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PROSPECTS OF UPGRADING CONTEMPORARY BUILDING FACADES IN LAHORE THROUGH BIOMIMETIC BUILDING SKIN

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ABSTRACT

Much attention is paid to the importance of building envelopes these days and it is seen that many façade problems have been solved by taking inspiration from nature. Biomimetics is the science that allows a deeper look into the appearance and behavior of organisms in nature. Biomimetics is solving the building problem by changing how buildings are being constructed as it takes notes from nature. This research uses nature to explore the prospects of efficient building skins that provide desirable and aesthetically pleasing solutions to building problems. Major dealings of the research include identifying core issues in the skins of Commercial buildings of Lahore that lead to inefficiency and inadequate connection between people and place. Since the building envelope separates indoor from outdoor, it is inherent for the façade to be well suited to the energy needs of the building. The main aim of this research is to produce a catalog of building skins based on natural phenomena that could help resolve the major requirements and needs of contemporary architecture in Lahore. An attempt has been made to upgrade building skins by taking inspiration from the various phenomena in nature and applying biomimetic principles of design to enhance the responsiveness of these otherwise mundane and monotonous skins. The catalog for providing façade solutions is developed using biomimetic principles as a core concept and then applying digital tools like Rhino and ParaCloud Gem to find the results in a form of building facades.

Keywords: Biomimicry, Nature, Building Skins, Biomimetic Facades, Digital Tools.

1. INTRODUCTION

"Learning about the natural world is one thing. Learning from the natural world—that's the switch. That's the profound switch." -Janine Benyus

The profession of architecture is at a critical point concerning reducing the impact of architecture on the natural environment. 'Biomimicry can be applied in architecture to improve the ways this built environment is perceived and planned, through on-site work, building construction, and everyday operations, and it can help to lessen the impact it has on this natural world through several approaches of reducing carbon emissions, waste and much more. (Button, 2016)
Scientific knowledge and findings are disclosing nature's secrets to solve problems. So, the knowledge which we have gained from the natural world and systems can be applied to the architectural world to reduce its environmental influence, and this is a significant point to ask: will

designers use construction techniques as technical-scientific knowledge to create an architecture that behaves like nature? To help answer this question this research will start by looking for contemporary architectural problems with a focus on building facades and then it looks for the reasons why we as architects shall use biomimicry as inspiration and how it can help us to solve the problems with current building skins.

Biomimicry (from bios, meaning life, and mimesis, meaning to imitate) is a technological science that is focused on putting nature's ideas into practice by imitating the natural systems and processes to solve our problems. (Benyus, 1997)

While simulating natural systems, a biomimetic approach to design takes a solution by utilization of a design process that is designed to meet the core design requirements holistically.

This research is an investigation into Biomimicry that is appropriate to a wide variety of fields. Nature is the ultimate laboratory with approximately 3.8 billion years of experience, nature has "experimental models" that are constantly being tested in realistic settings. Therefore, what works in these situations, stays, and what doesn't go.

From molecule clusters to the entire ecosystem, nature's inventions are lean, green machines that work. In addition, they practically take care of themselves. The flow of chemical and biological signals between the parts ensures that everything is as it should be. When something goes wrong, the signals fly back and forth, initiating actions that will either solve the problem or find a way to work around it. There is no waste and no maintenance. (Lee, 2011)

SCOPE AND LIMITATIONS

The scope of this exploration is limited to the examination and exploration of biomimetics as an important strategy for designing building facades. The authors have tried to come up with a catalog of aesthetically pleasing and more sustainable facades to be used. The idea is to experiment that how much diversity and creativity can be brought into the façade design process while using biomimetics as a principle of study. This research highlights the methodology of taking inspiration from nature as well as providing a visual presentation of improved facades of existing buildings in Lahore.

This research does not address the cultural inferences of the formal physical appearance (structural details) of a comprehensively designed architecture and the social qualities it ought to reflect. It should be taken as a research catalog that has used biomimetics and digital software to come up with the solution to the problem of having mundane and monotonous glass facades all over Lahore. Researchers can take these designs further for structural and fabrication purposes if the need arises.

2. METHODOLOGY

This research aims to determine the potential of applying biomimetic architectural principles in building facades, hence suggesting recommendations that can have a better way to upgrade contemporary facades in the near future (Figure 1).

This research will examine biomimetic building skins by investigating theoretical and proficient literature and case studies. Some examples of case studies will be investigated which have nature-inspired building envelope designs and will be analyzed while considering the degree and sources of inspiration. The research will start by realizing current problems with existing building skins and how in nature we find solutions to these problems because nature is sustainable. Like how we can use termite mounds techniques to maintain a comfortable indoor environment, spider web silk's ability to deter collisions, how the self-cleaning property of the lotus flower can alter the problem of cleanliness, etc.

It will continue by considering the logic of why and wherefore architects need to employ biomimicry as an inspiration source. After that, it proceeds onward to talk about architectural progressions from past to present. These examinations will be concluded with a discussion section on the distinctions, difficulties, and conclusions of the study.

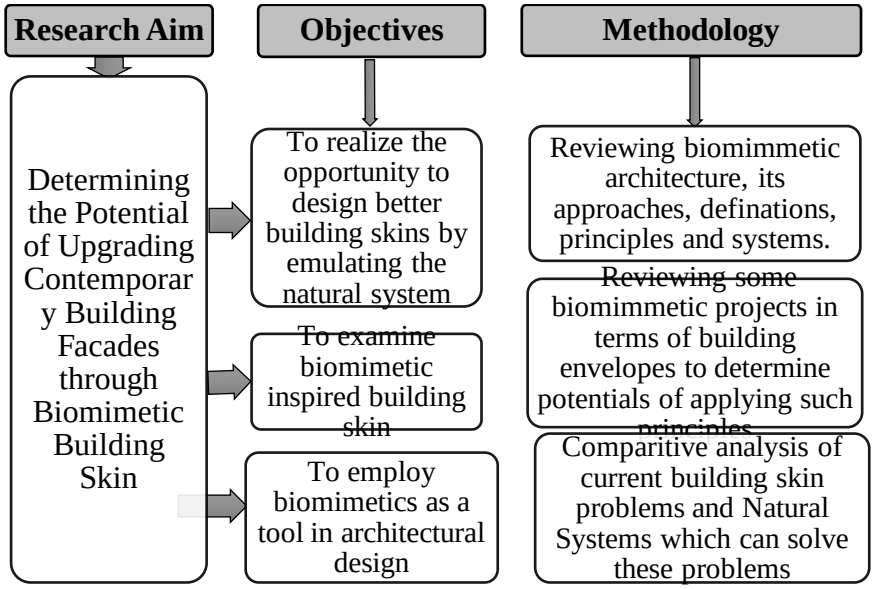
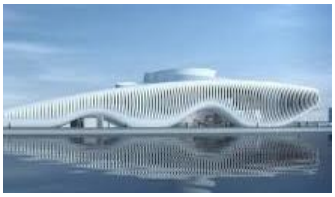


Figure 1: Methodology of Research

Table 1. Summary of all the case studies

No	Name of building	Inspiration and Design Concept	Technique for Energy Saving	Level of Biomimicry
1.	**National Stadium, Beijing**  (Herzog & De Meuron Architekten, 2020)	Bird's Nest: Big nest nurtures and embraces the beings present inside the Stadium	Sucking the heat from the soil and using it to heat the stadium in winter. While in the summer, the stadium has been cooled down by using the stored coldness from the soil.	Organism and Ecosystem level
2.	**Media-Tic**  (Geli, 2020)	Beehive cubic design: How architecture is developing new stability with the use of digital energy was themed by Media-Tic	To manage the climate of the building's interior, Pillows measure the heat, temperature, and the sun's angle.	Organism level
3.	**One Ocean Pavilion**  (Lima, 2012)	Bird of paradise flower (Strelitzia reginae): The Living Ocean and Coast	Compression chillers act accordingly climate of the surrounding of the building.	Ecosystem level

4.	**Facade of Torre De Especialidades**  (embellishments, 2013)	Fractals in nature: Can facilitate fresh air in the adjacent neighborhood.	Helps to scrub the air entering their host building.	Behavior level
5.	**Thyssenkrupp Quarter Essen Q1 Building in Essen, Germany**  (Chaix & Morel et Associés, JSWD Architekten, 2010)	Birds' feathers: To have an energy-efficient building	Bird's feather performance techniques were the inspiration for the shading system	Organism and Behavior level
6.	**Al Bahr Towers Responsive Façade**  (Jambu, 2017)	Traditional Islamic object "Mashrabiya" Composed of regional architecture, bio-inspired structure, and performance-based technology	The mashrabiya operates in the direction of the sun	Behavior level

3. PROBLEMS WITH BUILDING FACADES IN LAHORE

The research pursues a biomimetic approach to address the problems of buildings in Lahore. These building facades have been analyzed on the base of the following design considerations of contemporary architecture.

— Buildings have more than 40% glazing on facades which is causing heat issues in buildings in Lahore. Glazing of windows increased by more than 20% causing an energy crisis, increasing the building's running cost, and reliance on HVAC in the summer season. (Alwetaishi, 2019)

— The thermal performance of glass in space or a building has been measured based on the shading coefficient. 1.00-0.00 has been considered as the

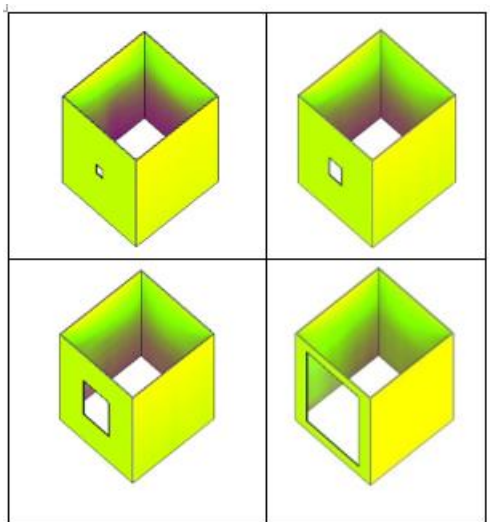


Figure 2: Window Wall Ratio Analysis on Revit Insight 360

range of its value. However, the shading coefficient of exterior glass in buildings in Lahore is more than 0.35, decreasing its shading ability.

- Heat gains and loss, shading coefficient, visual comforts, sun control, energy consumption, and thermal comfort should be the measurement for choosing the window and its glazing (Gregg D. Ander, 2016), but in Lahore, we are using single panel glass in buildings which are causing many problems.
- Orientation of the building has a major role in the whole system, therefore building orientation should be considered according to the need and sun direction. however, in Lahore at least two of the existing facades are exposed to direct sunlight/solar heat gain.
- Window wall ratio of building facades has not been considered a priority while designing which is causing heat gain issues in buildings in Lahore. As in (Figure 2) we can see how by increasing the window size the indoor light and heat gain increases.

Analyzing these building design considerations, Lahore Commercial buildings have a few major issues in their contemporary designs, such as:

- **HEAT GAIN**

To regulate the conditions of the indoor environment, the energy requirement is the main design concern for sustainability. The façade design had been related to the heating and cooling requirements which depend upon the energy consumed by the building. The facade is the main medium through which most of the light and heat are transferred between outdoor and indoor spaces. There is widespread use of glass in buildings in Lahore. For hot climates like Lahore use of commercial glass in buildings is not conducive.

