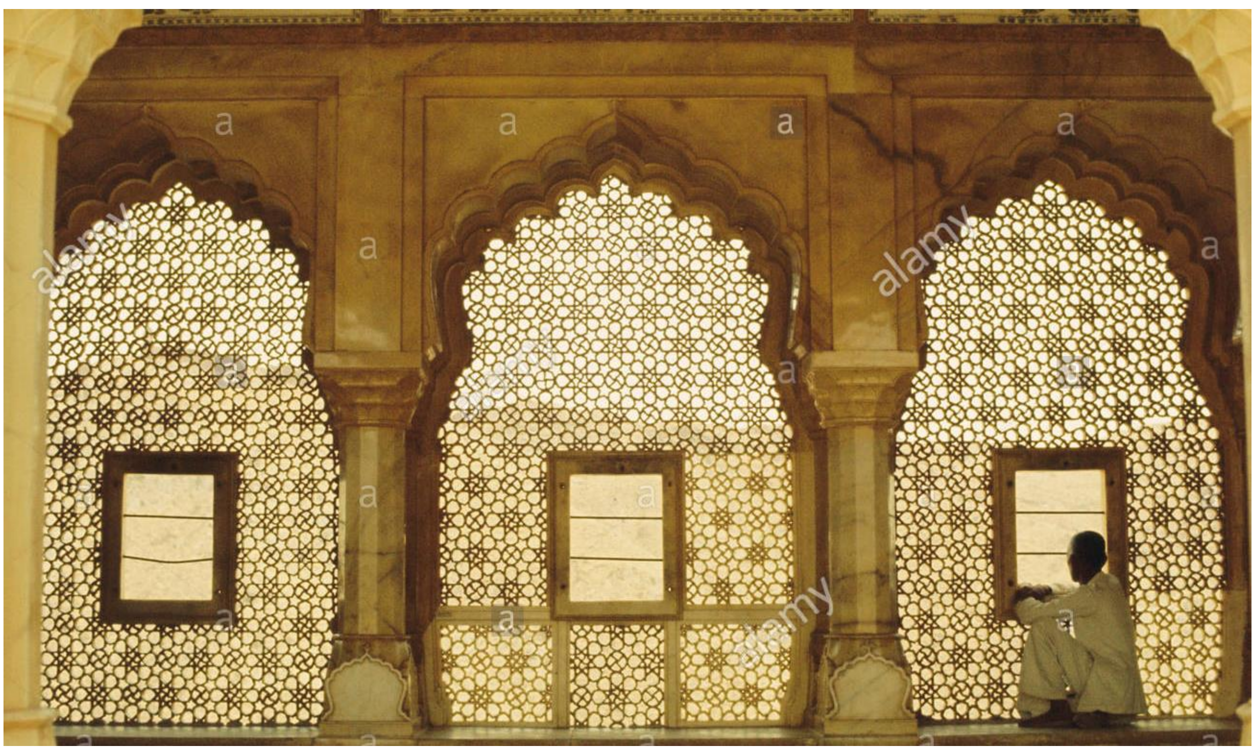


Figure 24: Traditional Jharokha or solar screens in a fort in Rajasthan, India using locally available stone.

(Image source: Alamy stock photos)

Biotic Intervention:

Adaptation techniques of native species and local cultural mores for initial ideas

-The cotton Story:

Cotton, seed-hair fiber of several species of plants of the genus Gossypium, belonging to the hibiscus, or mallow, family (Malvaceae).[20] Cotton is widely cultivated in in India and the plant fhas flourished in this region because of its adaptation to the local climate.

