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Adaptability of Parametric Structures in Various Climatic Regions

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Abstract:
*Pa*rametric design has revolutionized architecture with its flexibility and innovation, yet its adaptability to different climates is underexplored. This research aims to optimize parametric structures for various climatic conditions, promoting sustainable and resilient architecture. The goal is to design buildings that autonomously adapt to environmental changes, optimizing performance for sustainability and efficiency. This study enhances the understanding of creating adaptable, innovative, and resilient structures, contributing significantly to parametric architecture and sustainable building practices. Architects and designers will gain insights into developing environmentally responsive buildings that maintain optimal performance across diverse climates.

Keywords: Parametric Design, Structural Flexibility, Climatic Adaptability, Performance Optimization

I. INTRODUCTION

Grounded in mathematical principles, parametric design utilizes computer programs to adjust parameters for various designs. This approach goes beyond aesthetics, incorporating computational methods to enhance adaptability and functionality. Setting and modifying design parameters creates intricate structures and streamlines manufacturing, enabling efficient production and faster market entry as shown in Figure 1.

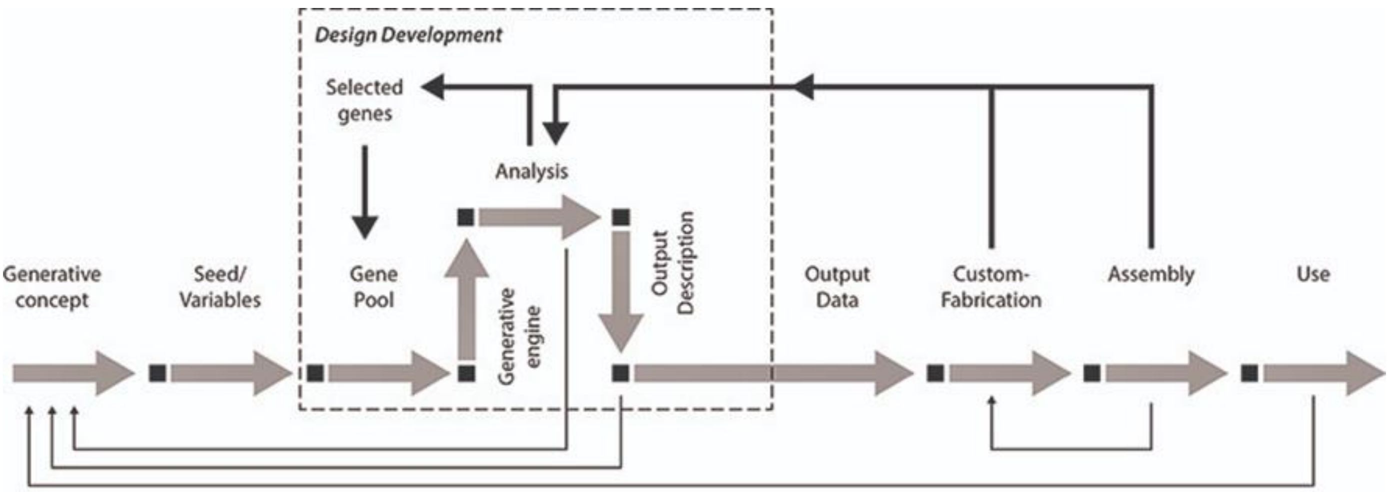


Figure 1: Parametric design and Manufacturing Process (Erlendsson, 2021)

A. *Emergence of Parametric Design*

In the 21st century, parametric architecture became a significant design trend. Luigi Moretti introduced the term "parametric architecture," and Frei Otto's soap film experiments advanced the concept. Antonio Gaudi's use of weighted strings for catenary arches in his models is an early example. The late 20th century saw software innovations like ProENGINEER in 1988, revolutionizing design. Gehry Partners, investing in CAD/CAM technologies since 1989, and Morphosis, under Thom Mayne, demonstrated innovative, cost-effective designs using advanced tools like Rhino and Grasshopper.

B. *Indulging parametric design with environment*

Parametric structures can be designed to respond to climate conditions, enhancing energy efficiency and occupant comfort. In warm and humid regions, designs focus on shading and ventilation. In cold regions, they maximize solar heat gain and minimize heat loss. Composite regions balance both needs. This approach also improves stormwater management and reduces environmental impact.