- **MAINTENANCE ISSUES**

Every building requires regular maintenance for steady performance, be it a residential or commercial building. Despite the perception that design errors lead to maintenance issues however environmental actions also contribute to the deterioration of facades and claddings (J.D. Silvestre, 2011). Climate agents, increase the erosion process and natural aging of building exteriors during their life (Jorge de Brito, 2020). The typology of the façade and the life of the building design decide the level of inspection and maintenance required for that specific building. The expensive repairs and replacements could be saved if the errors and flaws are detected at an earlier stage. Yet maintenance can be expensive, and clients and architects should search for solutions that require the least amount of maintenance.

- **AESTHETICS**

A building's stability depends on the load of the external climate and the specific position of the building concerning topography, rural or urban context, altitude, and sea distance and in considerate w.r.t climate and context of the city (Mark C. Phillipson, 2016). These aspects are not entirely in the control of a designer and contribute to the climate locally. Maintenance needs vary according to the local environment and so does the degradation situation (Cristina Matos Silva, 2015). Constructional requirements on commercial buildings' facades have changed, along with demands on the aesthetic quality of the building facades and surrounding urban context.

Using different advertisement banners on buildings is also trending in Lahore which is making it less aesthetically pleasing and dominating the facades. There are new technical ways of doing advertisements like digital screens on facades but in Lahore, the printing medium is dominant which is causing aesthetic problems for the facades of commercial buildings. Eden tower Lahore (Figure 10) depicts the use of different huge, massive shapes in a single building which makes it aesthetically lower than other buildings.

- **ACOUSTICS**

A building envelope acts as a barrier between inside and outside environmental conditions. A window gives the strongest acoustic link in the building envelope between the indoor and outdoor environment as it is least resistant to outdoor environmental conditions. The infill materials of a building facade determine the acoustic performance of the curtain walls of that building. Using

sound amplitude panels, glazing, and by having an airtight construction improve the acoustics. By modifying the shape of the façade or by using high-performance components, the sound insulation of facades can be enhanced. The reduction of sound pressure level at the outside of the building envelope is influenced by the façade shape in noisy areas of Lahore. Due to simple plane façades in Lahore, acoustic problems of facades are not in consideration and the concept of a façade with a different kind of shielding can be considered to mitigate the problem.

- **CONTEXTUALLY SOUND**

In its broadest sense, the term 'context' relates to the interrelated conditions or circumstances that apply to something that occurs or exists. In terms of the built environment, 'context' can refer to the circumstances which surround a particular project or site, and to which it should connect and relate in some way. The structures and buildings that create the built environment do not exist in isolation but are designed and conceived to support, respond to and enhance their environment and surroundings. With the idea of context come implications of the tradition, the locality, the existing fabric, and the vernacular. By embedding the purpose of a design within the essence of its environment and surroundings, a connection linking old and new can be made, maintaining or creating a philosophical 'place'.

The **context** of a building or site in Lahore might include:

a. Local culture.
b. The topography of the area.
c. Architectural style.
d. Local materials
e. Local construction techniques.
f. Weather of Lahore

Table 2: Analysis of Commercial Buildings of Lahore

Sr No.	Buildings	Problems	Pictures
i.	**Big City Tower, Front Façade**	NW is the facade facing the main Gulberg boulevard. There is an excess of heat gain due to direct sun exposure on the glass facades (SE, SW, NE, NW) sides of the building.	 Figure 3. Big City Tower, Front Façade (https://mapio.net/pic/p-16085354/)
ii.	**Siddique Trade Centre, Western Façade**	Due to using a lot of glass on the (SE, SW, NE, NW) facade of the building envelope, heat gain has been increased.	 Figure 4. Siddique Trade Centre, Western Façade (https://www.zameen.com/Property/gulberg_siddique_trade_center_siddiq_trade_centre_800_sqft_office_for_sale-9702918-11222-3.html)

iii. **Mega Tower, Front Facade** — The entire building envelope is covered with glass on all sides (SE, SW, NE, NW) and is directly exposed to the sun, which is causing heat gain issues.

Figure 5. Mega Tower, Front Façade **(**https://www.facebook.com/megatowr/photos/a.729148643903833/729148650570499/)

iv. **Rabi Centre, Western Facade** — The façade which is exposed to direct sunlight is covered with glass on all sides (SE, SW, NE, NW) which is the cause of heat gain in the building. Also, the façade is not maintained properly, and low maintenance of the building makes it less appealing

Figure 6. Rabi Centre, Western Façade **(**https://www.pinterest.com/pin/567172765320765594/)

v. **Aashiana Center, Gulberg Lahore** — Aashiana Center has an excess of glass on the building envelope. Also, experimentation was done with the amalgamation of different shapes which are not enhancing the beauty of this building. It is an example of maintenance issues, heat gain issues, and not aesthetically pleasing.

Figure 7. Aashiana center front Façade (https://ashiana-shopping-center.business.site/)

vi.	**Al Hafeez Business Center Gulberg, Lahore**	Windows placement on the building façade does not look well thought out and thus causing aesthetical problems in the building	 Figure 8. Al Hafeez Business Center Gulberg, Lahore (https://www.zameen.com/Property/lahore_gulberg_office_836_sqft_al_hafeez_business_center-7711643-7-4.html)
vii.	**Makkah tower, Liberty Lahore**	Low maintenance of the building makes it less appealing. The entire building envelope is covered with glass on all sides (N, S, E, W) and is directly exposed to the sun, which is causing heat gain issues.	 Figure 9. Makkah tower, Liberty (https://www.skyscrapercity.com/threads/gulberg-makkah-tower-mix-complete.603918/page-2)
viii.	**Eden tower, Lahore**	Different huge, massive shapes in a single building do not set well and make it aesthetically less appealing.	 Figure 10. Eden tower, Lahore (https://www.zameen.com/Property/gulberg_gulberg_3_office_for_rent_eden_tower_main_boulevard_gulberg_3-16601147-3824-4.html)

ix.	**Arfa Software Technology Park**	This building does not portray its local context according to material use. The entire building envelope is covered with glass on all sides and is directly exposed to the sun, which is causing heat gain issues.

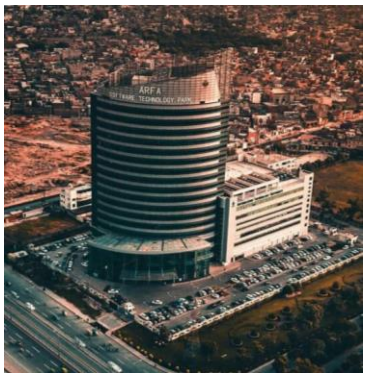


Figure 11. Arfa Software Technology Park (https://www.pinterest.com/pin/211880357455452311/)

x.	**Ali Tower, Western Façade, MM Alam Road Lahore**	Ali tower has excess glass use on all the facades of the building. It is directly exposed to the sun, which is causing heat gain issues.

Figure 12. Ali tower (https://www.skyscrapercity.com/threads/gulberg-ali-tower-mix-12-fl-complete.351986/page-14)

4. BIOMIMETIC APPROACHES

The concept of biomimetic architecture should meet sustainability criteria concerning building envelope design. Since nature has been a source of inspiration for us, a different phenomenon is studied in biomimetic architecture to make use of this knowledge for building skin designs and sustainability. This part discusses various natural processes to draw ideas that could help in developing functional and manageable solutions for building façade problems discussed earlier.

4.1 CACTUS AS BIOMIMETIC SOLUTION FOR HEAT GAIN OF BUILDINGS

Cacti plants know best how to adapt to their surroundings. These plants have survived extreme temperatures for many years and adjusted accordingly. A cactus is a succulent plant adapted to dry, desert-like conditions (Jauregui, 2018).

Cacti (Figure 13) have survived in their ecosystem because of their multiple adaptations, during the process of transpiration, to decrease water loss these cacti leaves are

Figure 13: The Cacti (Dines, 2012)

reduced to needle-like spines. Attack by predators has been defended by these leaves. For a relatively long period, to store water these stems have swollen water-storage cells. Even during light showers, it absorbs maximum water. In scorching heat, it reduces desiccation.

Cactus has ribs that provide shade and enhance heat radiation**.** The contrast between light and shade of the cooling ribs of the cactus produces rising and falling air currents, improving heat radiation. The vertical structure of a cactus prevents it from burning in the sun. Needle-like spines protect the cactus from the sun by scattering direct sunlight and preventing damage from excess solar radiation. During night or rain, the downward pointed spines absorb water to transport it towards shallow roots in the soil below. Cacti have waxy skin to prevent the evaporation of water. Cacti have very efficient root systems to extract water. Most of the roots go deep into the soil and have fibrous roots which surround the surface. The shape of the cactus allows for maximum water storage while minimizing surface area for water loss. (Dines, 2012)

4.2 ROLE OF LOTUS LEAF FOR RESOLVING MAINTENANCE ISSUES

The building's operational capability and maintenance are affected by the climatic and environmental impact on the building's envelope and form. Since 1986 this issue has been discussed by surveying building failures and resulted that 58% of building problems usually begin from inoperative designs. (Nuzaihan ARAS Agus Salim, 2014).

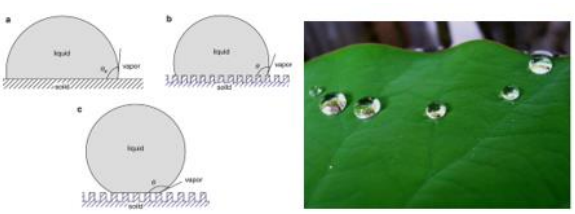


Figure 14: Effects of Leaves (Hans J Ensikat, 2011)

To produce more sustainable and durable designs each design element like materials, systems and technologies has been improved. Concerning maintenance issues, the lotus plant has exhibited excellent characteristics. To resolve maintenance issues in building envelopes lotus has been studied and analyzed in detail. For self-cleaning surfaces, lotus leaves are considered a good inspiration. Regarding perfection and stability in water repellency (Figure 14), lotus shows better results than many other plants (Hans J Ensikat, 2011).