Adaptation:

The leaves have a **large surface area** which allows the plant to maximize its exposure to light and help in transpiration. The leaves of the cotton plant act as a **screen** to protect the fruit in extreme weather***.***

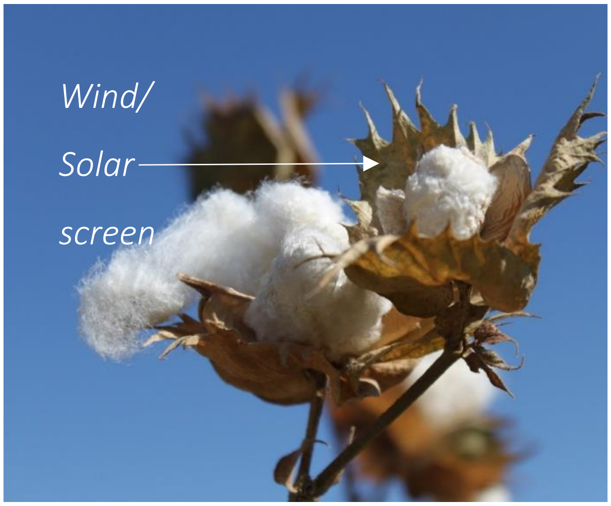


Figure 25: The cotton Plant (Source Pintrest.com):

[20] https://www.britannica.com/topic/cotton-fibre-and-plant

-Cultural Mores: Terracotta

Use of terracotta for its thermal properties: Evaporative cooling, a technique that has been in use for several centuries in the Asia, Middle East and Africa, is a passive cooling process in which a body or an object is cooled by the evaporation of water from its surface**.**

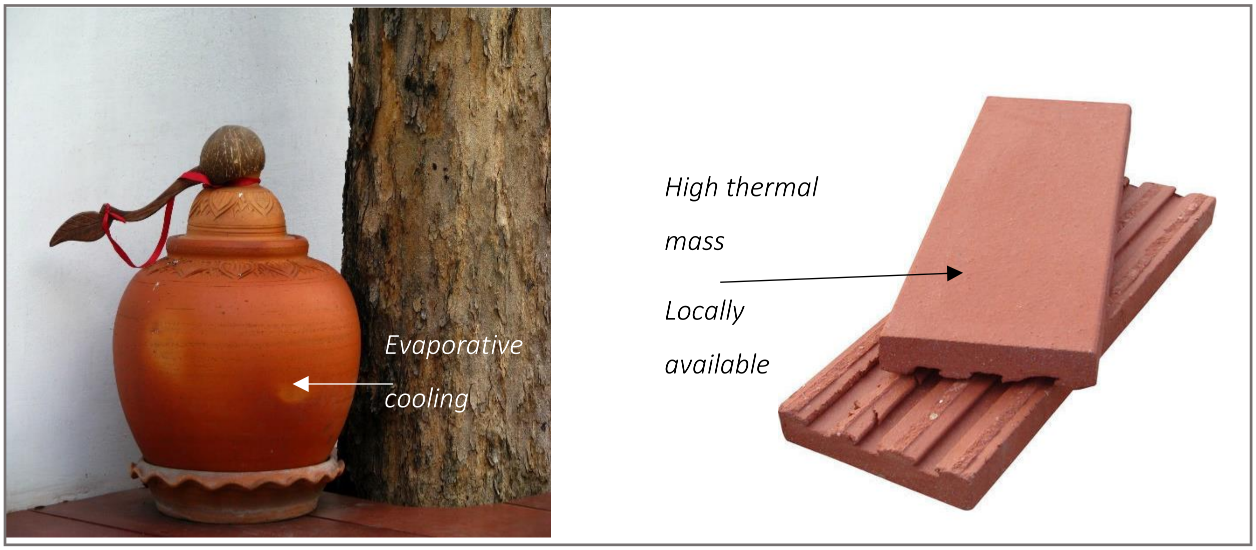


Figure 26: Traditional usage of Terracotta in various forms (Source: Pintrest.com)

Incorporating Biotic Ideas in Design Improvement:

Developing the solar screen:

