Computational Design of a Bio Inspired Responsive Architectural Façade System

Florina Dutt and Subhajit Das

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Abstract

This research intends to illustrate a nonlinear relationship that could be drawn between the fundamental processes in living systems and architectural design of responsive surface. The research focuses on deriving a set of parametric relationships from the phenomenon in cell biology and generating an architectural expression of a responsive façade system. The research methods primarily investigates the cell – to – cell connection in mammary epithelial cell system and review the evident relay of communication across the entire system of cells . This thorough investigation unfolds the logical parameters of the biological system that delineates the dynamic feedback mechanism and changes in the cell surface conditions initiated from the changes in the extra - cellular environment (ECM). The research findings of this complex mechanism are further translated though parametric modeling tool (in this case Generative Components) to model the causalities of the changes in cell environment and surface condition changes. In the next phase of our research we have explored the architectural utility of this hybridized model operating in a user defined controlled environ, and not just a mere response to biological stimulus.

1. INTRODUCTION

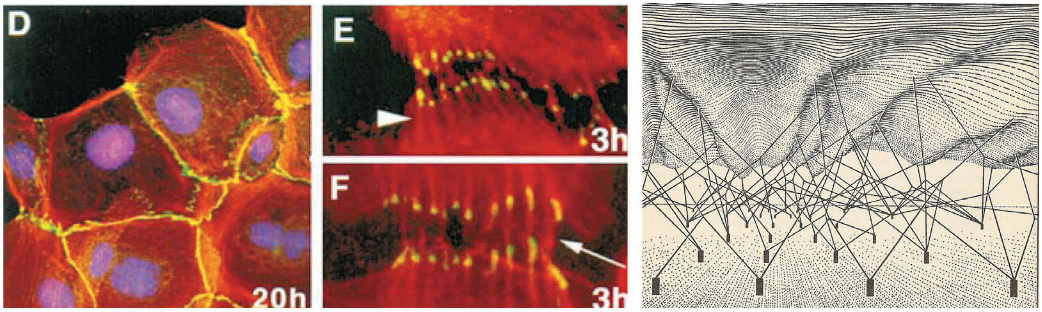
1.1. Context of Biological Research ??

Some biological research prefaces the architectural design method to explain the complex nonlinear relationships drawn from the biological model to substantiate the parametric model of architectural surface /façade design. The study investigates the intricate process of relay of communication across the system of tissues made up of smallest units of epithelial cells. The cell membrane is visualized as an active conveyor of changes when complex procedure of cellular transmission occurs. We are interested in the dynamic relationship between cytoskeleton (inner cellular content) and extra cellular matrix (ECM) separated by the cell membrane (outer cellular covering). The vision that the cells within the tissues functions as an integral unit in architecture comprising their adjacent micro environment was strengthened from the views of cell biologist Paul Weiss in 1945 [7]. According to Paul Weiss "the living units are enmeshed in the microenvironment that (includes extracellular Matrix ECM) binds them to the substratum" [9].

Mina Bissell, refined this idea to suggest that a state of "A dynamic reciprocity exists between the extracellular matrix on the one hand and the cytoskeleton and the nuclear matrix on the other hand" [2]. In order to model the biological system parameters, we specifically choose to study the interaction of human mammary (human breast) epithelial cells with the extracellular matrix components, laminin, Tenascin-C & E-cadherin (protein). The reason behind this specific choice of mammary epithelial cells is the presence of the characteristic epithelial cell junction and their behavioral changes observed in normal vs. malignant conditions. The changes in the cellular junctions impacts the changes in the cell surface conditions which forms the core focus of this research. This idea could be further illustrated through Conrad Wellington's epigenetic landscape's abstract machine, a dynamical system tied by relations that echo throughout. If we suppose that some of the 'pegs' in Waddington's model are environmental factors, rather than genetic loci, it can be manifested that deviations in these environmental vectors are relayed to the surface that acts as an active interface to demonstrate the changes in the environment [4]. Similarly any changes in the extracellular matrix condition relays changes in the cell surface condition which could be the basis of the responsive surface design in architecture where the changes would be instigated by external environmental conditions and user needs .

1.2. Biological Research Model

The biological research model that instantiates the parametric design model for the responsive surface, is inspired from the changes observed in mammary epithelial cells. The mammary epithelial cells transform form an orderly state (normal state) to disordered disruption as they turn malignant.



◀ Figure 1a shows formation of adhesion junctions between epithelial cells. The image on the extreme right shows Wellington's epigenetic model.

The normal mammary epithelial cells rest on a layer of laminin (sheet of basement membrane over which the epithelial cells are arranged), and the cells surrounding breast cells produce Tenascin-C (a protein present in extracellular matrix ECM). The Epithelial cells maintain physical contact with their neighbors through junctions (combination of Adherens junctions, gap junctions, tight junctions and desmosomes). Adherens junctions are connections between adjacent epithelial cells. These are anchored to the cytoskeleton of the cells. Tenascin C promotes tumor formation or cell disruption. The effects of change in the configuration of cells from an orderly state to that of disordered disruption, is that of cancer. E-cadherin is another protein element present in the ECM (Extra cellular matrix or exterior cell environment) that helps to create these junctions. The presence of Tenascin-C indicates, decreased E- cadherin function that can lead to cell disruption, losing the Adherens junction connections and tumor growth [5; 7; 8]. Increase in the Tenascin-C content of ECM changes the Adherens junction properties that reconfigure the cell surface and cytoplasm into a disordered state and vice versa. Consequently, Tenascin-C is being used as a control parameter of study in this research. The cells maneuver from the orderly configuration to a disorderly state by Tenascin-C and back to the phenotypical expression of orderly behavior in the absence of Tenascin -C. Cytoskeleton here acts a medium to transfer response to the cell surface form the Adherens junctions. The interface of change is the cell -surface/ cell membrane and the initiator of this change is the chemical content of ECM, while the medium of transmission is the junctions and cytoplasm. We decided to focus on cell-to-cell connections for the sake of the clarity in the study of relationships, which will further help us to map the biological process with a greater degree of precision.