When you need hydrophobic surfaces, the designs have been developed by referring to water-repellent surfaces. The Lotus flower has been considered an excellent example of a hydrophobic surface in nature by scientists. For having a superhydrophobic surface, lotus leaves are considered an excellent case study. For discouraging wetting, lotus leaves have a rough surface structure. The tubules on the surface that contains non-polar methyl groups are made of wax. Interactions with water have been reduced due to this non-polar wax. When a rough surface is introduced, the material increases its surface area to squeeze into the gaps and interact with the surface. Thus, the material isn't as effectively able to lower its energy through interfacial interactions, so it relies more on geometrical optimizations (assuming the shape of a sphere.) In the case of the lotus leaf, this phenomenon is slightly different because the papillae have uneven heights. This decreases water adhesion to the leaf's surface even more, because water is forced to bead up and it rolls off easily. (Jordan, 2016)

4.3 USE OF CONIFERS FOR RESOLVING ACOUSTIC ISSUES

Winslow said that "One of the fundamental advantages of trees is their provision of the ecosystem for us, which helps the entire environment". According to scientists, trees have a powerful impact on controlling air pollution, and the sound absorption properties of conifers are found to be the most effective in controlling noise pollution among trees. So, Conifers could be used by designers in acoustic control of towns and urban areas. (Kinver, 2020)

Sound attenuation is a process that is used by conifers to reduce the noise pollution in a building or its surrounding. (TREES-ENERGY-CONSERVATION, 2019)

According to scientists, if the amount of noise is to be reduced in an urban environment, conifers (Figure 15) are preferred over broad leave trees.
Researchers are of the view that if trees with more absorbent barks are used in a certain area, it could help to absorb surrounding noise more efficiently. It is for the same reason that they have suggested placing conifers where sound is to be reduced since their barks are more absorbing than those of broad-leaved trees. 'Moreover, tree density is the main factor in controlling noise reduction. The greater the density of a tree, the more effective it will be in reducing sounds coming from nearby sources. (Morrison, 2020)

Figure 15: Use of Conifers (Gooden, 2019)

4.4 CREEPERS AS A SOURCE OF AESTHETICS FOR BUILDING FACADES

For keeping the walls of the building dry and for protecting the building from heavy rains the evergreen plants like creepers have been installed. Ivy creepers often cover entire walls and shade them against the extreme heat of the sun during the hot summer days and allow cool air inside (Staughton, 2021). Architects have experimented with buildings for many years by opting for different shading solutions but after a long run, they have come back to "green", which is using (Figure 16) ivy for the facades again. (IVY, 2019)
Green facades or creeper walls are a good solution for creating vertical greenery on large scale. Green facades are more cost-effective as they need little maintenance in terms of time and cost. The creeper can be grown along walls to greater heights, and over building facades without any restriction. Reduction in the heat flux into the indoor and outdoor spaces of the building was done by covering the walls with creepers. Through the transpiration and reflectance process of creepers, the building tends to be more energy efficient. (Köhler, 2008)

Figure 16: Building Facade covered with Creepers. (Ceyudeszanj, 2016)

Ivy has rapid growth and can climb up the buildings, walls, and canopies fast to keep the walls of the building dry and to protect a building against heavy rain. Ivy creepers often cover entire walls and shade them against the extreme heat of the sun during the hot summer days and allow cool air inside. Ivy also helps in protecting facades from frost, salt, and pollution. The only time ivy might not be useful and could be a hazard is when the building has existing structural damage because the ivy will grow its roots into cracks and crevices. (IVY, 2019)

4.5 ADAPTATION OF FISH SERIOLA RIVOLIANA TO ITS ENVIRONMENT

There is a direct impact of context on building façade and the role of an adaptive envelope is inevitable as it contributes majorly to building operation and its sustainability. In nature, fish have brilliant characteristics in terms of adaptation relative to their context. Therefore, *Seriola rivoliana*, which is a very dynamic fish in terms of quick adaptation to the environment, has been studied in detail and analyzed at various levels to foresee its role as an inspiration in building envelope design. Fish are among aquatic vertebrates that have been in existence for many years. They are different from other animals due to their aquatic environment and special features like gills, scales, fins, and tails. (Kelsen, 2020)

Figure 17: Fish Being Water Habitat (Aguinaldo, 2018)

The feature which helps them to adapt to living in the water (Figure 17) is a streamlined body shape that is covered in scales. Making them swim easily and reducing the water flow resistance. They have thin bones and a flexible backbone along with flat fins and tails. This helps them in maintaining the balance of the body, swim easily, and change their direction in the water. For the process of respiration in fish, the gills are the main organs. It allows the absorption of oxygen from the water.

5. DESIGN THROUGH MODULES

5.1 CASE STUDY OF BANK OF PUNJAB LAHORE

Lahore is a hot climate area and most of the facades of its buildings are brick made, but recently the use of glass in buildings especially of commercial nature is increasing rapidly, without due consideration of climate and contextual aesthesis.

Bank of Punjab (Figure 18) is one of these buildings, it is observed that due to excessive use of glass on the facade without even considering its context and climatic conditions, its causing heat gain issues, maintenance problems, and many more.

Figure 18: Bank of Punjab Lahore

5.2 CACTUS AS BIOMIMETIC FAÇADE INSPIRATION

5.2.1 Characteristics of Cacti and its Mind mapping

Inspiration has been drawn from the cactus' characteristics. Cacti are regarded to be a good example of heat resistance in nature, as described in the previous section. The adaptive feature is the primary reason for the survival of cacti in specific surroundings (Cactusway, n.d.). And few of its characteristics are as:

Leaves: During the process of transpiration, to decrease water loss these cacti leaves are reduced to needle-like spines. The needle-like leaves defend the attack by predators.
Stem: For a relatively long period, to store water these stems have swollen water-storage cells.
Root system: Even during light showers, it absorbs maximum water.
Thick waxy cuticle: In scorching heat, it reduces desiccation.

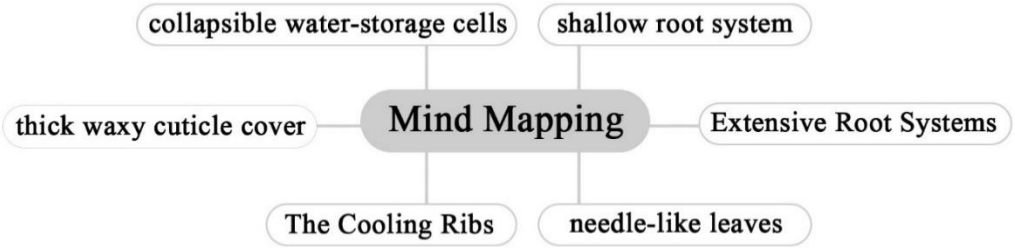


Figure 19: Mind mapping of Cactus Plant

5.2.2 Deriving the design of Module

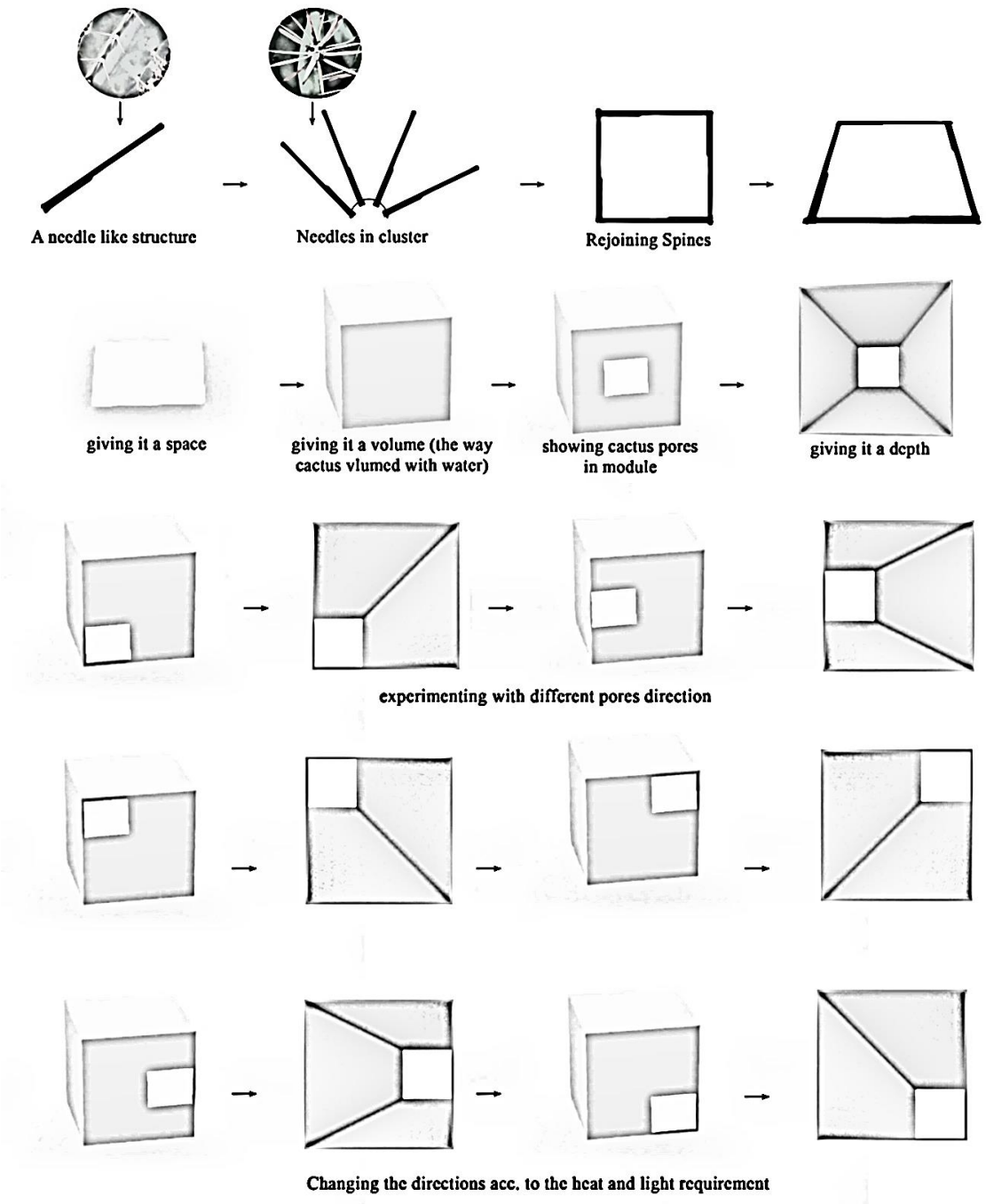


Figure 20: Module Development from Cactus

Levels of Module Derivation for Cacti Inspired design are followed as:
Form: The basic shape of the module has been derived from the characteristics, properties, and features of cacti through mind mapping as in (Figure 19).
Process: The movement of openings of the module (Figure 20) in the whole façade are forming shading devices that have been derived from the characteristics of the pores and needle-like leaves.
Software: The module is modeled in Sketchup and replicated to form a complete façade using a digital fabrication software Paracloud gem.

The final module depicts the effect of a needle-like structure and its use in the façade gives a cooling effect in the context of Lahore.

5.2.3 Module's Façade Mechanism

The use of module form will depend upon the need for heat and light in the specific space of the building façade and the façade direction will change according to the direction of the sun. (Figure 21) depicts that the Module's opening depends upon the sun's direction, At 6 am the opening will be in the opposite direction of the sun i-e; West-South, to give a shading device effect and with the change of sun direction the façade's opening will also be changing as shown in (Figure 22).