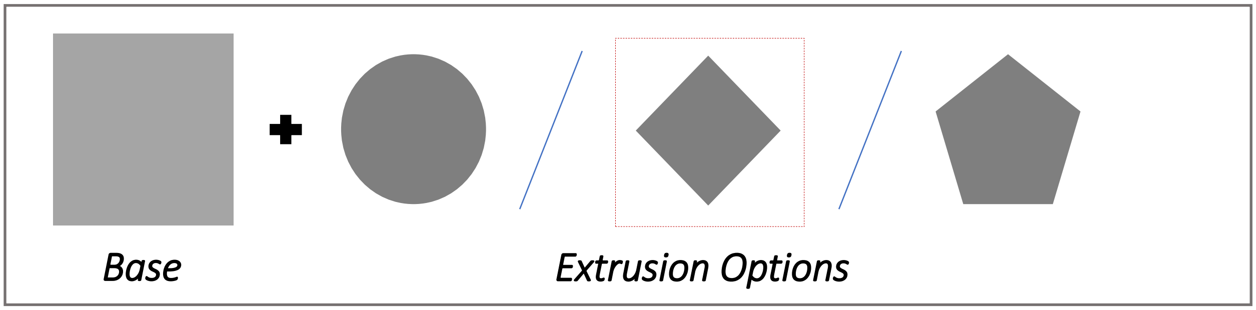
The solar screen evolves as a natural reaction to the incoming radiation. In order to make maximum use of available site factors it is necessary to adopt biological interventions in the design. Here taking inspiration from the cotton leaf, one of the main design goals is to maximize the surface area of the screen in order to dissipate heat quickly.

For maintain thermal comfort terracotta has been used to achieve high thermal mass for maintaining internal temperature within comfort range.

This can be achieved in a 3-step process:

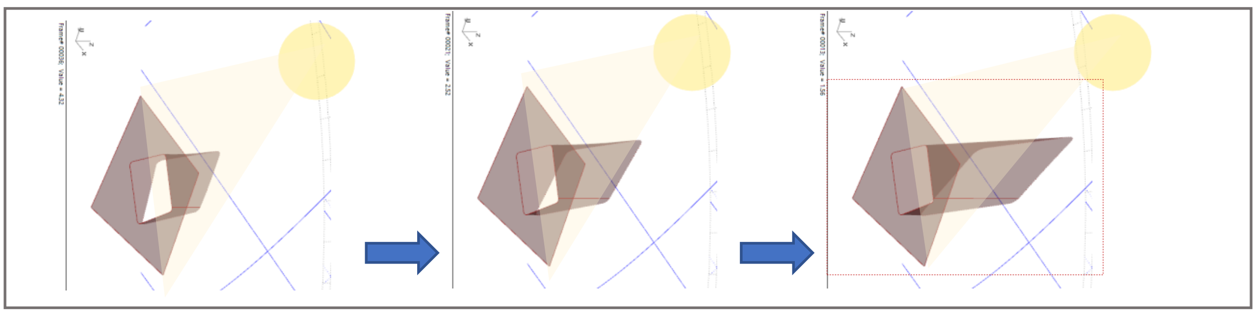
1. Shaping the screen to maximize surface area -biomimicking the structural adaptations of the cotton leaf. A single oculus could be designed and replicated across the wall area to achieve the desired effect.
2. Providing a projection factor that would help it shade from the lowest sun angle on winter solstice while maintain WWR ratio of about 50% to maintain visual comfort and ventilation.
3. Applying materiality that is local, easily available and biophilic in nature -*terracotta*.