Architecturally, the dynamic relationship of surface in a hybridized model, presents a refined environment in which different material component can affect the degree and magnitude of transmission of dynamic behavior. In an abstract view, architectural elements through their composite complex systems might become more like cells, able to transmit information attenuated or intensified by their materiality. The computational model shares same level of complexity and constraints as that of the biological system of cell-to-cell interaction. We drew an analogy between the proposed responsive surface design framework and the cell system research based on logical as well as intuitive parameters. The cell membrane is considered the active responsive surface, the tenascin-C & E-cadherin parameters in ECM model are considered environmental factors affecting changes, the cytoskeleton reflex complied with the user-end control parameters and adherens junctions & desmosomes are visualized as tubular steel connections between the two layers of responsive surface.

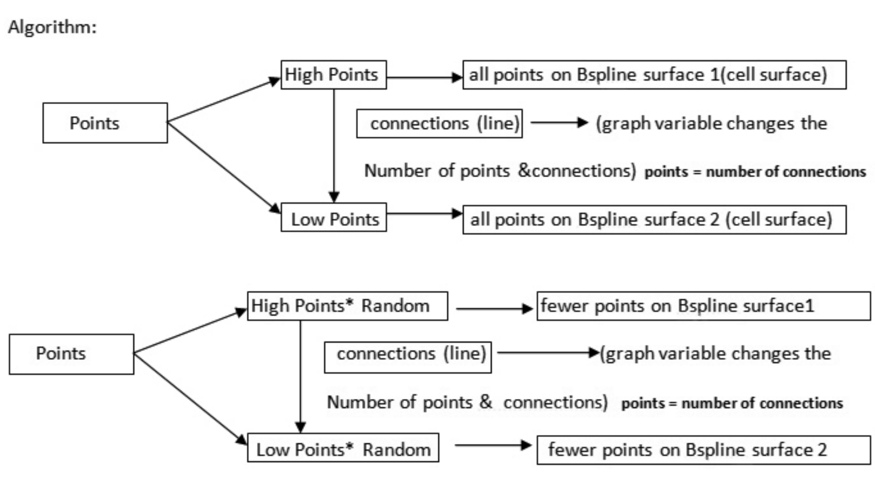
1.3. Interpretation & Preliminary Model Development

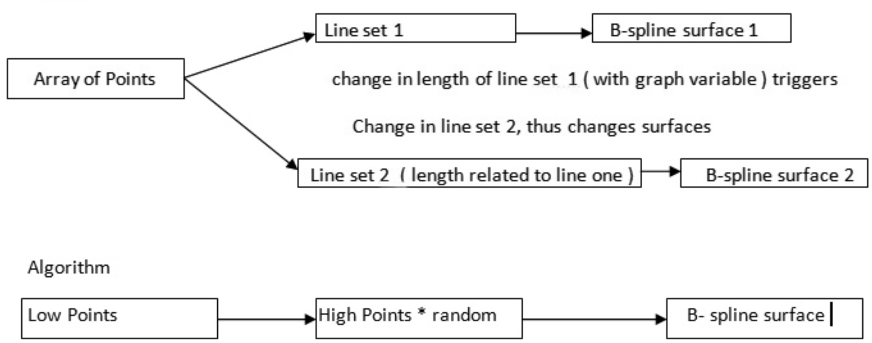
In the course of study of the cell surface as an active interface of changes, we tried to simulate its behavior in certain parametric relationships. What we were focusing on, is the surface response due to the changes in the connection in the cell-to-cell junction in the epithelial cells. Therefore, we systematically went to look into different elements, the parameters controlling them and changes triggered by them into the elements considered at a local level.

Model 1: We considered sets of points on two fixed surfaces and tried to build connections in the form of a line. We set a graph variable that would affect the changes in the number of connections form more to less. The upper set of points was named the high points and the lower set of points was named the low points.

Model 2: A random factor was added to the set of points to test if we can come out of a strict array of points, to test if we can show that those points that are not on the surface are reconfiguring and been seen as the breaking junctions. Although it did not act as a successful model, yet the random factor that was added to the points gave us a direction to come out of the strict grid with a single layer of points.

► Figure 1b shows the flow diagram of Model 1 & 2 respectively.





◀ Figure 1c shows the flow diagram of Model 3 & 4 respectively.

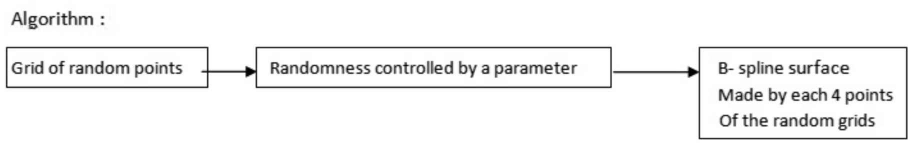
Model 3: Two of the surfaces are joined by an array (double array) of points and the lines form that array of points. The line lengths are related by a single parameter of graph variable. Here we get the understanding of how a single graph variable can change the connection pattern and then the surface profile. The local changes start to affect the global change of surface form this point. This gives us a direction of how to modulate and refine the change so that we get to study the intricate changes in the surface level.

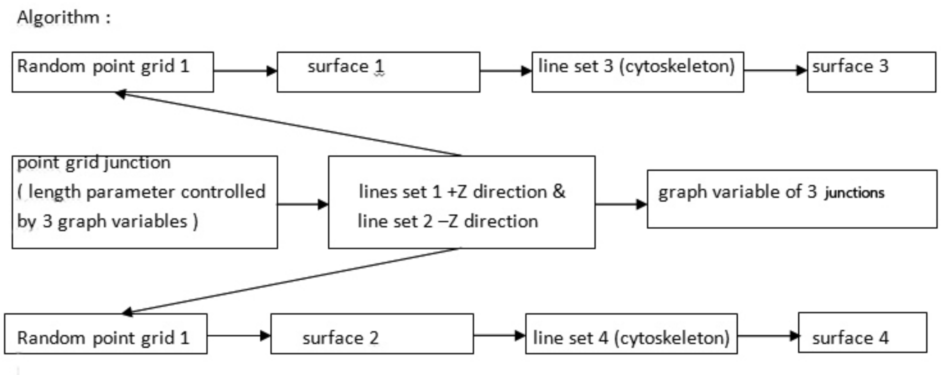
Model 4: This is a model to test if the number of low points can be connected by a parameter to change the number of high points. Each of these low points gives rise to few numbers of high points. Their formation always is done by keeping a minimum distance between them and giving a random factor to break form a strict linear grid. Then B- spline surface is formed using the high points. This is a step to simulate the connection changes in cell-to-cell junction; here the low points triggers changes in the number of high points and thus the surface formation. Also as the number of low points sometimes gives more sometimes less number of high points that indicates the strength of the junction and how it affects the surface. Therefore, we get different surface profile even when the low point count is kept constant.