C. *Aim of the Study*

This research paper aims to assess the adaptability of parametric structure in different climatic conditions, designed through different parameters and case studies.

D. *Objectives*

The objectives of this research paper are as follows:

- To explore the design principles of parametric forms with relevance to literature and case studies.
- To delve into a set of design parameters for parametric forms in various climatic regions.
- To analyze the building model (prototype) in regard to relevant parameters through the advanced software.
- To suggest design approach and strategies for the adaptability of parametric structures.

E. *Scope*

The scope of this research paper are as follows:

- This study will probe various parameters that influence the design and adaptability of parametric structures in different climatic regions.
- The approach will include comprehensive analyses of practical applications and challenges faced by the existing parametric structures located in different climates: warm and humid climate, composite climate and cold climate of India.
- Utilizing advanced software such as Grasshopper, Ladybug and other plugins to evaluate a prototype-building model focusing on certain parameters in such regions.
- Development of adaptable design approaches for parametric structures in varying climatic conditions.

F. *Research gap*

A research gap is the limited exploration of integrating climate-adaptive design strategies alongside quantifiable parameters within parametric design.

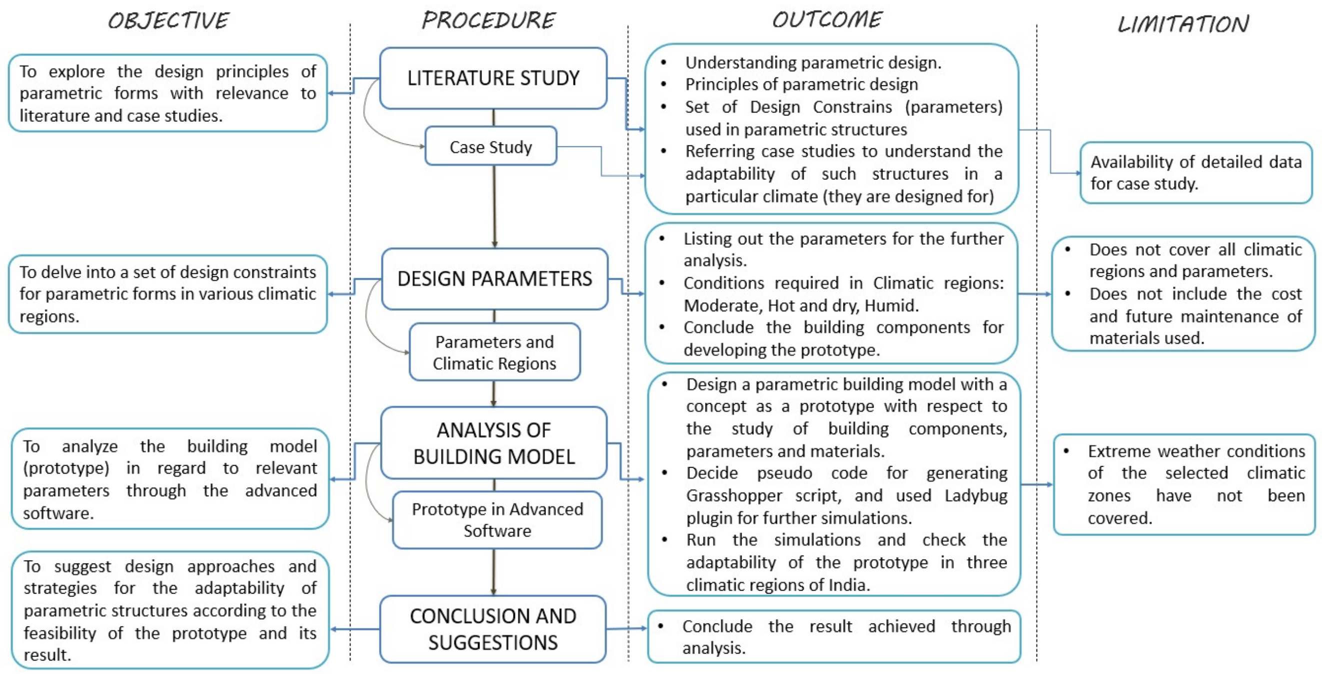
G. *Limitations*

The limitations of this research paper are as follows:

- This study does not cover the following climatic zones: hot and dry climate, and moderate climate of India.
- Potential limitations in software capabilities for accurately simulating complex climatic conditions.
- Implementing adaptable designs charge additional investment, both during construction and for ongoing management which will be not covered.