A: Shape the Oculus for screen



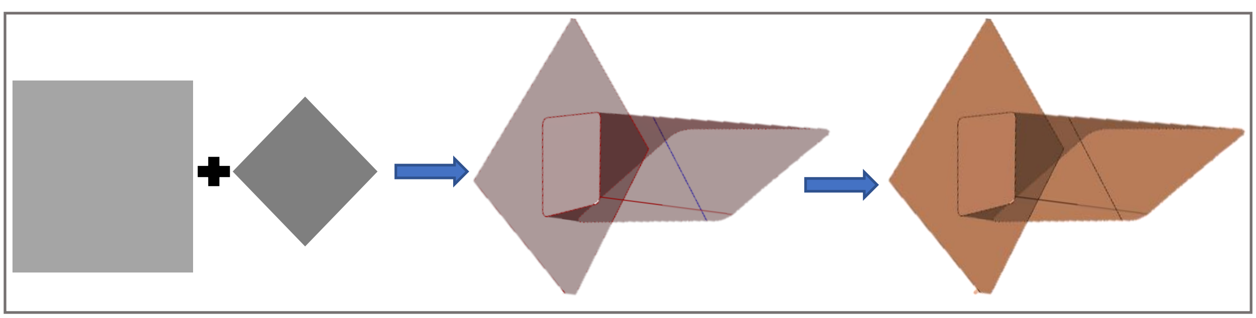
Biotic investigation indicates that **larger the surface area** for the opening would provide better heat dissipation from the screen. Option 2 is easy to fabricate and provides larger surface area vs the cylinder.

B: Sculpt the Oculus



Sculpt the oculus module based on lowest angle of sun: 48^{0} on 21 Dec; increase in projection enables complete shade as observed in the 3^{rd} diagram.

C: Define Materiality



Study of the local culture helps recognize **terracotta** as an excellent material for the screen due to its high thermal mass, easy availability and low carbon footprint.

Design generation:

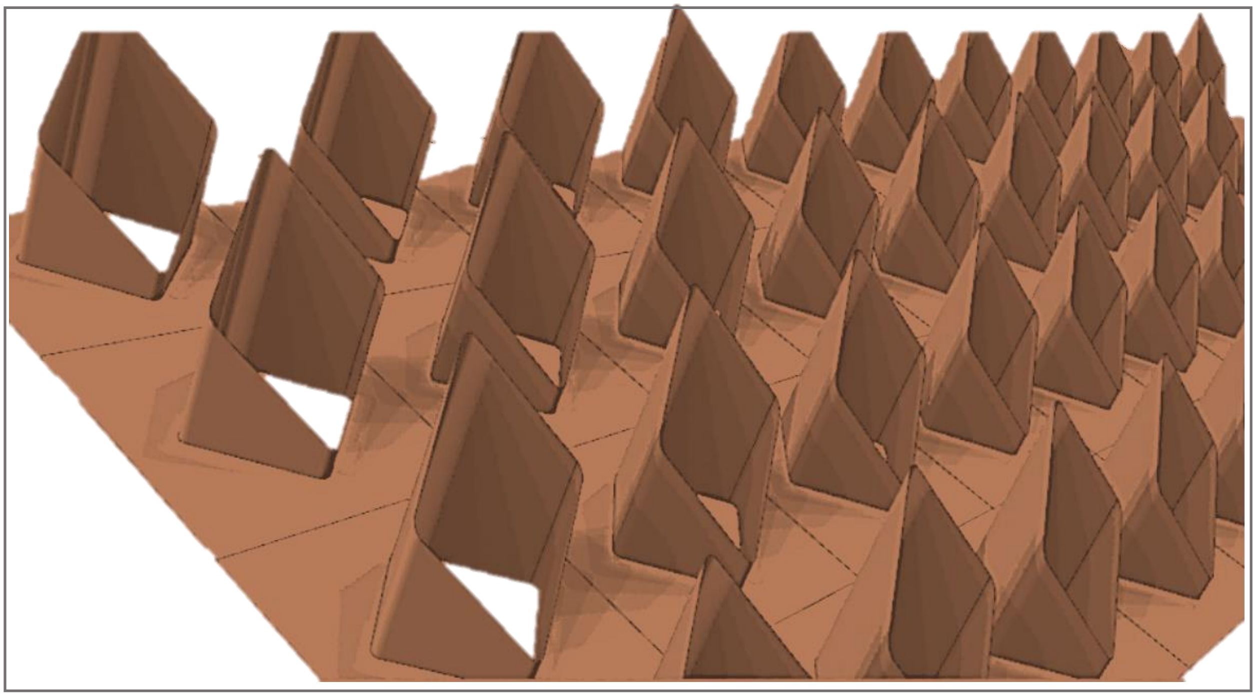


Figure 27: Terra Skin- Facade developed through Biotic Framework

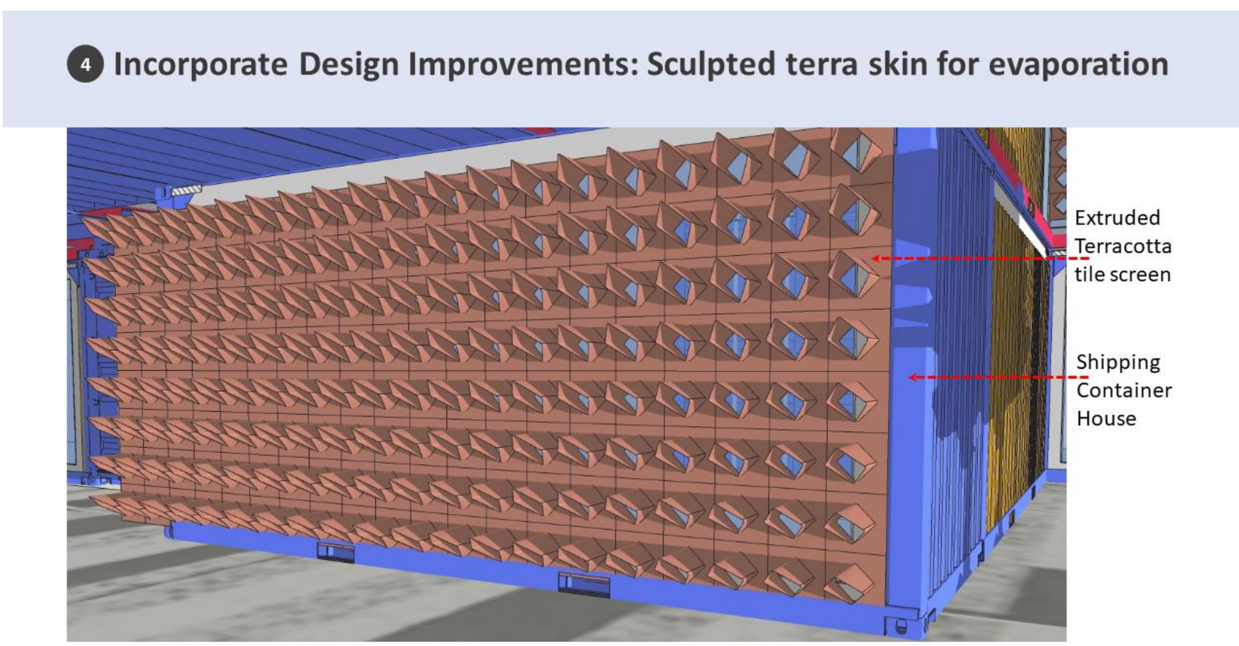


Figure 28: Applying the Terra skin to the container Module as a means of achieving thermal comfort

Chapter 4: Conclusions

The Terra Skin facade

The terra skin evolves as response to the biotic framework. It is however interesting to note that each time a variable in the design is changed for example a balcony projection instead of solar screen or a lintel shade is chosen as the preferred means instead, it will give rise to new design options which can then be tested for their efficiency using parametric analysis. In this case a daylighting study of the screen shows its effectiveness against incoming solar radiation.