Determination of surface

The cell surface being identified as a random point set point set, and as mentioned earlier the with Tenascin condition where there is drop in the connections and reconfiguration occurs we are able to connect a parameter to change the point randomness depending on the ECM conditions . So in the parametric model four points constitutes a surface component at is subjected to change with the change in the number and position of the points. These changes are random.

► Figure 1d shows the flow diagram of Model 5 & 6 respectively.



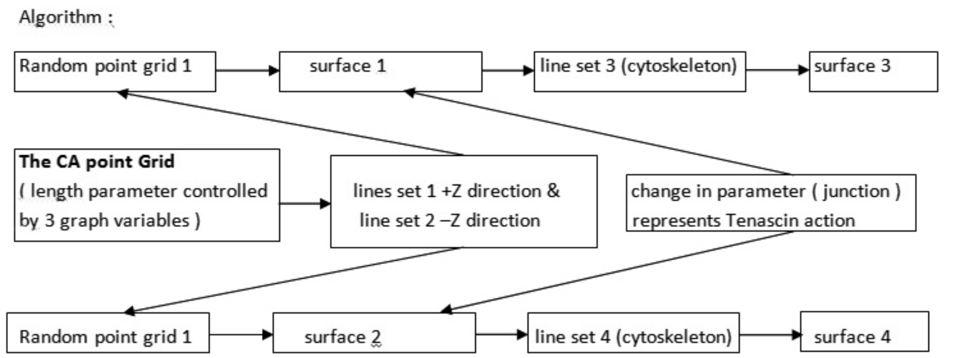


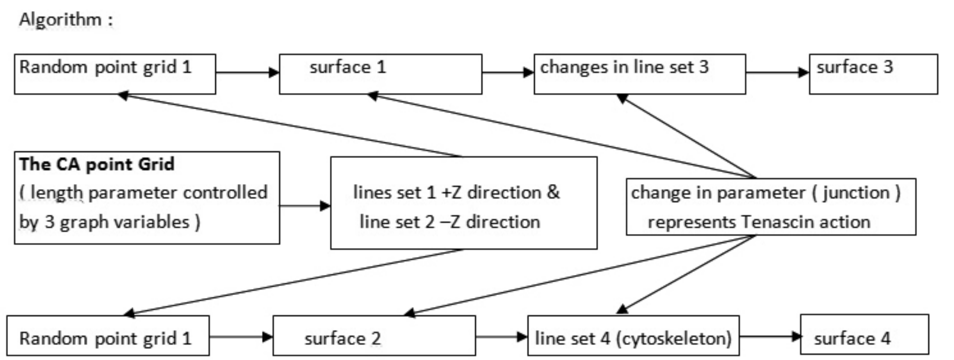
Model 5: The surface made of random point set is tested in different co- ordinate system and each of those are considered to be at cell to cell junction in the array of cell to cell arrangement in mammary epithelium. This gives us the notion to think about their connectivity. In addition, how these connectivity relays the changes to the surface level.

Model 6: We looked into random connections that are points joined by the lines in random connectivity, regular connections one to one connections and one point connecting several points in the surface. The model that we further progressed with is the random connection model. These connections were thought to function as cell cytoskeleton. Determination if the junction types and their controls in the Model

With the course if the study of the biological system we saw three types of junctions existing primarily, the tight junction, desmosomes and adherence junctions. They are varying in their degree of changes and tightness accordingly. Therefore, we set parameters so that the junction's changes at different degree up to a maximum range they are subjected to and see the changes. This is the place where we tried to look in to how proximal changes lead to distal effects.

Model 7: This model is an investigation of changes in the process of relating the changes at different levels. We take a single cell junction to look in the changes. The cell-to-cell surface is connected by junctions of three types. The junctions have different ranges of changes controlled by three graph variables with different maximum range and step size. This changes the surface conditions. Each of these surfaces is connected to the other parts of the surface through cytoskeleton. At this point, no changes can be relayed to this next level of surface that is connected to the active surface through cytoskeleton.





◀ Figure 1e shows the flow diagram of Model 7 & 8 respectively.

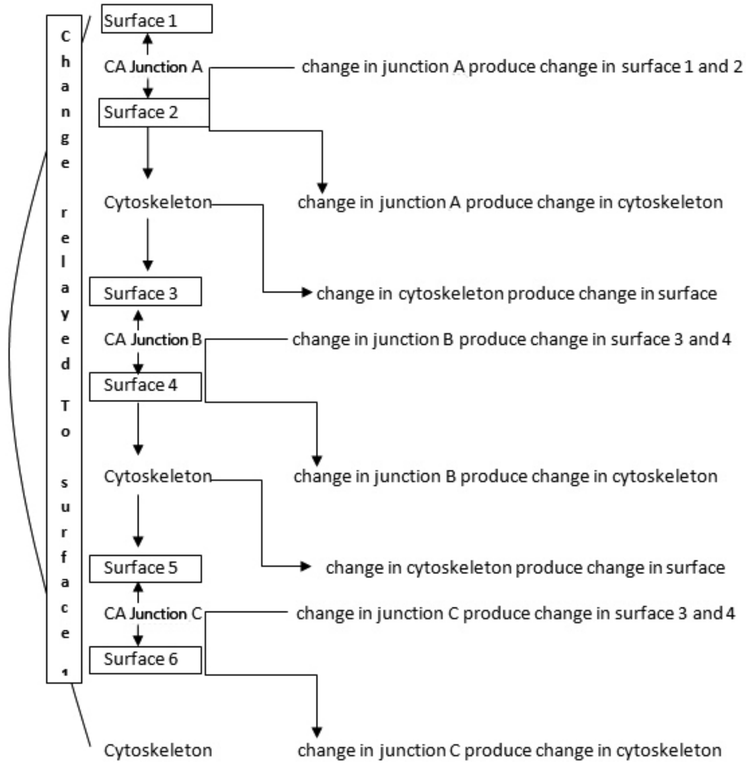
It consists of a regular grid of cells, each in one of a finite number of states, such as "On" and "Off". The grid can be in any finite number of dimensions. For each cell, a set of cells called its neighborhood (usually including the cell itself) is defined relative to the specified cell.