H. *Research Methodology*

The mind methodology for the research on the adaptability of parametric structures in various climatic regions is shown in **Error! Reference source not found.**.



LITERATURE STUDY

I. *Integrating Computational Design (CD) with Parametric Architecture*

Combining Computational Design (CD) with Parametric Architecture revolutionizes architecture by using algorithms and digital tools for complex, efficient designs. This synergy enhances creativity, precision, and adaptability. It allows architects to explore numerous design combinations, creating tailored, responsive, and sustainable structures that push the boundaries of traditional design, ensuring functionality and resilience.

J. *Adaptability of Parametric structures*

An adaptable structure suitable for various climates features dynamic shading and insulating panels, allowing efficient adaptation to climatic changes. Walls should balance thermal mass and insulation for stable temperatures year-round. Efficient pipe layout and return air management minimize hot or cold spots. Using energy-efficient appliances, recycled materials, and renewable energy reduces energy demand. Ventilated cavities in walls manage heat and insulation, while moisture-resistant composites prevent mold. Green roofs, reflective coatings, and solar panels enhance energy efficiency and adaptability. These elements and passive techniques ensure the building remains habitable and energy-efficient across different climates, significantly reducing annual energy consumption.

CASE STUDY

Examining the adaptability of parametric structures in various climates through "One Ocean," "Aviva Stadium," and "South Beach," showcasing how these designs address environmental challenges, enhance performance, and improve aesthetics.

K. *"One Ocean" - A Thematic Pavilion*

The Yeosu EXPO 2012 pavilion, designed by SOMA (refer Figure 2), features a kinetic façade with 108 GFRP lamellas for natural ventilation and a seawater heat exchanger for climate control as shown in Figure 3. Located on South Korea's southern coast, it adapts to temperate weather, representing "The Living Ocean and Coast", which refer Figure 2. The One Ocean Pavilion serves as an educational space, promoting responsible ocean resource use and innovative coastal solutions.

Figure 2: Top View (5osA, 2009)

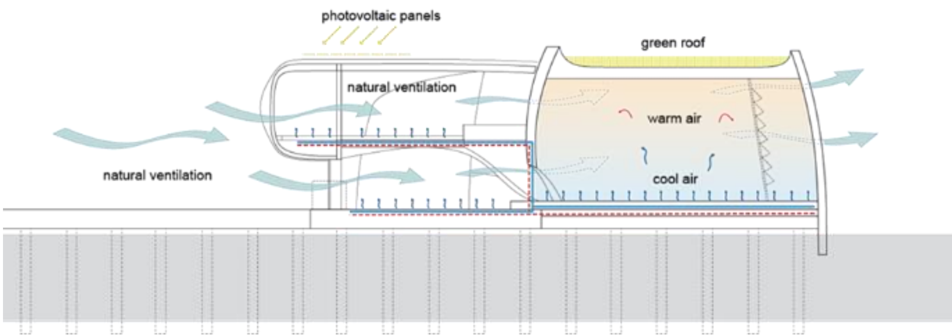


Figure 3: Wind direction and Ventilations (Transsolar, 2024)

Post-EXPO, it remains a cultural landmark and tourist attraction, integrated into a new walkway in a former industrial harbor. Its design fosters marine conservation awareness and sustainable practices. Key features include vertical cones, scenic paths, rooftop terraces, and interactive exhibits on marine ecosystems and sustainability. Solar panels provide about two-thirds of the building's annual energy needs. The kinetic facade, composed of 108 vertical lamellas, enhances circulation by capturing visitors' attention and guiding them toward the entrance. Its dynamic movement creates an engaging experience that encourages exploration as shown in Figure 4.