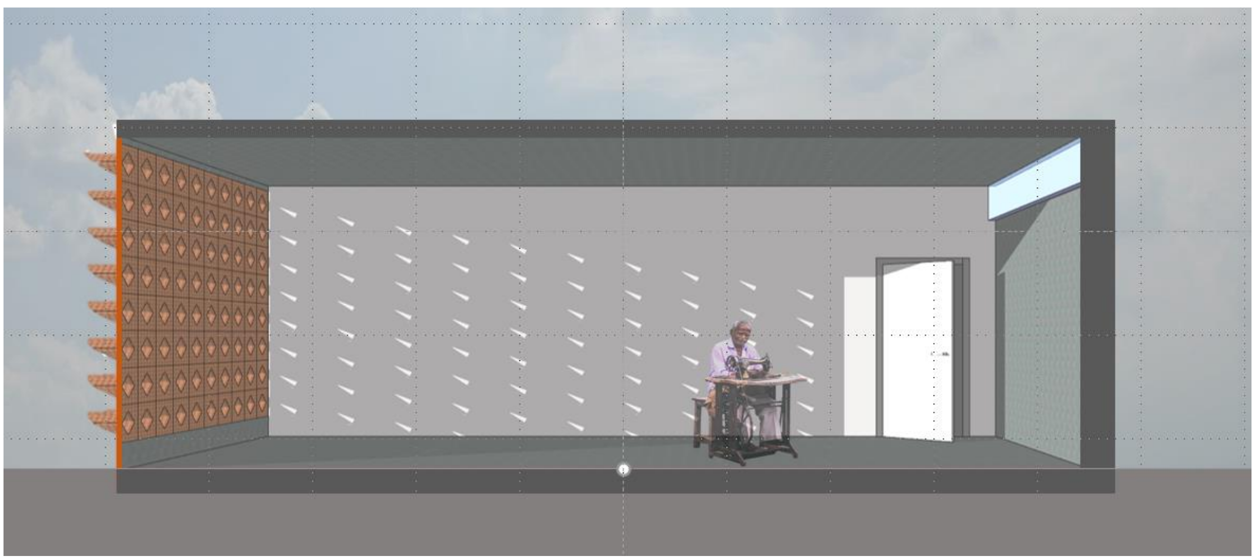


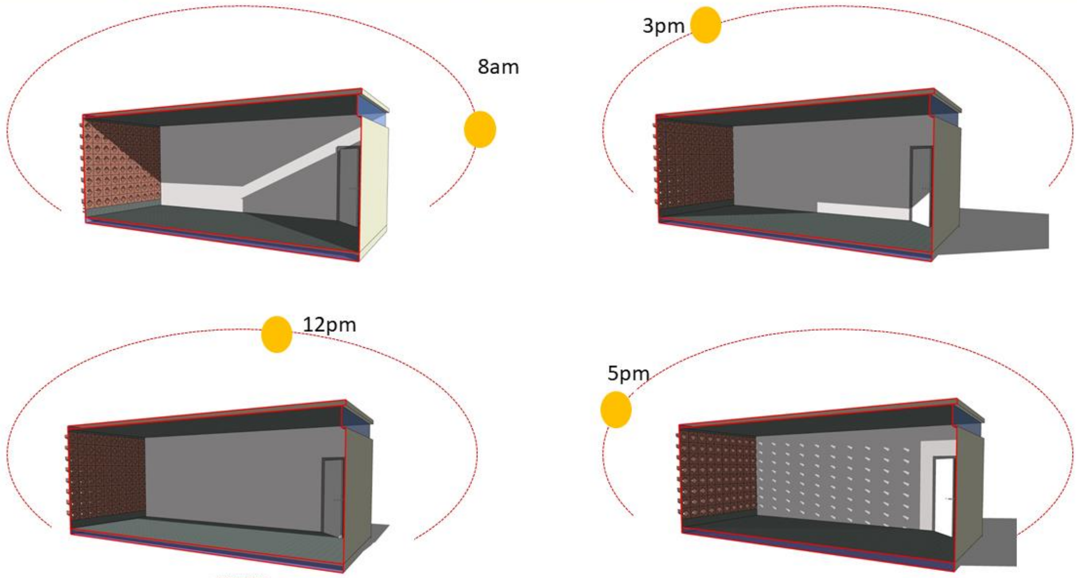
Figure 29: Section of Container Showing effect of applied solar screen

The screen also acts as a mode of privacy, cooling system and helps create a moment during sunset.