For example, the neighborhood of a cell might be defined as the set of cells a distance of two or less from the cell. An initial state (time t=0) is selected by assigning a state for each cell. A new generation is created (advancing t by 1), according to some fixed rule (generally, a mathematical function) that determines the new state of each cell in terms of the current state of the cell and the states of the cells in its neighborhood. For example, the rule might be that the cell is "On" in the next generation if exactly two of the cells in the neighborhood are "On" in the current generation; otherwise, the cell is "Off" in the next generation.

The application of cellular automata as getting out of the rigid grid (which is also arbitrary) into another random grid, but with inherent local relationships that are closer to the nature of a cell surface made up of smaller components as described. Therefore, we apply this set of rules.

Model 8: The grid helps us to see local changes and behaviors in a different dimension. There are some parts between the junctions that remain quite flat and regular by the change of junction parameters, but parts

► Figure 1f shows the flow diagram of Model 9 respectively.



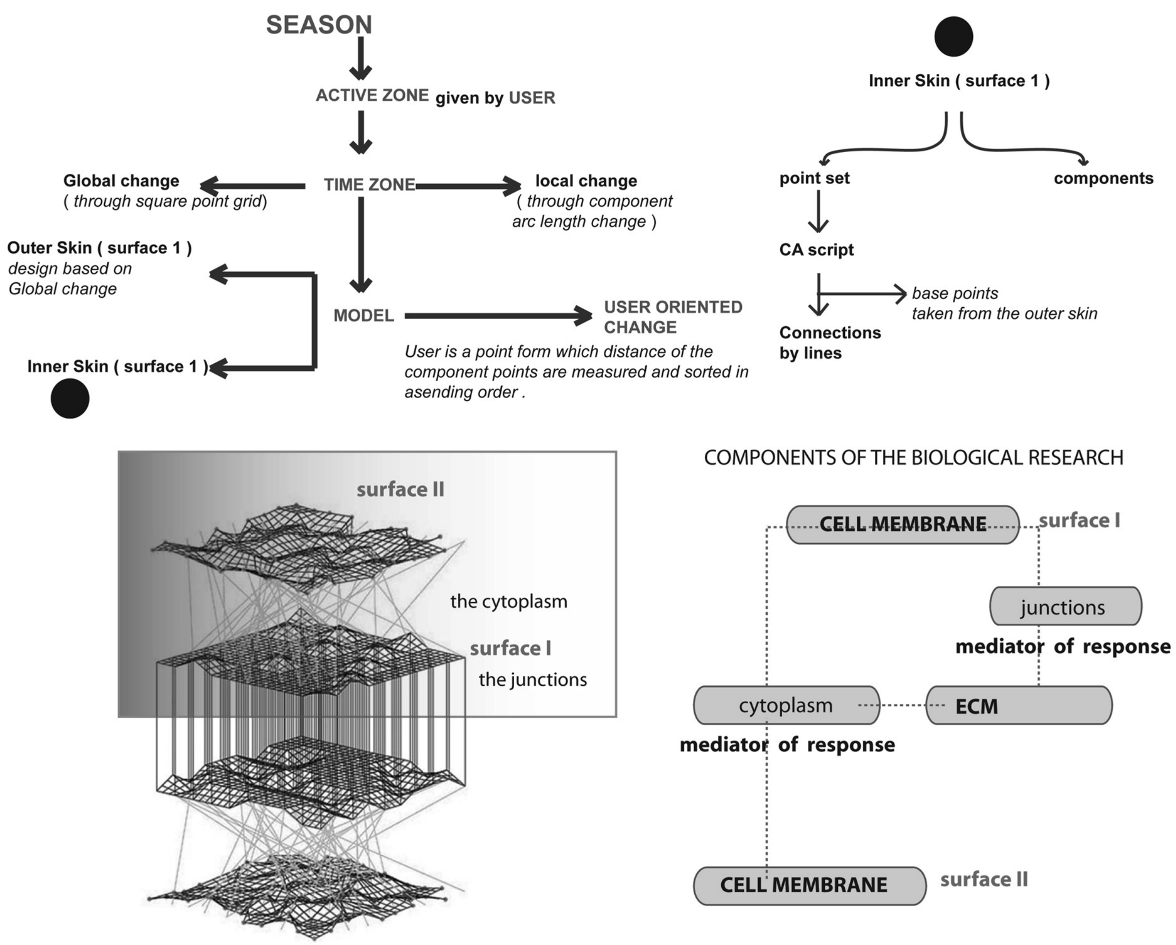
it's random. This can give us more architectural application by replacing the cells parameter in the cellular automata and junction parameters by certain criteria of design.

Model 9: In the last model, we could not build up the change in the other surface, i.e. surface 3 and 4 through the change in parameter. This time we put extra parameter that reconfigures the connections on the cytoskeleton and affects the surface 3, 4 to have distal changes. As we were studying the relay of communication at various levels that is form ECM to basement membrane, junctions to cell membrane and cytoskeleton and the dynamic reciprocity of these communication and focusing on a single cell to cell interaction with the effect that it produces over the surface with the parametric changes, the most important part remains in how the loop of dynamic reciprocity is acting. In actual cell environment, there are numerous cells and the change in one parameter causes a local to a global change at different degrees depending on the location if the cell surface w.r.t to the point where the change is triggered. For the parametric study, we took three cell-to-cell junctions and studied the relay of communication if the parameters are changed.

1.4. Preliminary Computational Framework

The concept of responsive architectural surface and 3dimensional space has been duly adapted from the biological research of ECM cell-to-cell connections, as it has been cited in the previous section. The complex computational model has been framed in Bentley's Generative Components parametric software. A surface embedded with smart components on 4-point grid base, is modeled on the four sides of the space/ room to be tested against both external and internal environmental parameters. External factors considered are wind, day lighting and humidity conditions of the room , while the internal factors specifically focused on occupancy, time phase and user location. Two back-to-back surfaces are modeled (on each of the four sides of the room) with a cavity in between to negotiate both external and internal environmental changes respectively. Refer Fig. 6.

▼ Figure 2 The flowchart on top shows the pseudo code of the framework. The flowchart on the bottom explains the basic algorithm derived from the bioresearch of epithelial cell systems.