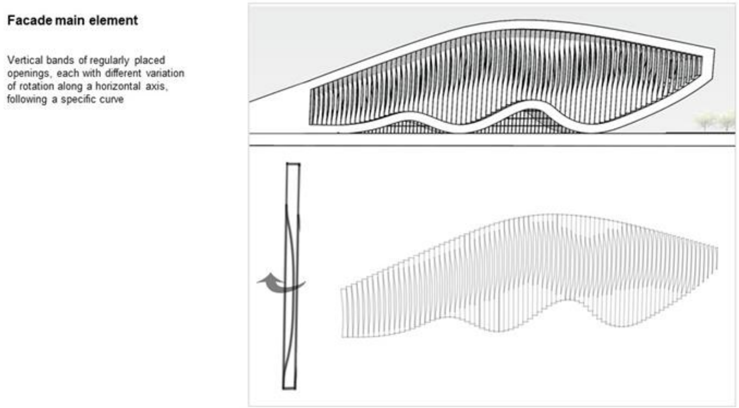


Figure 4: Kinetic Façade- Main Element (Kulla, 2019)

L. *"Aviva Stadium"- An Integrated Parametric Design*

The Aviva Stadium in Dublin, completed in 2010, is owned by the Irish Rugby Football Union and the Football Association of Ireland, refer Figure 5. Located at 62 Lansdowne Road, it covers 67,000 square meters with a built-up area of 58,000 square meters. Designed by Populous and Scott Tallon Walker, it features a "Horseshoe Truss System" as shown in Figure 5 and seats 51,700 spectators.

Figure 5: Aviva Stadium, situated along the Dodder River (on east) (Brophy, 2024)

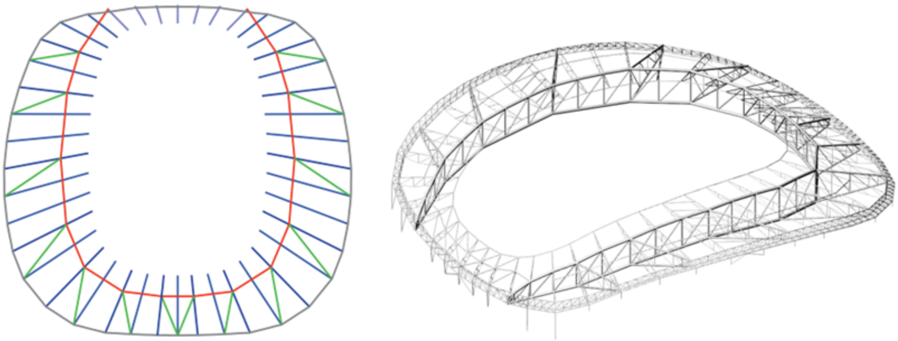


Figure 6: Schematic diagram of structural hierarchy and Structural members output from the parametric model. (Paul Shepherd, 2011)

The stadium's wave-like roof and advanced facilities make it a top venue for sports and entertainment in Dublin's temperate maritime climate. It was the first stadium fully designed using parametric modeling software, ensuring a harmonious design with optimal natural light and minimal impact on nearby buildings as shown in Figure 7.

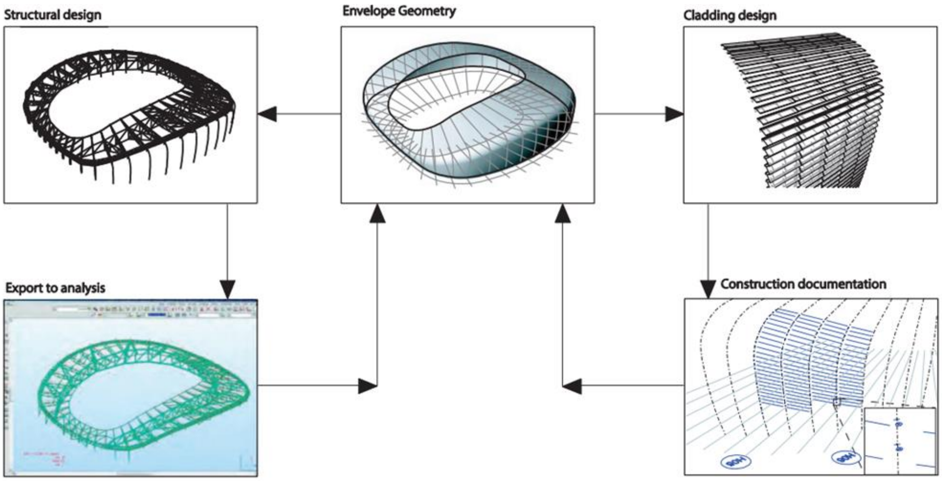


Figure 7: Collaborative Design Process of Aviva Stadium (Paul Shepherd, 2011)

M. *"South Beach"- A Green Spine*

South Beach in Singapore, designed by Foster + Partners, integrates energy-efficient urban sectors like shops, cafes, restaurants, a hotel, and public spaces with restored buildings. It features two high-rise towers (shown in Figure 8), a landscaped pedestrian avenue (green spine), and an innovative canopy that shields public spaces from the tropical climate.