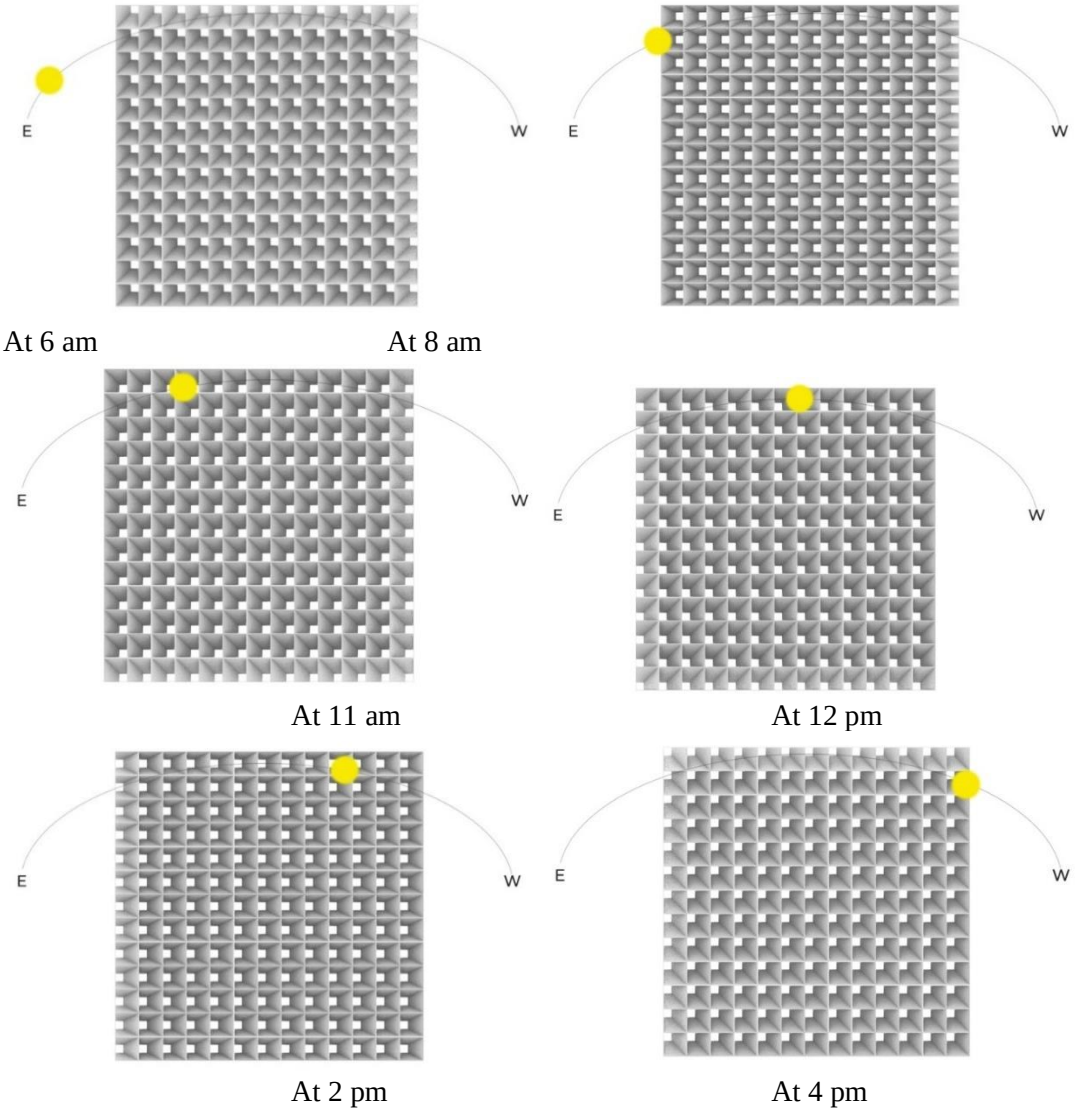


Figure 21: Module Façade Mechanism

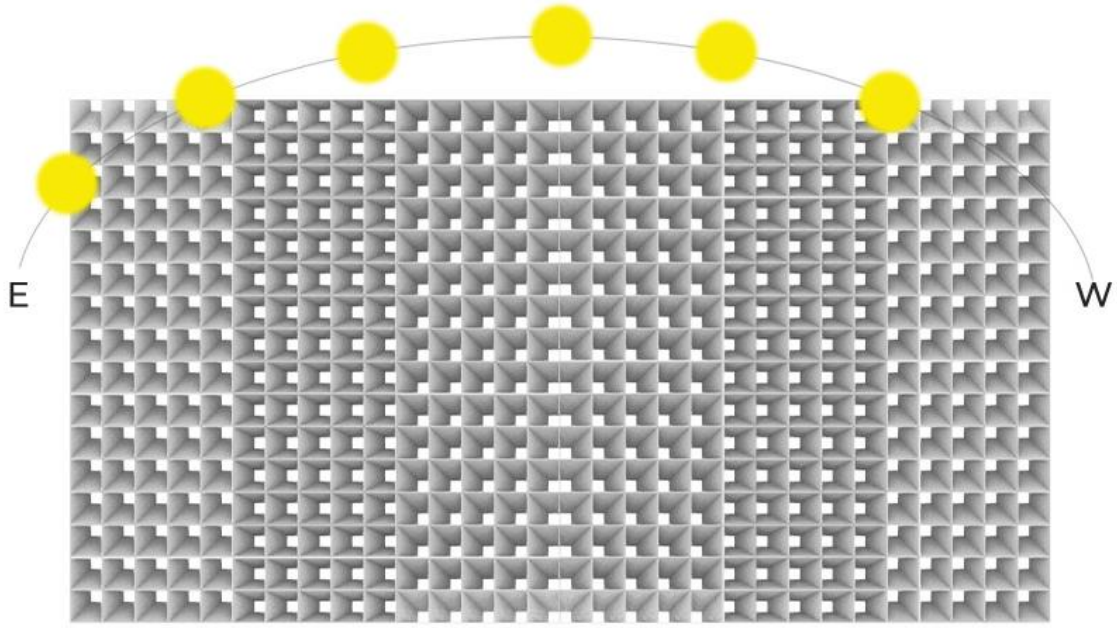


Figure 22. The direction of the Module changing from 6 am to 4 pm

Overall Building façade will change its opening from

i) South-West to West
ii) West to West-North
iii) West-North to North-East
iv) North-East to East
v) East to East-South respectively.

Figure 23: Cactus-inspired Module Application on Bank of Punjab façade

By using this module on the Bank of Punjab Façade (Figure 23), we can control the amount of direct sunlight due to which we can ultimately control heat gain and heat loss of the building.

5.3 LOTUS LEAVES BEING USED FOR MAINTENANCE

5.3.1 Characteristics of Lotus Leaves and Façade Solution Mind Mapping

Lotus leaves have become an icon for self-cleaning and water-repellent surfaces as discussed in biomimetic approaches. Dirt particles are picked up by water droplets and forced to slide away from the leaf surface (Hans J Ensikat, 2011). The major properties of Lotus which make it stand out are:

Water repellent Lotus leaves: The lotus leaf exhibits water repellency majorly due to hierarchically uneven papillae present at the leaf surface that force dirt particles to roll away along water thus keeping the surface clean.

Minimization of the water-to-leaf Contact Area: In form of clusters, the whole surface has been covered with short tubules. Lotus has the highest papillae density in comparison to other papillae plants. (Hans J Ensikat, 2011)

Resistance against Environmental Stress: Resistance against environmental stress is due to provided durable water repellency which has been caused by effective protection through specialized epidermal structures. (Hans J Ensikat, 2011)

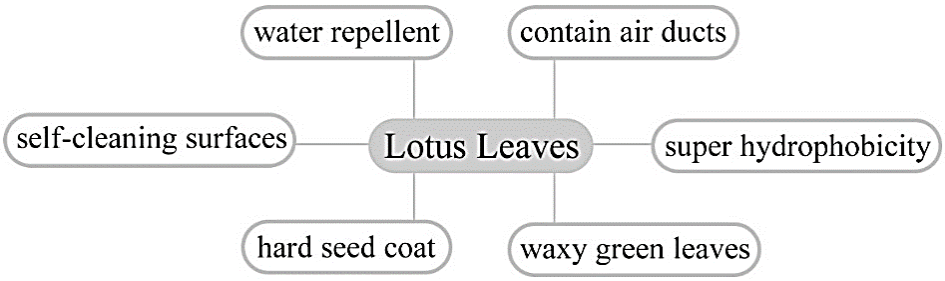
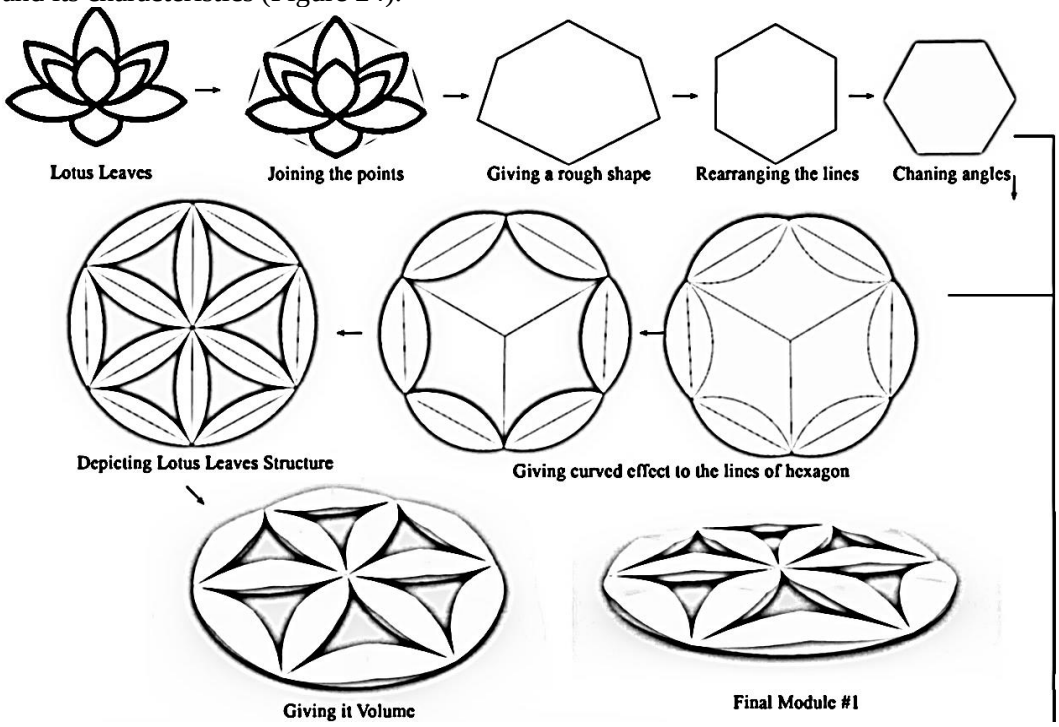


Figure 24. Mind mapping of Lotus Leaves

5.3.2 Module Derivation from Lotus Leaves

Inspiration: The basic shape of the modules has been derived from the vector of the lotus leave and its characteristics (Figure 24).