The research strongly focuses on the responsive qualities of the building skin to understand, how it adjusts itself with the immediate environment like sun angle, air-quality, wind direction & occupancy. The research intent is to develop the external and internal framework of the façade module of a few story building. The walls or surfaces are formed of smart components whose mutual interaction is designed in a fashion, which imparts response to the internal and external environment. It comprises of some kinetic components similar in nature to Topotransegrity structures. The term "Topotransegrity" is used to describe a kinetic structure, which constantly evaluates its surroundings and reconfigures according to these changing conditions. It is a generic responsive structural system, which adapts to isolated spatial requirements. The structure is capable of various transformations, which range from small-scale surface articulations to large surface deformations, which can generate temporary enclosures (Neumayr, 2006). We considered sets of points on two fixed surfaces and tried to build connections in the form of a line. We located a graph variable in the system which would affect the changes in the number of connections from more to less. The algorithm has been coded keeping in mind two weather conditions /seasons - summer and winter. Considering the interrelated effect of the smart components on the façade and the unified effect of each of the four facades (2 leaves on each side, total 8 surfaces) on each other, the first step towards the

framework of basic algorithm was to enable the active zone. Active Zone is where the specific user or user group is located. With reference to this active zone, all the other smart components out of this region shall remain unchanged to environmental condition to save energy and complexity in maintenance while in operation. This centers the environmental problem to the effective region of the user's location & comfort zone. The preliminary computational framework is formed based on the **SEASON** (summer /winter) , the **ACTIVE ZONE** (user location) , the **TIME ZONE** (the sun position), and the MODEL (responsive designed surface) .

1.5. Project Site & Scope

The project is conceptualized as a designed product, which would act as an envelope for an architectural space or a room or habitable space in any site across the globe. The original intent is to understand and explore the negotiation of the building skin & the environment with due calibrations in its responsive parameters to optimize the energy expense and indoor comfort conditions. Therefore, the decision that we have taken in the subsequent sections is considering its architectural application as a building envelope or façade anywhere around the world. For this research project, we assumed the site is located in a hot and humid tropical climate and thus the necessary calibrations on the surface parameters are done accordingly.

2. DESIGN METHOD

The design methods of the responsive surface explain the fundamental construction of the parametric model and how it works. This includes the details of the parametric framework for surface construction, the sun position locator, smart components of the façade . It also introduces the Algorithm or the working principal of the designed framework with the change in the weather condition parameters

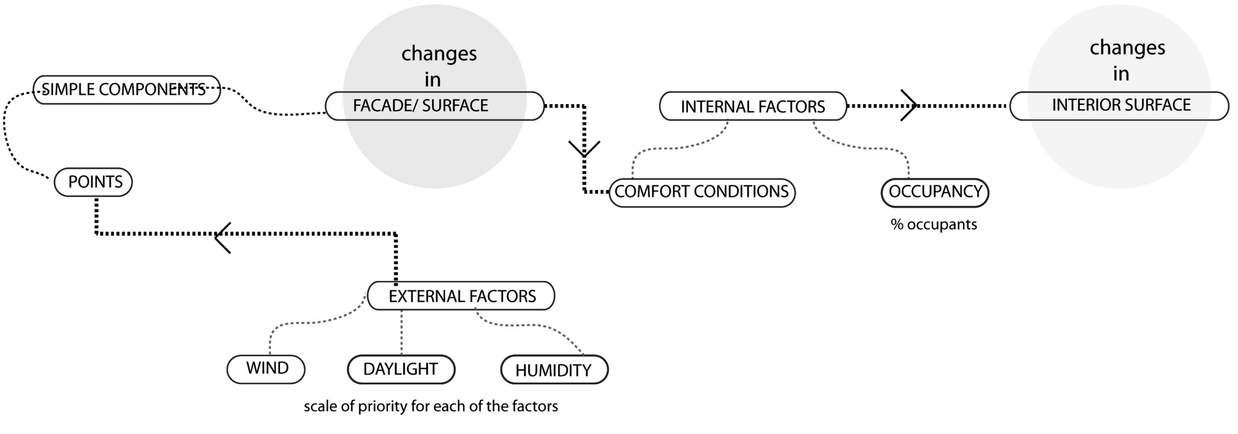
1.6. Surface Construction

A rectangular grid base, (before embedding the smart components, which reacts to the environment), formulates the basic construction of the surface. Two kinds of surface typologies have been tested, one is triangulated and the other quad or square shaped. Due to dynamic surface changes, deformation possibilities and easy feasibility of fabrication, square shaped surface components are selected.

1.7. Components of Sun-Point

The entire 3D model setup of the enclosed space of four surfaces is tested against an actual sun component coded in Bentleys GC framework. The sun essentially is the key external parameter that initiates and controls changes in the environment. Thus, the surface and eventually the 3dimentional space responds to the sun parameter. The arguments and variables created are, date, time (in hours), month and latitude [6]. The next crucial step in the system was to connect the sun system with the surface grid points over the centroid of the embedded smart components. This enhanced the possibility of creating change in each component with any measurable change in the sun position. Refer Fig. 5.

▼ Figure 3 explains the basic pseudo code formulated for the various internal & external factors interaction with the building skin in the computational system.



1.8. Smart Component Design

The component populated on the square shaped point grid on each facade is a simple square lamina further subdivided into four triangular sub panels, which could rotate on the edge of the square lamina. Each of the sub panel's tip or one of the vertices when closed meets at the centroid of the original base square surface. This form of design essentially eased the possibility of closed and open conditions of the panel, which worked as automated window panels. The opening and closing of the sub panels of the smart component was regulated by actuators, which triggered necessary response to the sub panels after observing substantial external or internal environmental change. Refer Fig. 4.