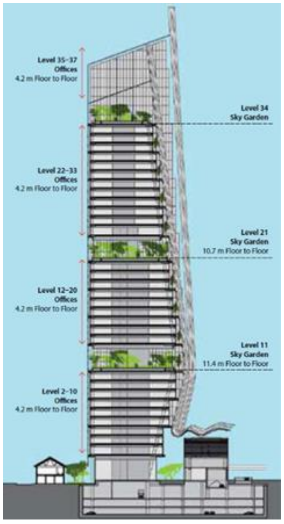
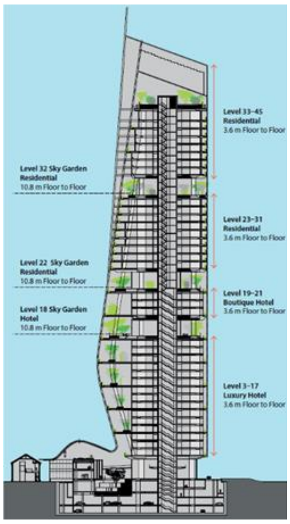
(a)  (b) 

Figure 8 (a): The north tower contains multi-tenant office space and (b) The south tower contains a hotel and residences. (Roland Schnizer, 2017)

The canopy at South Beach, Singapore, designed by Foster + Partners and Arup, is crucial for sustainability. It shields public spaces from sun and rain, harnesses solar energy, and promotes natural ventilation. The canopy's design (refer Figure 9), validated through on-site measurements, significantly reduces temperatures and enhances comfort. It features steel and aluminum louvers, a Vierendeel truss system, and an integrated rainwater collection system. The structure's lightweight, single-layer design ensures structural integrity and ease of fabrication. Field studies showed the canopy lowers felt temperatures by up to 13°C compared to other canopied spaces and 17°C compared to unsheltered areas.

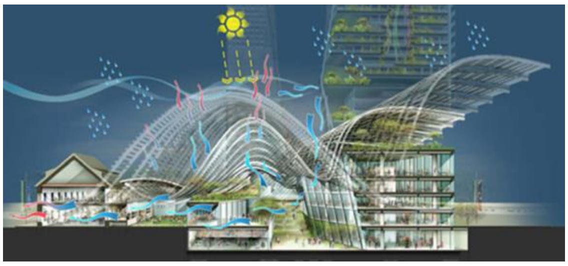


Figure 9: The canopy channels breezes and blocks harsh sunlight (Inhabitat, 2008)

Figure 10: Louvers of the canopy reacting to sunlight (Partners, 2018)

The design aims for a BCA Green Mark Platinum rating through passive, active, and power-generating strategies. Key features include sky gardens, rainwater collection, solar panels, and a microclimatic canopy. The project exemplifies climate-responsive architecture, enhancing urban sustainability and comfort while preserving historical elements.

PROTOTYPE DEVELOPMENT AND SIMULATION

The main objective of designing the prototype is to develop a system of fenestration and façade that adapts to climate changes and makes the building efficient for living without any other mechanical cooling or heating systems.

N. *Concept*

A fenestration is crafted to adjust automatically based on the amount of glare or daylight needed. This concept is modeled after the functioning of eyelids and pupils, as illustrated by our natural response to excessive brightness; instinctively, we squint or close our eyes. In dim lighting, our pupils dilate and our eyelids fully open, while strong glare prompts our eyelids to close and our pupils to constrict, following the same principle, the sliding panels of the fenestration are designed. The design of the wooden louvers is influenced by the sine curve, allowing them to rotate 180° in response to solar radiation. (Refer Figure 11 for Building Prototype and Figure 12 for Concept)