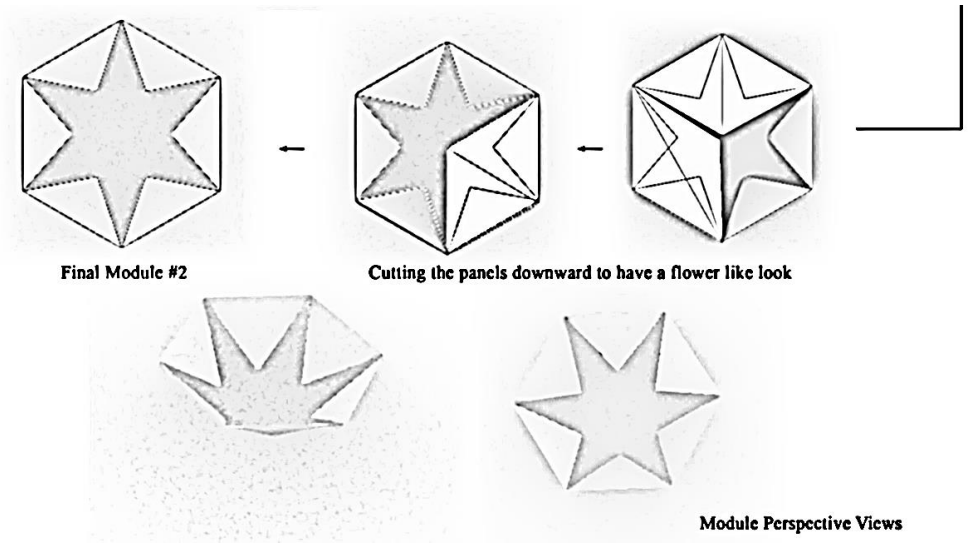
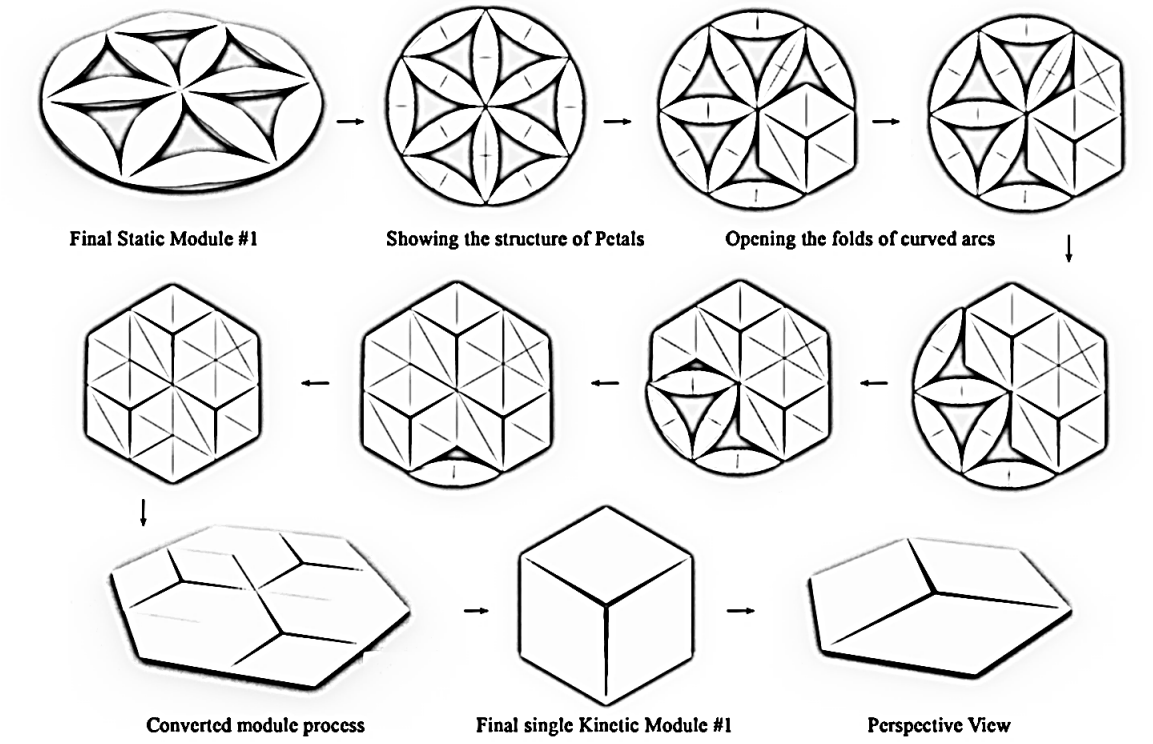


Figure 25: Static Module Formation

Process: The formation of the module and then its opening and closing depict the solution for the maintenance of building facades (Figure 25, 26).
Formation: The module is modeled in Sketchup and replicated to form a complete façade using a digital fabrication software Paracloud gem.



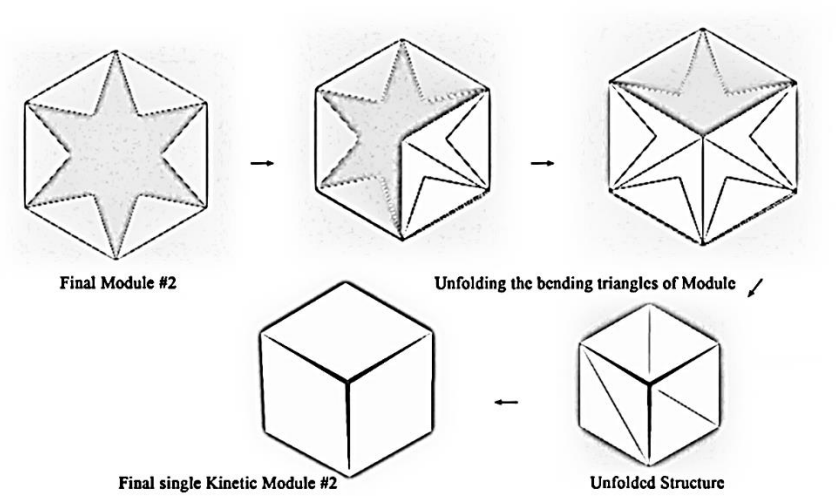


Figure 26: Kinetic Module Formation

5.3.3 Facades Mechanism for maintenance

While using the module as a static façade (Figure 27), if a maintenance issue has to be addressed then the module could be converted to a kinetic facade (Figure 29) by the opening of its petals and curves.

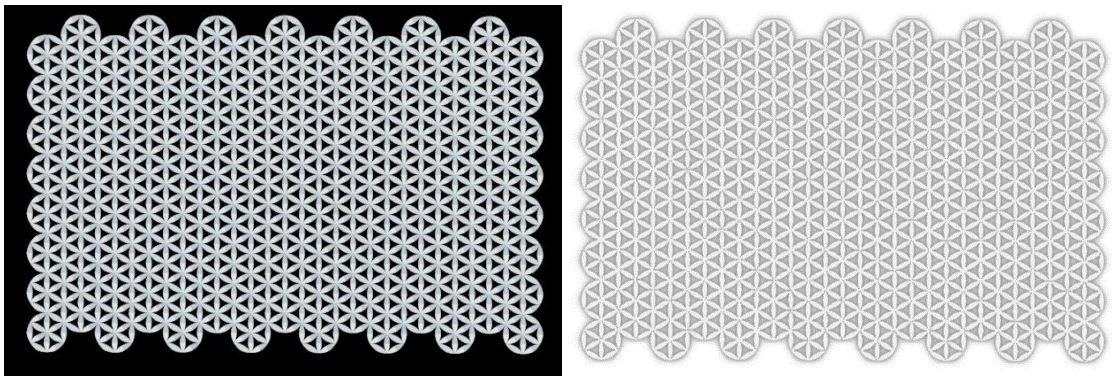


Figure 27. Static Facades

This module has been applied to the Bank of Punjab (Figure 28) for a better understanding of making the facade aesthetically pleasing and providing shade for excess glass on the facade.

Figure 28: Lotus-inspired Static Module application on BOP Façade

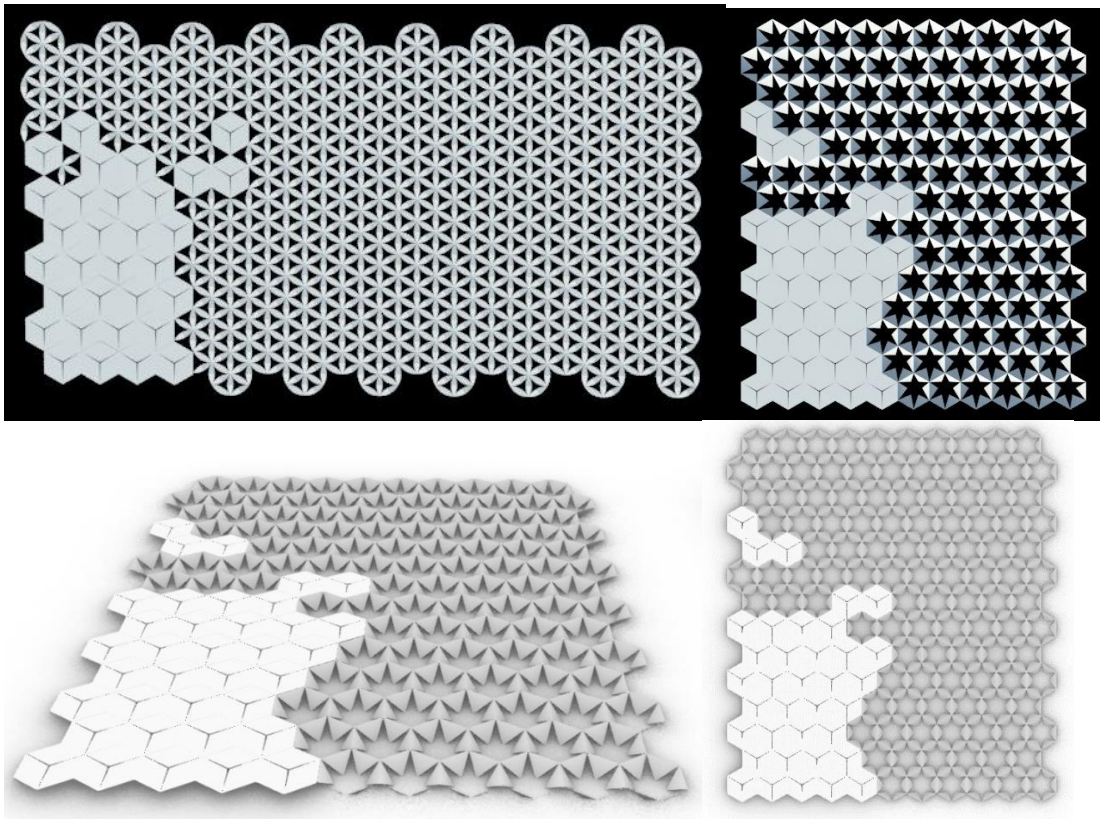


Figure 29. Kinetic Facades for maintenance purposes

Figure 30: Lotus-inspired Kinetic Module application on Bank of Punjab Façade

This module has been applied to the Bank of Punjab and it's visible in (Figure 30) that the facade is kinetic in nature, due to which maintenance issues of the facade can be easily addressed by the opening and closing mechanism of each module.

5.4 IVY CREEPERS AS A SOURCE OF AESTHETIC ELEMENT IN BUILDING ENVELOPE

5.4.1 Mind Mapping of Ivy through evaluation of its characteristics

Trees being one of the most beautiful elements in nature have enhanced their beauty and shaped up ecosystems. Their role is not restricted to just being an aesthetic feature but there is much more to it when it comes to urban and landscape designs. (Gooden, 2019)

Aesthetically Appealing Areas: Trees are one of the most aesthetically pleasing elements in our landscapes. They signal to change seasons, at times by producing flowers and sometimes by bringing brilliance. They are the main contributor is increasing the beauty of any landscape.

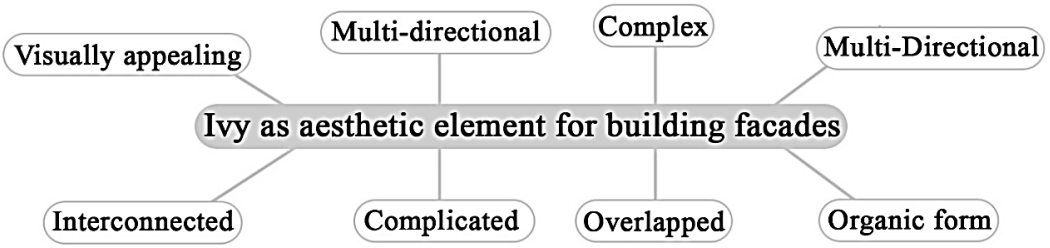


Figure 31. Mind mapping of Ivy Plant

5.4.2 Module Derivation

Inspiration: The basic shape of the module has been inspired (Figure 31) by the vector of the growth of the creeper.

Process: The formation of the module and it's joining with each other has been derived from the joining of the creepers (Figure 32) and its overall look.

Formation: The module is modeled in Sketchup and replicated to form a complete façade using a digital fabrication software Paracloud gem.