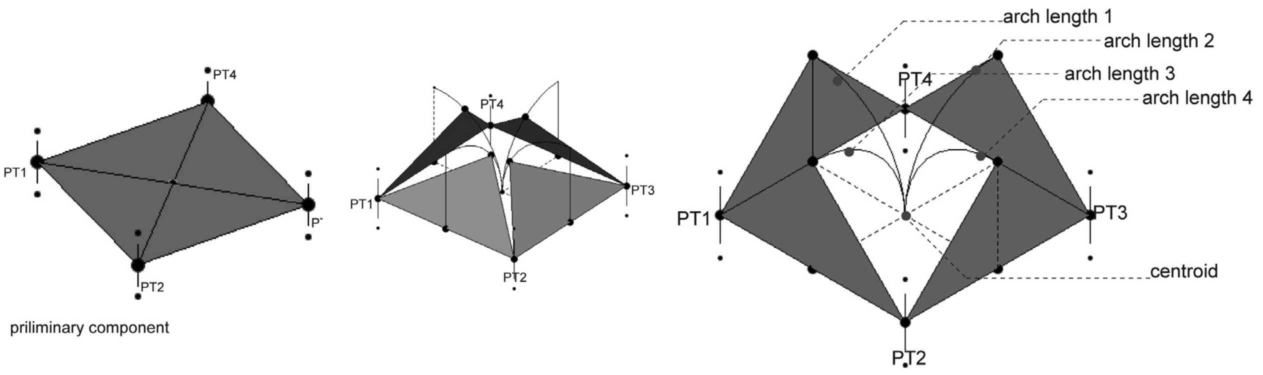
1.9. Advanced Algorithm

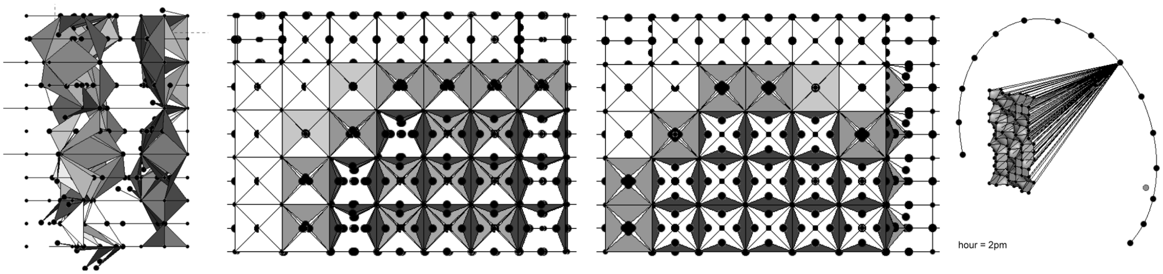
The angle between the centroid of the smart components to the sun was calculated, which necessarily is an important parameter to calculate solar insolation, radiation and day lighting.

Local & Global Change

Necessary changes were implemented on the opening amount of each of the sub panels of the smart components, based on the angular values obtained for the smart components inside the active comfort zone of the user's location, the active season and exact time. They could achieve five discrete states from 0 to 5. Here 0 signifies fully closed state and 5 being completely opened state.

▼ Figure 4 depicts the smart component, populated over the surface at different opening levels.





▲ Figure 5 shows the sun movement and the facade change accordingly at different times.

This change is termed as local change as it affected the smart components. Another level of change demonstrated the change in the point grid over the surface, by making larger deformation on the topography of the surface. This change transformed the surface from a 2 dimensional lamina into deformed undulated surface condition, which would be termed as global change. Both of the global and local changes are supervised by algorithmic control to instantiate a better surface geometry, which is optimized to sun position in a specific time at a specific season of the year. (Refer Fig. 7). The inner surface is connected with the outer surface, with the help of thin stainless steel structural tubular connections (lines), which conveyed changes on the topography of outer skin into the inner skin, respectively based on season. This change is calibrated by a Cellular Automata rule (11; 10). The growth of these line segments or tubular connections was dependent upon the neighboring line segment's state at any specific instant. Cellular Automata rule was chosen for its complexity and dynamic rule conditions to add variety in our system. The complex computation allowed surface response on both of the leaves of the façade due to relevant change in the external sun. (Refer Fig. 5.).

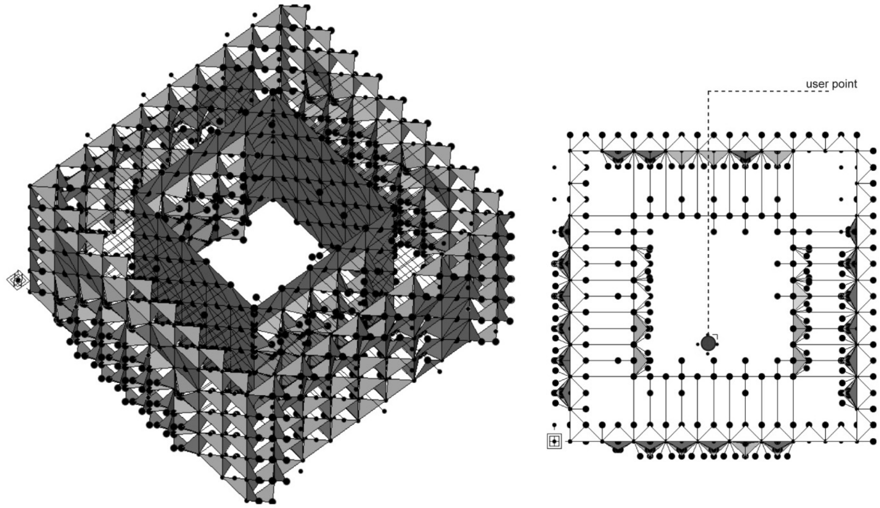
1.10. Summer & Winter Changes

Summer:	Outer skin- Partially closed for sun and harsh climate protection
Inner Skin:	Open to add in ventilation and active hot air movement to the outside.
Winter:	Outer skin- Mostly opens for visually connected day lit spaces.
Inner skin:	Closed to add day lighting, but to prohibit the entry of winter cold air.

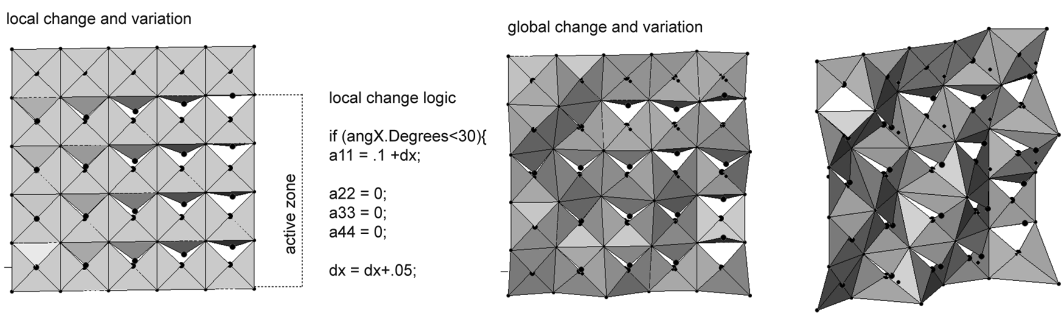
1.11. Wind Parameter Control

Basic philosophy followed while controlling the wind movement through the façade into the internal space is that wind flows from a positive to negative pressure gradient. Adding to that if the width of the inlet is narrower than the outlet then the wind velocity increases. Thus in the GC model, wind has been exemplified as a curve with the starting point outside the room and