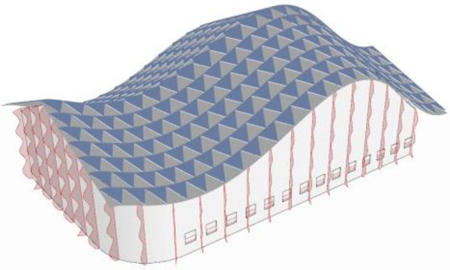


Figure 11: Prototype for testing

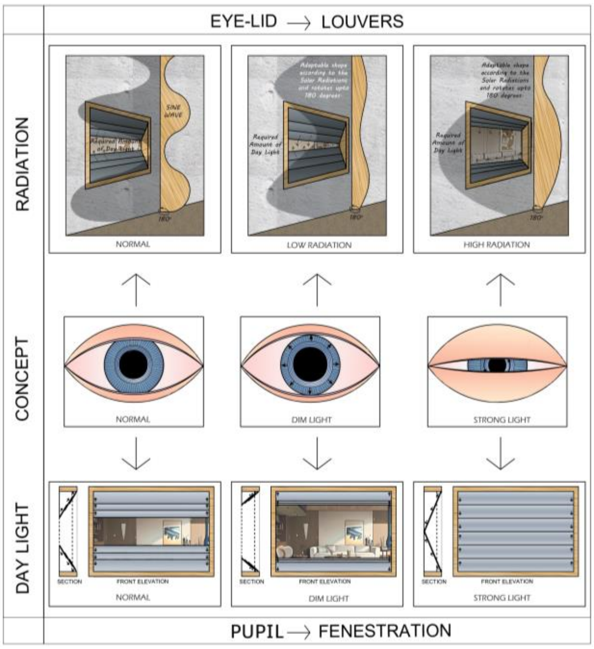


Figure 12: Concept

O. *Grasshopper Script*

The grasshopper script was designed (as shown in Figure 15) according to the pseudo codes shown in Figure 13 and Figure 14.