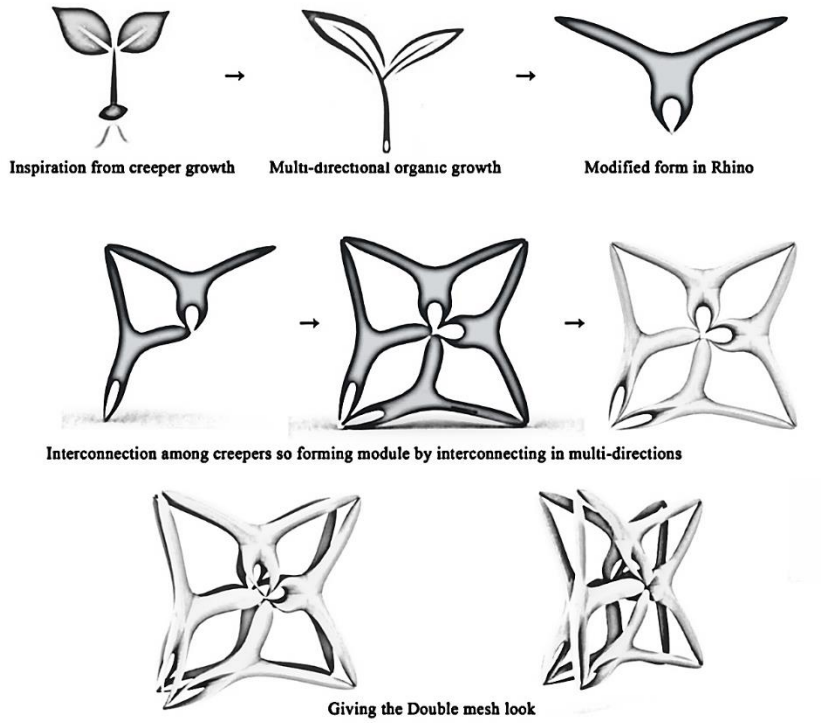


Figure 32: Module formation from Ivy leaf

5.4.3 Aesthetic Façade

The joining of the module with each other is depicting the concept of creepers and its overall look is giving a solution to the Aesthetical problems of Lahore's building facades (Figure 33).

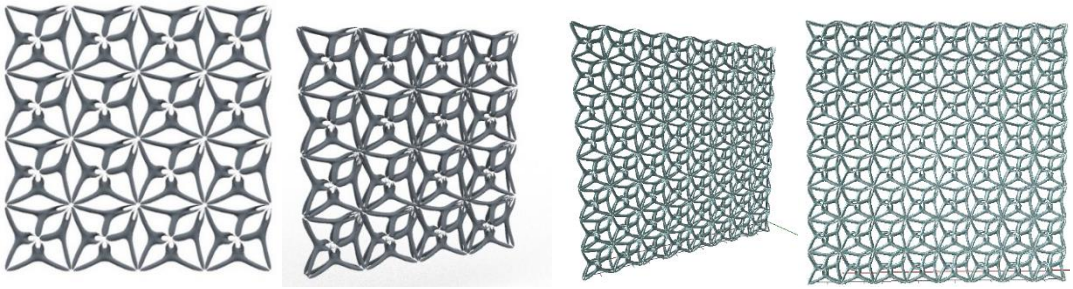


Figure 33. Resolving the Aesthetical Problem of Facades

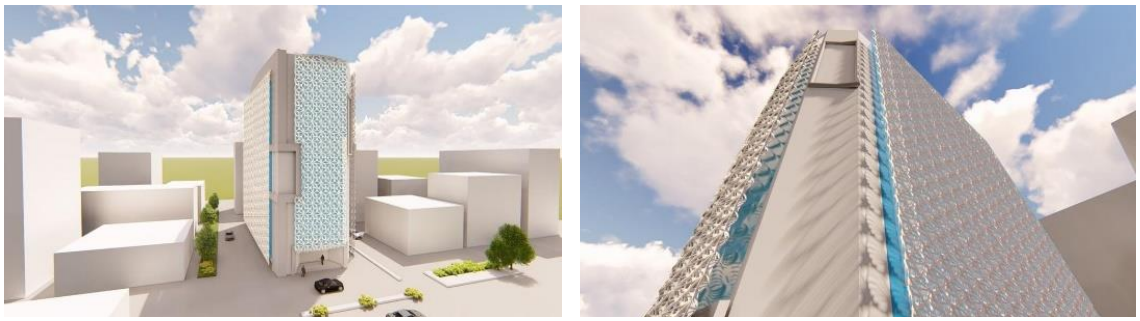


Figure 34: IVY inspired Module application on Bank of Punjab building facade.

This proposed module for the aesthetical effect could be used on the Bank of Punjab Façade (Figure 34) to improve the aesthetics of the building. As the change, the facade's aesthetic could be seen in the above-proposed pictures.

5.5 Conifers as a source of Noise Reduction in Buildings

Trees are our protectors against needless sounds and pollutants in the surrounding environment. If trees are planted in the right places, the benefits we could obtain from them are numerous. They prevent incoming noise from surroundings and absorb pollutants. They also protect us against harmful UV radiation reaching us by providing shade.

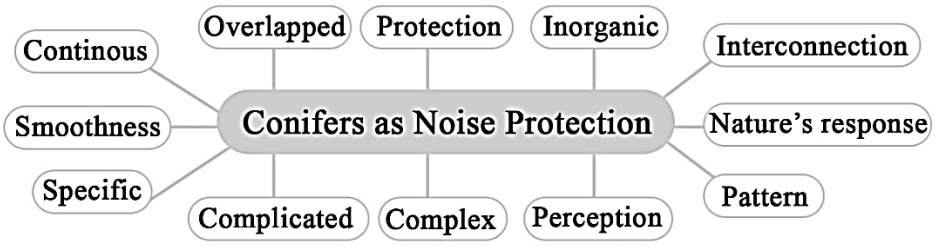
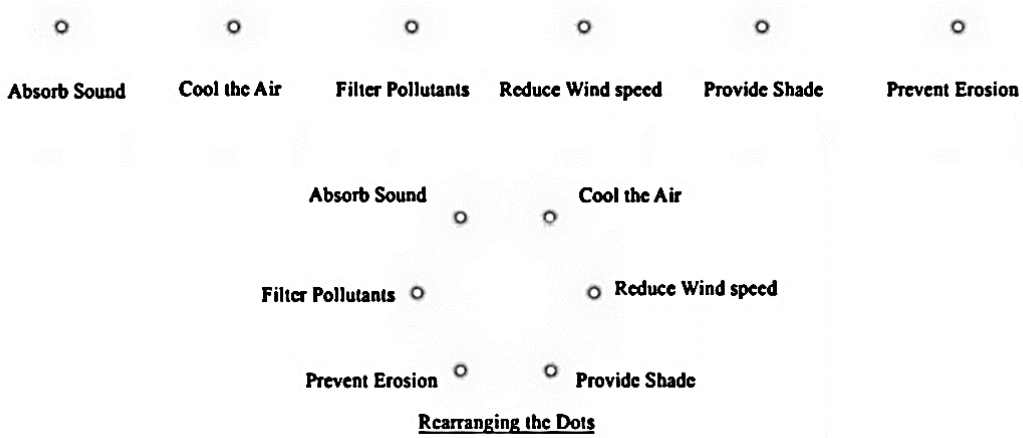


Figure 35. Mind mapping of Conifer Trees

5.5.1 Module Derivation



Inspiration: The basic shape of the module has been inspired by its major 6 characteristics (Figure 35).

Process: The formation of the module and its reversed joining with each other has been derived from the analysis and mind mapping of Trees.

Formation: The module is modeled in Sketchup and replicated to form a complete façade using the digital fabrication software ParaCloud Gem.

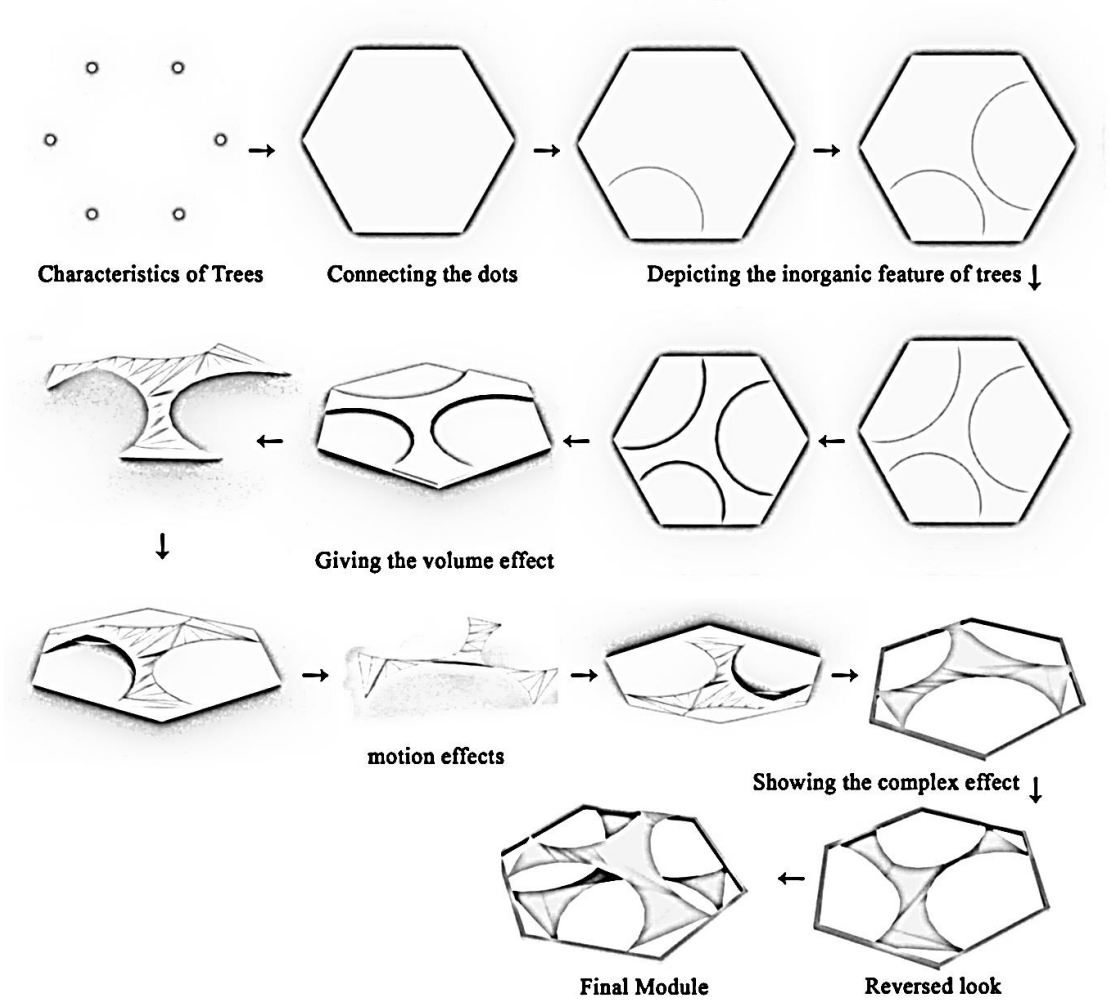
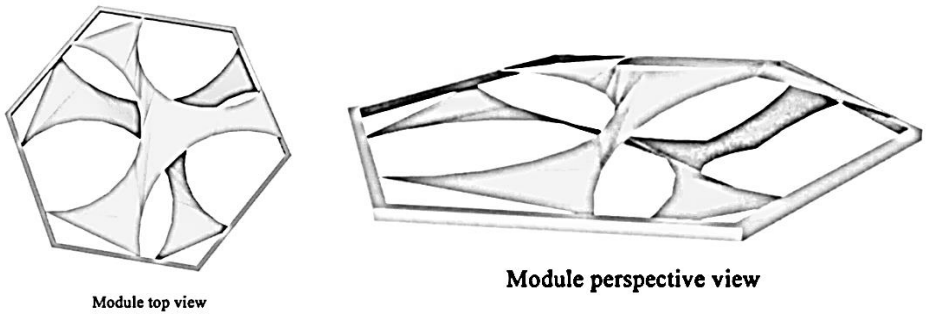