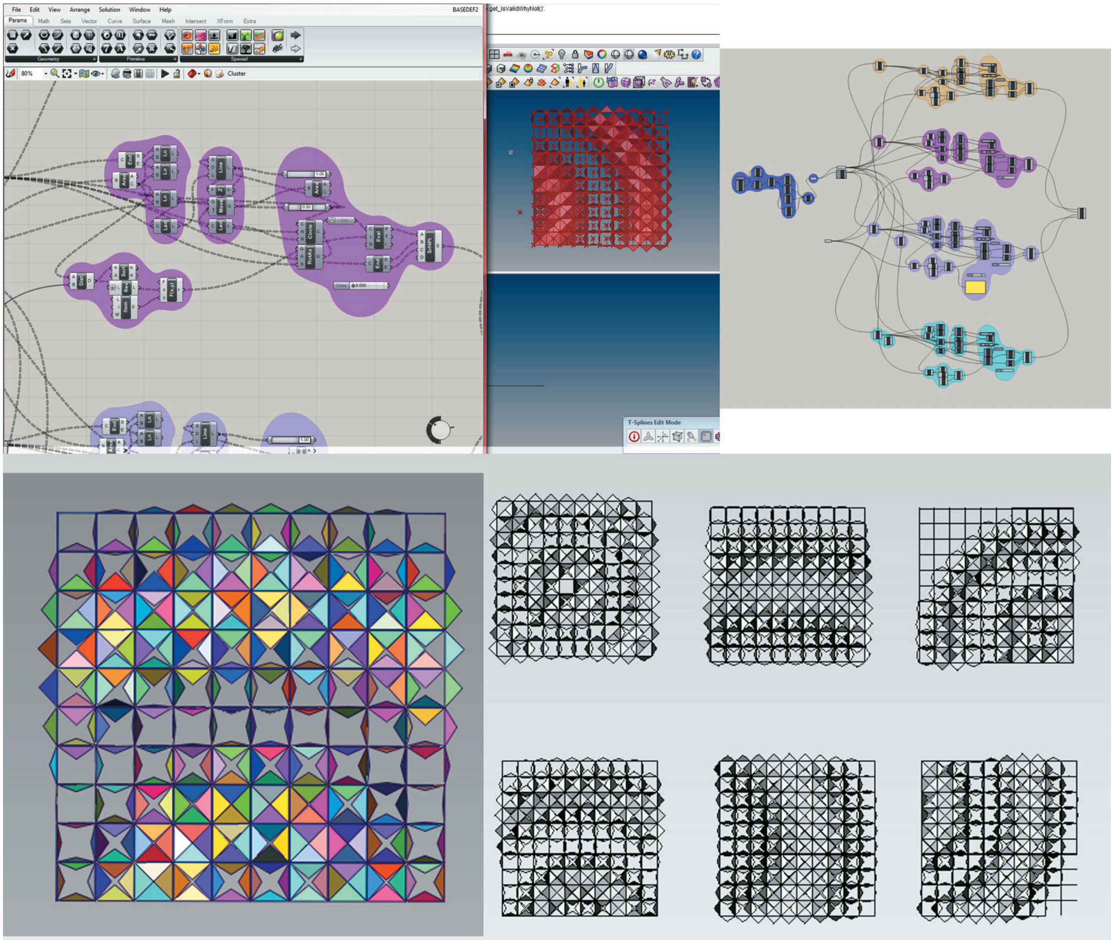
► Figure 6 depicts the construction of double-layered surface interconnected by cellular automata rules. The red point is the possible location of the user inside the space.



► Figure 7 shows the existence of local and global change in the system respectively in summer and winter season.



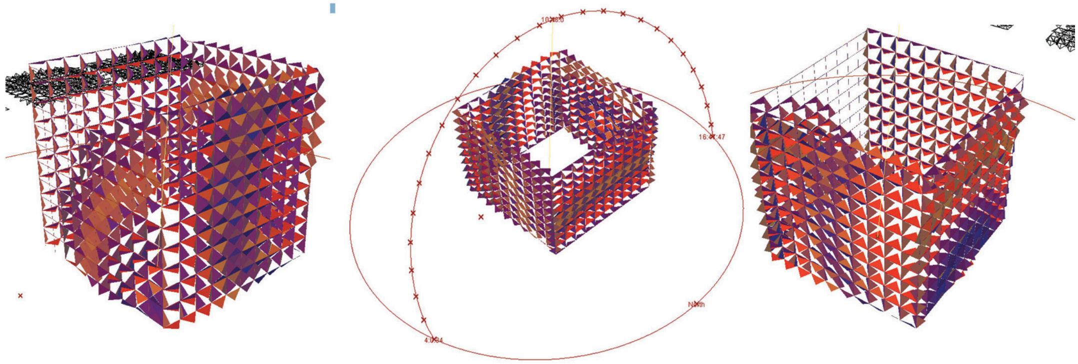
the end point inside the room. The algorithm has been coded to facilitate lower cross sectional opening on the outer leaf of the façade towards the wind inlet zone and much wider cross sectional opening on the inner leaf of the same façade. This technique enhanced the wind inflow velocity during summer days thus alleviating comfort conditions inside the room. While the wind escapes from the room, the same strategy has been followed with narrower opening on the inner leaf while wider opening on the outer leaf. (Refer Fig. 6.)