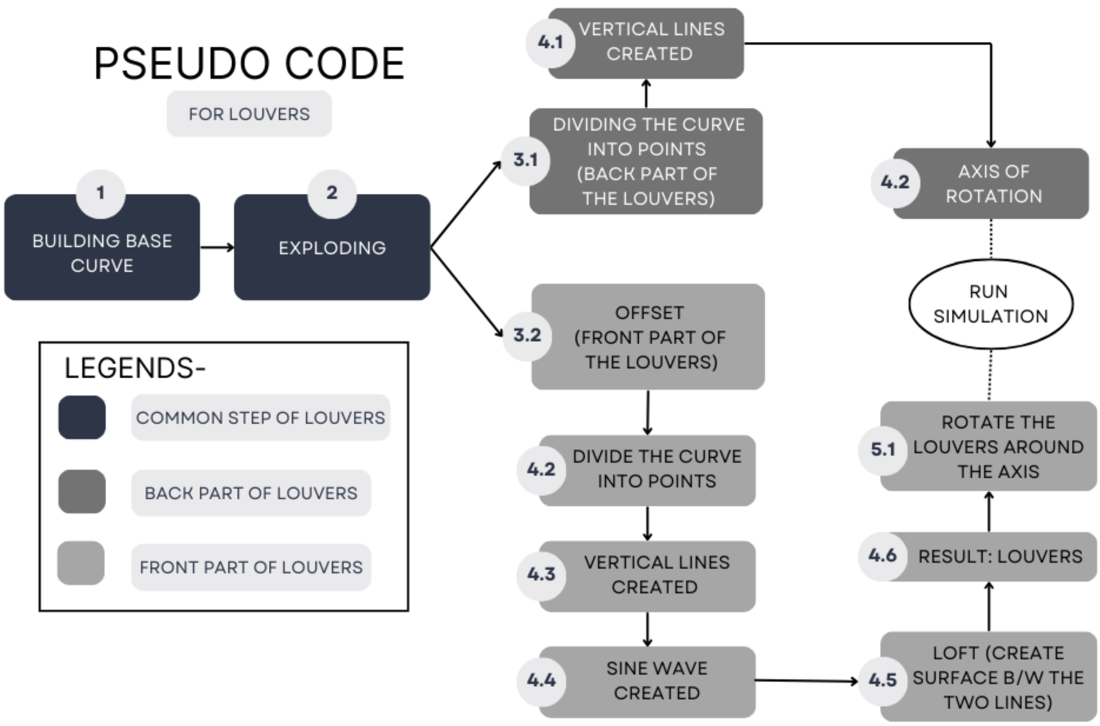


Figure 13: Pseudo Code for Louvers

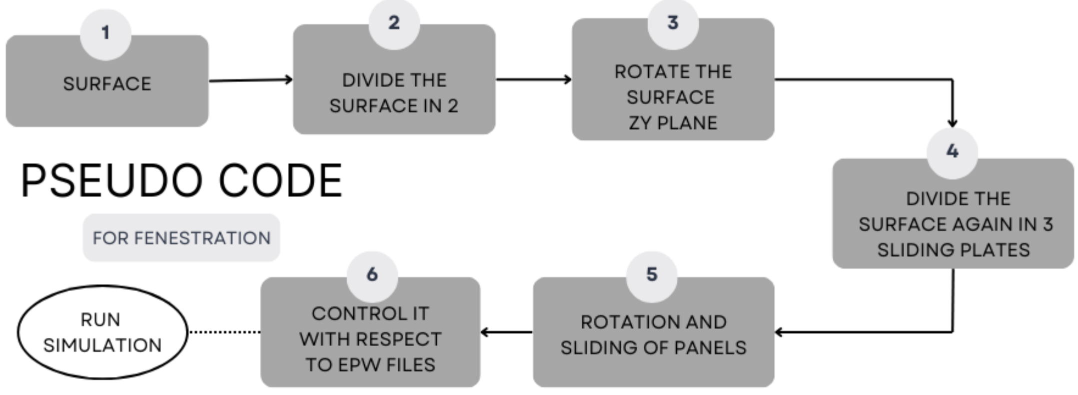


Figure 14: Pseudo Code for Fenestrations

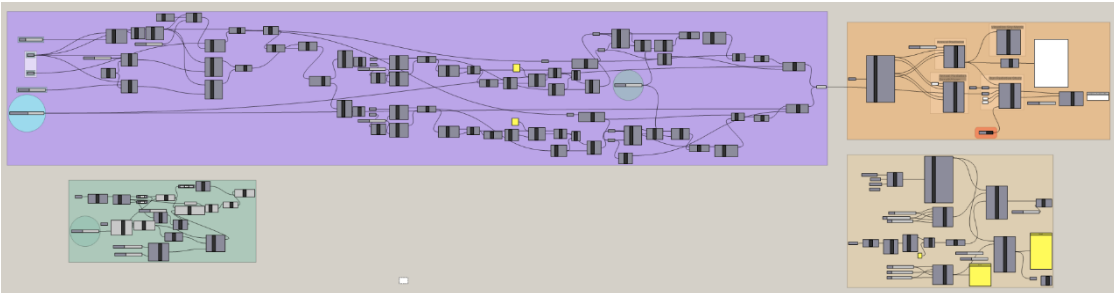
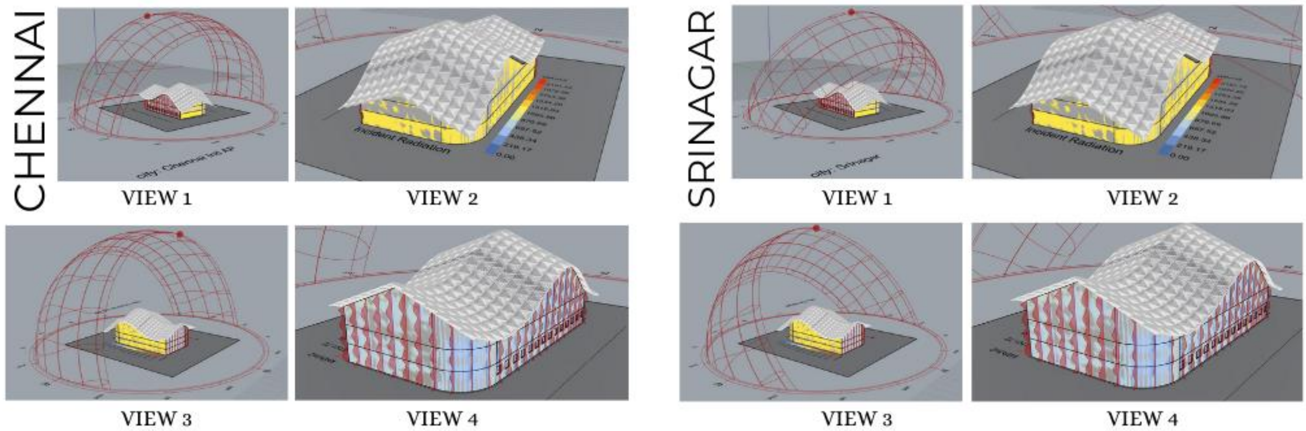


Figure 15: Over all Grasshopper Script

Simulation and Result

Louvers and fenestrations are implemented in north and west walls to run the simulation and check efficiency toward solar radiations between south-west and north-east sides as shown in Figure 16.