Figure 36: Module Derivation from conifers



5.5.2 Module Population

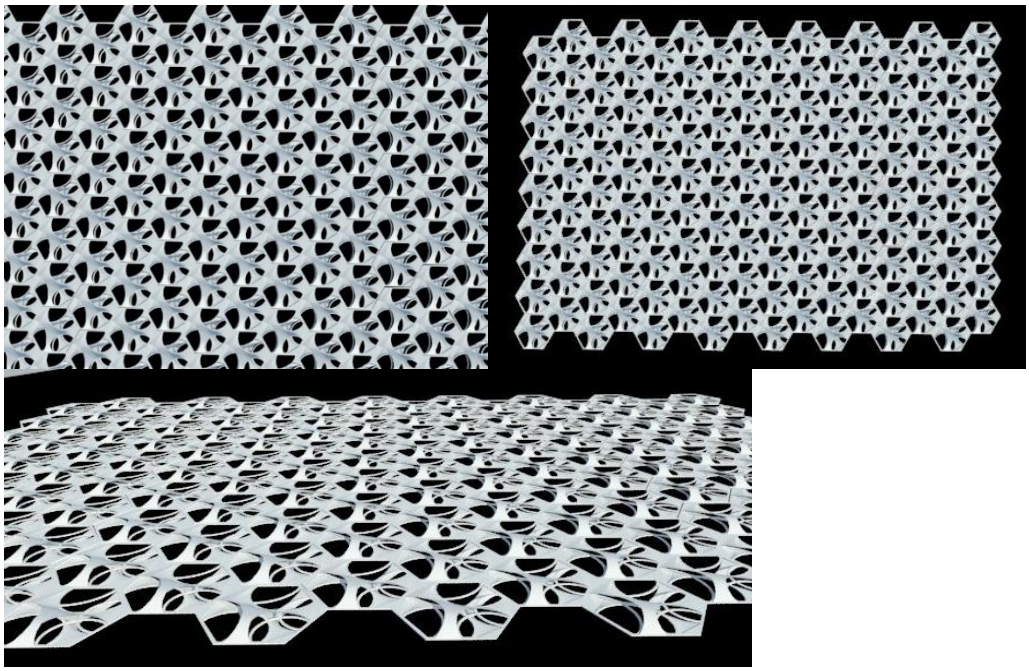


Figure 37. Populating the Module

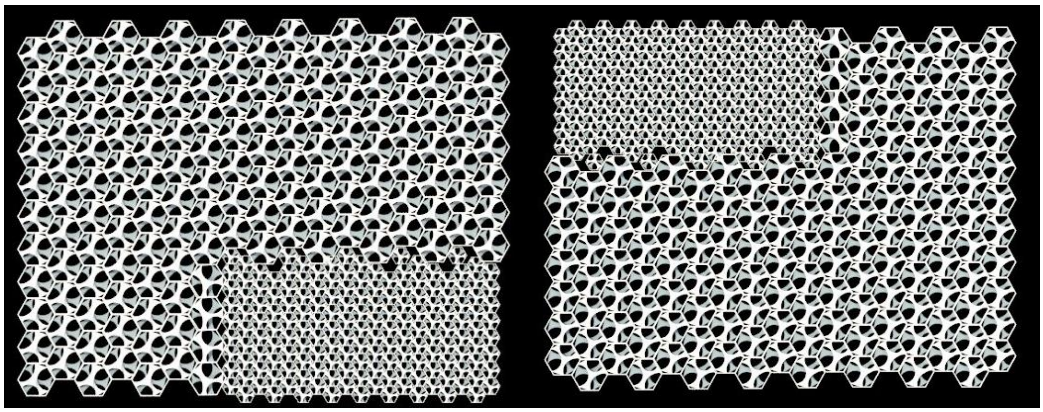


Figure 38. Resolving the Aesthetical Problem of Facades

5.5.3 Module Mechanism to reduce Acoustic problems.

The joining and population of the module depending upon the ratio of noise problems in that specific area or in that specific building portion. As in (Figure 39) if the acoustic issue is occurring in the North-East corner of the building, then the population will change according to the problem in (Figure 40). Module population will be in exceed on West-South side as noise problem has been detected over there.

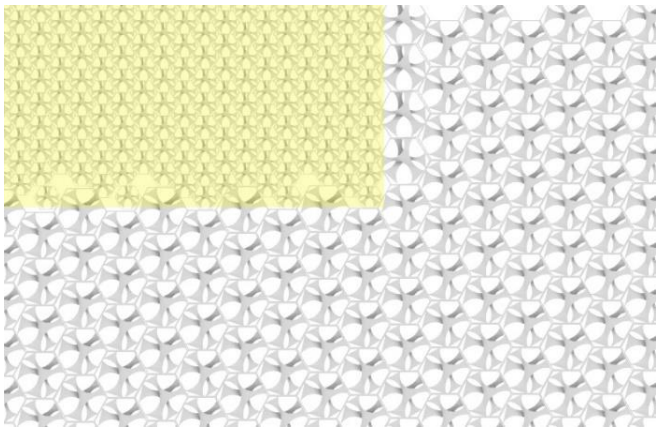


Figure 39. If the Noise problem is in the North-East of the Building Facade

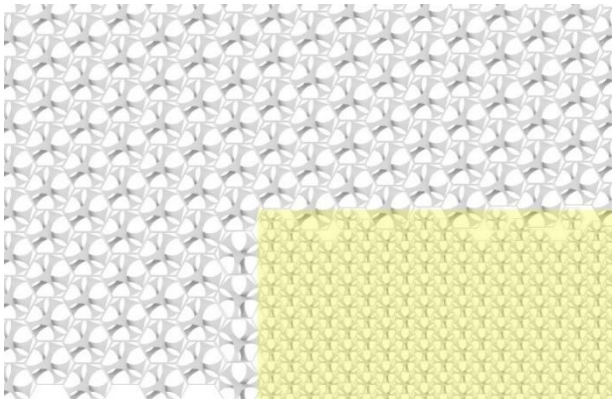
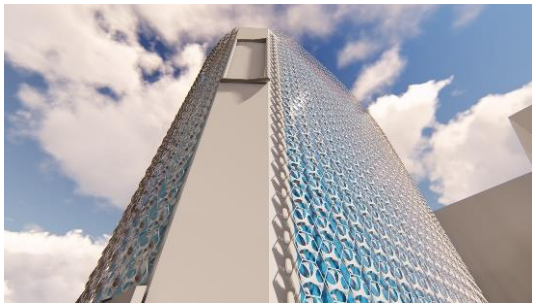


Figure 40. If the Noise problem is in the South-West of the Building Façade

This module has been applied to the Bank of Punjab building (Figure 41). Due to the use of excessive glass, the noise in this building is also a major issue. This module contains the properties just like the trees which act as a noise barrier and also by varying module sizes on the façade, the amount of noise could be controlled inside the building.



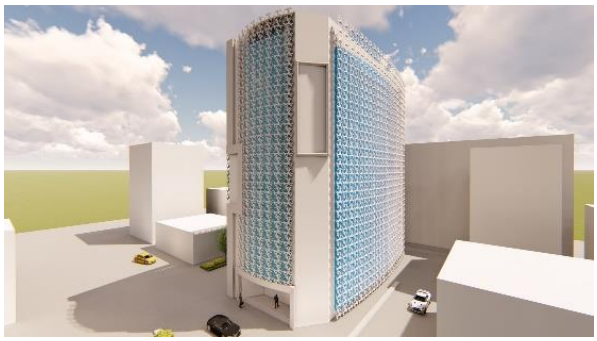


Figure 41: Module application on Bank of Punjab Building for noise reduction.

5.6 SERIOLA RIVOLIANA FISH BEING ADAPTIVE TO ITS ENVIRONMENT

5.6.1 Characteristics of Seriola rivoliana Fish for being adaptive to its surroundings and its mind mapping

— The streamlined bodies of fish allow easy movement through the water.
— Tails in fish help them to swim rapidly for long periods.
— Fish that do not travel long distances as a part of survival strategy, generally have square or rounded tails, which are a useful adaptation for quick acceleration and stopping. (Breslin, 2018)

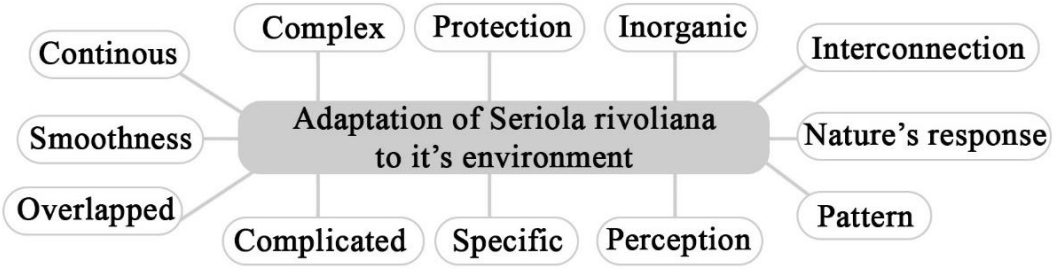


Figure 42. Mind mapping of Seriola Rivoliana

5.6.2 Module Derivation

Inspiration: The basic shape of the module has been derived from the main biomimetic shape of the fish.

Process: The formation of the module has been derived from its abstract mind mapping (Figure 43) by giving specific angles and levels to the module form.

Formation: The module is modeled in Sketchup and replicated to form a complete façade using a digital fabrication software Paracloud gem.