Testing the skin to see how it matches up with regards to the set design goals showcases that the screen achieves visual and thermal comfort conditions

❹ Incorporate Design Improvements: Testing the Sculpted terra skin

Shading through the screen on 21 Dec (lowest sun angle)



C. Daylight Analysis: (Tool – Rhino| Diva)

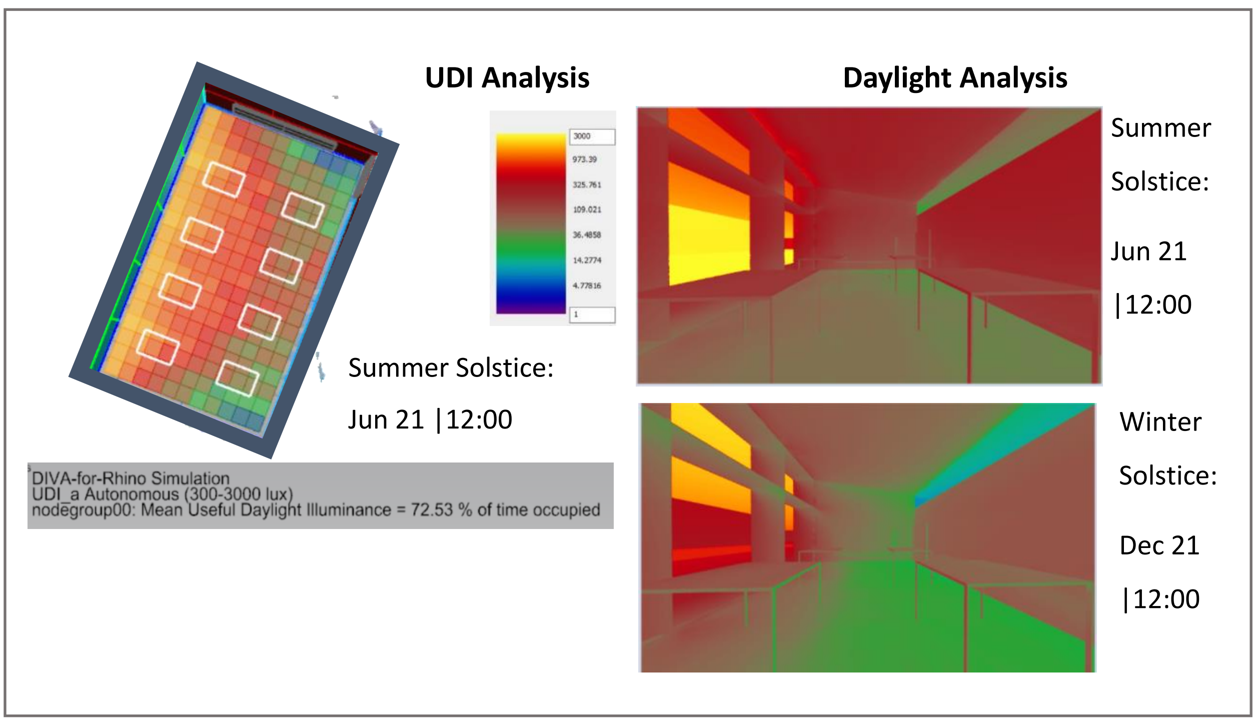


Figure 30: Lighting analysis to check effectiveness of screen

Description of Terminology used for assessment

- **<u>Illuminance</u>**

Unit: -Illuminance (Lumen/unit area)/(Lux or Foot candle)

Definition: Illuminance measures the amount of light falling onto and spreading over a given surface area.

- **<u>UDI- Useful Daylight Analysis</u>**

Unit: percentage%

Definition: UDI measures the percentage time of the year that requirement illuminance criteria for daylighting is met.

- **<u>Insolation</u>**

Unit: kwh/m2

Definition: The amount of incident solar radiation that is received over a unit area of given surface and varies according to latitude, sky condition, and site topography.

- **<u>WWR: Window to Wall Ratio</u>**

Unit: percentage%

It is the percentage obtained by dividing total glazed area to total wall area of an envelope.

- **<u>Psychometric Charts</u>**

Definition: Denotes graphical representation of thermal properties of air in a region.

List of Figures

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- Last image: THE BIG PICTURE: Eco housing with terra skin

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