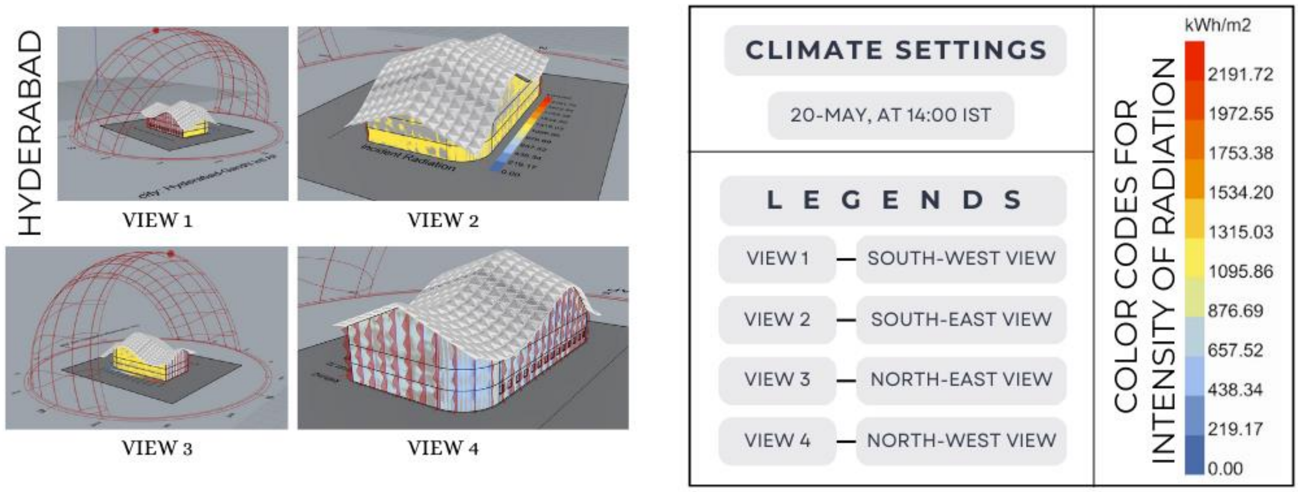


Figure 16: Simulation- Radiation Intensity with and without Louvers and Fenestrations

As the south-west normally faces most radiation in afternoon and north-east faces least radiations. Here after implementing the fenestrations and louvers, it shows that south-west side has the radiation between 0.00 kwh/mm^2 to 10.00 kwh/mm^2 in all 3 regions, where as in north-east face which has no designed fenestration and louvers, it shows that 1753.38 kwh/mm^2 to 1095.86 kwh/mm^2.
The roof is equipped with solar panels that provide the necessary electrical energy to power the mechanical operations of the louvers and fenestrations. By incorporating these elements into the façade, the interior space can eliminate the need for traditional mechanical systems, while still maintaining optimal thermal comfort and ventilation.

CONCLUSION

The research on the "Adaptability of Parametric Structures in Various Climatic Regions" emphasizes the significant role of adaptive design elements such as fenestrations and louvers. These elements, designed to adjust automatically based on the amount of glare or daylight needed, mimic the natural response of eyelids and pupils to varying light conditions. Just as our pupils dilate and eyelids open wide in dim lighting and constrict in response to strong glare, the sliding panels of the fenestration adapt to control solar radiation effectively. Furthermore, the wooden louvers, influenced by the sine curve, can rotate 180° to respond dynamically to solar radiation. The study demonstrates that the southwest façade, equipped with these adaptive features, maintains low radiation levels between 0.00 kWh/mm^2 to 10.00 kWh/mm^2 across all regions. In contrast, the northeast façade, without these features, shows much higher radiation levels. This highlights the importance of integrating adaptive designs in parametric structures to enhance energy efficiency, thermal comfort, and overall building performance.

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