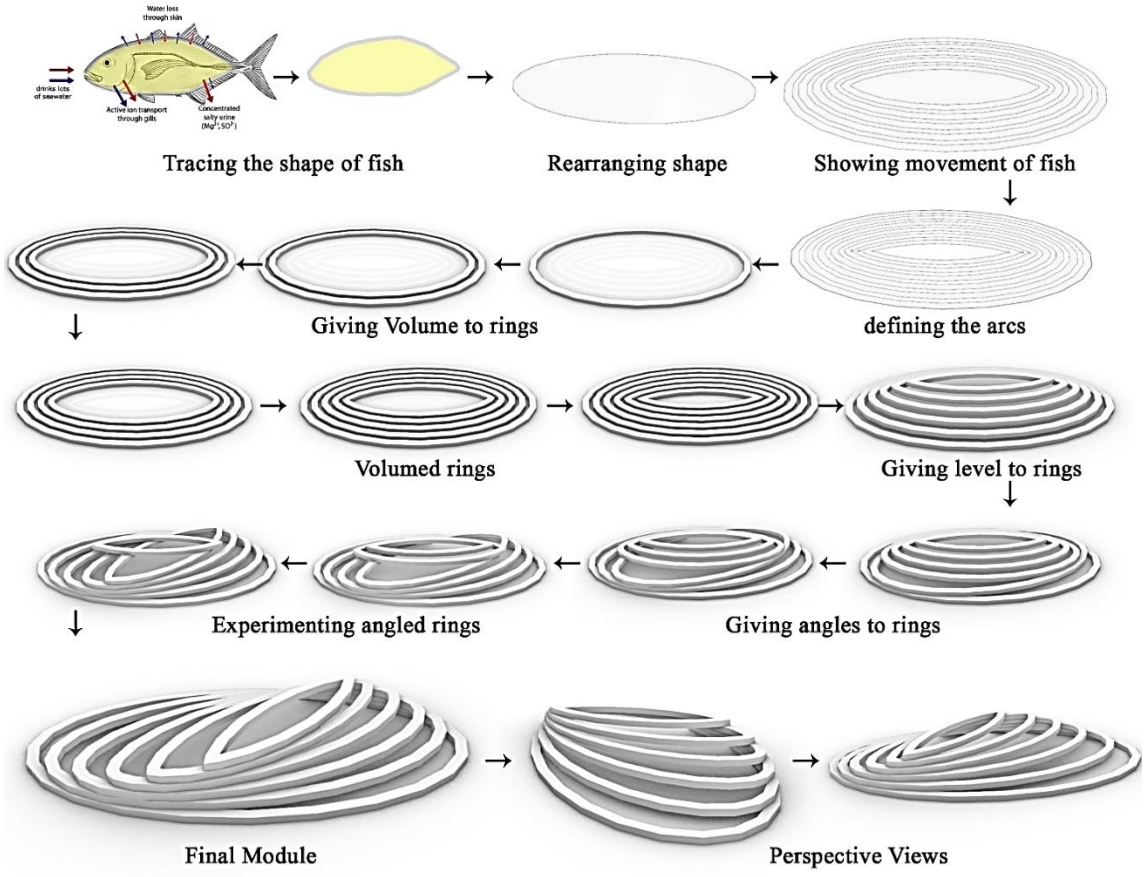


Figure 43: Module Derivation

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5.6.3 Seriola rivoliana fish Adaptation inspired Facades.

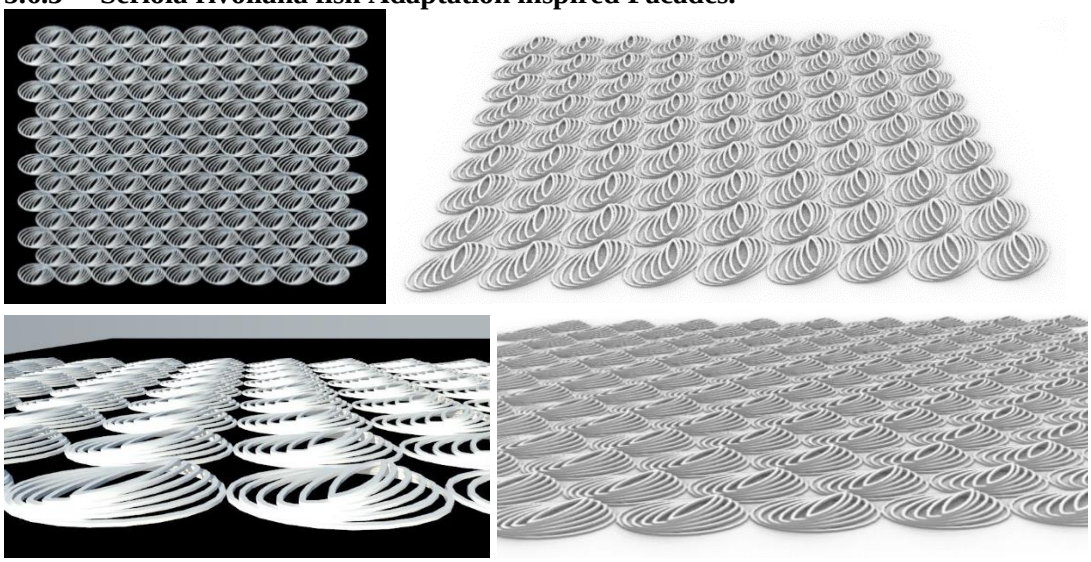

Figure 44. Inspiration for Contextually Sound Facades

Figure 45: Module Application on Bank of Punjab building

Bank of Punjab facades glass does not depict the contextual effect of Lahore, but to make it a little contextually sound a mesh which could also be known as "Jali" has been proposed and this mesh's module has been derived from fish and its relationship with water (Figure 45).

6. CONCLUSIONS

To achieve the aim of the research, the study of the biomimetic architecture concept for building facades is conducted by reviewing literature and studying some examples of biomimetic projects. This study is done on building envelopes/skins, and it determines the potential of applying such principles to Increase building efficiency through the approach of biomimicry concept for building envelopes by applying biomimetic approaches. Comparative analysis of current building skin problems and natural systems which can solve the identified problems efficiently have been explored to develop building envelope designs.

For this purpose, one of Lahore's buildings is studied in detail to analyze all problems and apply its solutions to that building to prove the biomimetic approach as a solution for different façade problems.

While considering and studying the biomimetic approaches which have been used worldwide for different design problems, it can be concluded that many of the Lahore buildings' facade problems can be resolved through biomimetic approaches. An understanding is developed to realize how researchers reviewed the concept of biomimicry applied in the building envelope design. This approach can be taken further and may help in solving problems of design elements in the building envelope.

Table 3: Natural Species considered for their specific characteristics for solving problems.

Species		Weather				Feathers											
		Tropical	Polar	Desert	Water	Thermo Regulation	Water management	Insulation and conserving heat	Noise control	Structural Shading	Structural Shading	Self-cleaning	Self-healing	Produce energy	Self-protection	Produce Oxygen	Purify water
Plants	Cactus			▪		▪	▪	▪		▪					▪		▪
	Lotus	▪		▪			▪					▪	▪	▪	▪		
	Trees	▪		▪		▪	▪	▪	▪	▪	▪					▪	
	Vegetation/ Creepers	▪		▪	▪	▪	▪	▪	▪							▪	
Animals	Fish				▪				▪						▪		

One of the most important focuses of this research was manageability leading to efficient biomimetic facade designs. It was to understand how organisms adapt to nature and the way their properties can be applied to building façades through a biomimetic approach that allows efficient management of issues like heat gain, maintenance, acoustics, aesthetics, and contextuality for the building envelopes (Figure 46).

The characteristics of the building envelope design are important criteria of this research. Among the issues catered are:

Heat gain: In buildings, approximately 30% heat gain is reduced through adaptation of biomimetic façade derived from cacti properties as an inspiration for better building envelope design. In a city like Lahore where annual heat gain values are high, by application of biomimetic façade, building energy load will be reduced which will aid in overcoming or reducing the energy crisis in our country if the same design patterns are followed in other buildings.

Maintenance: Building maintenance is made easier by adapting of façade exhibiting like that water repellency in lotus which is the inspiration for the proposed façade. Building an envelope that has reduced particle adhesion allows easy surface maintenance of the façade.

Aesthetics: Biomimetic approach for building design allows the formation of visually appealing envelopes.

Acoustic control: With increasing noise pollution, specifically in cities like Lahore, acoustic control plays a major part in efficient envelope design. The biomimetic approach led to the formation of layered volumetric modules in the building façade that allows the reduction of noise levels within a building.

Contextually sound building façade: With the biomimetic approach for façade upgradation, a major concern arises which is building relationships with the surrounding context. The research shows in nature different examples are found for context adaptation by organisms. One such approach is adapted for an envelope design proposal that allows the building to relate to its context by catering to heat gain issues while matching the *jail* patterns in the vicinity.

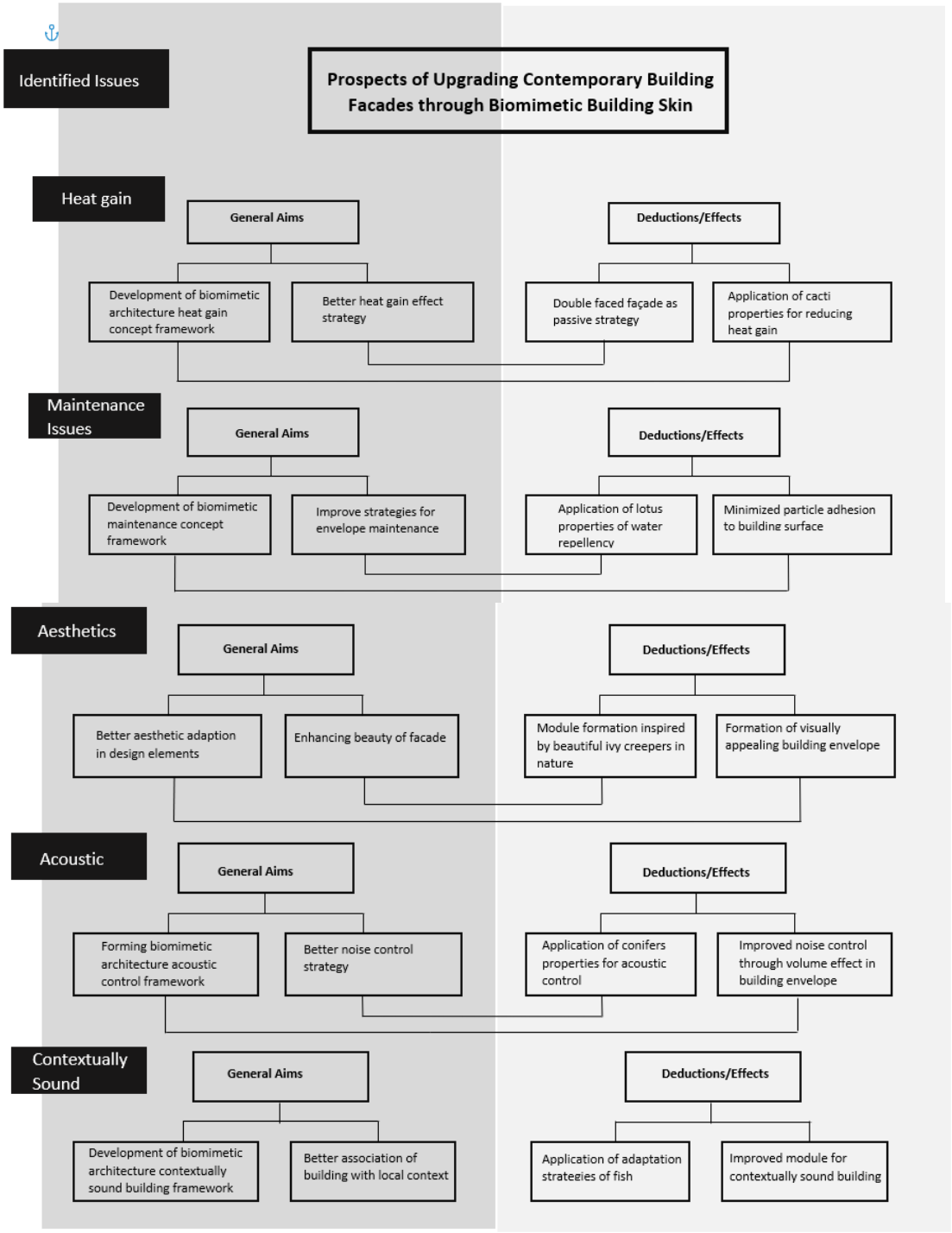

Figure 46. Recommendations for façade upgradation through biomimetic design approach

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