1.12. User Comfort & Target Performance

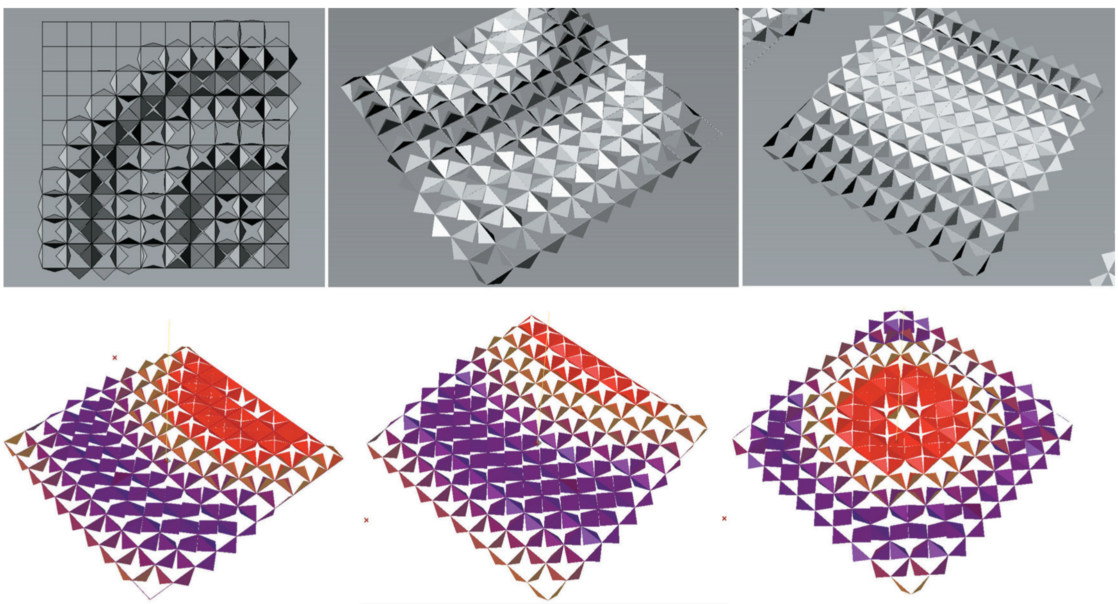
▲ Figure 8 shows the system developed in Grasshopper and the simulated façade options generated.

The user comfort in this research is limited to the parameters of day lighting, thermal comfort & natural ventilation criteria. The sun parameter acts as the initiator of the changes on the surface/ façade that affects the global as well as the local change in the components of the designed system. The façade is differentiated into various sections depending on their location with respect to the user. The resultant form of the façade is dependent on the sun position as well as the user location at a certain time. This exemplifies the complex feedback loop between the user and the external environmental parameter where the façade plays an active role. The notion of such complexity is to reach the optimum user comfort level where system change is actively governed by external environmental parameters & user location. The system identifies active and passive zone on the façade system depending on user location. An active zone is marked by its proximity to the user. This selective mechanism entails energy saving while catering for user comfort.



▲ Figure 9 shows the energy simulation performed on the four responsive facades of the room.

▼ Figure 10 shows the energy simulation results on each façade of the room. Blue zone indicate low solar insolation values while the red zones demarcate higher insolation regions.



2. DESIGN PERFORMANCE & SIMULATION

The proposed responsive façade so designed was further tested with state of the art energy simulation analysis tools to understand the pros and cons of the system so instantiated in terms of user comfort and energy consumption. To aid the process, we developed an analogous computational design model in Grasshopper add-on of Rhino. This model behaved in exactly the same way as the Bentley's GC model behaved. The benefit that we obtained was that the system was much lighter for the system memory to handle and thus complex nonlinear manipulations could be simulated to record unprecedented system behavior. Moreover, the new model imparted the possibility to connect the computational framework with ecotect's solar insolation analysis with the help of Gecko Plugin for Grasshopper. The simulation results for various panel openings at various times of the day and in various months of the year were recorded to analyze the net performance of the automated façade. Some of the observations from the simulation studies are enumerated as below:

The West façade illustrates significantly high solar insolation levels in the afternoon. Thereby during summer season, the façade was manipulated to have slightly opened pores on the outer skin and completely open pores on the inner skin for enhanced ventilation system. This change in the configuration revealed much conducive solar insolation level, substantially increasing blue regions over red regions on the façade.

The simulation studies of the various design options comparing with the amount of façade transformations over a day revealed the most optimized design option generated based on incident solar insolation values.

Enhanced user comfort was imparted by calculating the amount of blue regions over the day hours during summer season. Our design goal was to maximize the blue region at the least possible façade components transformations.

During extreme winter conditions the situation was reversed, higher solar insolation results were welcomed, and thus red regions over the façade were intended to be maximized.

Hence, various design options of the façade and the solar simulation studies of the same revealed hidden design data and associated possibilities, which were inherently augmented by the computational manipulation of the responsive façade system.

3. SCOPE OF RESEARCH

The proposed system and algorithm could be understood as a placeholder of an actual responsive surface or façade system. The research model could be optimized and used as per required design conditions with enhanced site specification and precision. Moreover, the research investigates a method of application of systems biology (a relatively new and major emerging field that focus on the systematic study of complex interactions in biological systems, thereby using a new perspective to study them) to correlate the loosely coupled modularity in the architectural design that could otherwise be the cardinal feature of complexities . In this case, the systems biology of mammary epithelial cells and its behavior in different ECM condition was studied. The relational complexity in the cell behavior with the various changes in the ECM manifests strong resemblance with architectural design components and their association with the contiguous environmental condition. The non-linear systems and relationships are mapped with the help of algorithmic tools to generate architectural manifestation and sophisticated feedback system, sustainability measures and performance related criteria's in a building system. The scope of the research lies in the exploration of the translation process from biological system into a refined architectural apparatus.

5. CASE STUDY AND ACTUATOR BASED SYSTEM

The generic idea of the responsive facade and actuator based autonomous system is perceived to contain a Perception Layer, a Decision Layer, and an Action Layer [1]. This basic framework of actuators would be synchronized to act in a feedback loop of both environmental control and individual user control. However, the actual set up of the framework of this actuator-based system is beyond the scope of this research. In the process of substantiating the responsive façade system and investigating the existing technologies, the relevant findings and studies are enumerated.

1) The primitive actuator based systems have been put to applications in the façade of L'Institut du Monde Arabe, Paris by architect Jean Novel (1987) carrying several actuator based motorized apertures to control the light entering the building according to the weather conditions and season of the year. They are fully automated, not allowing the user interaction in the building to have a high granularity of control over their own space [3].

2) "Aegis Hyposurface", exemplifying an actuator-based system manifesting dynamic reciprocity between surface components and external electronic stimuli from the environment. The facetted metallic surface driven by pneumatic pistons has the potential to deform physically as a response to external stimuli such as sound, movement or light. The dynamic terrains were generated by real-time calculations.

3) The Flare modular system acts as living skin supplemented by individually controlled pneumatic cylinders. Each unit in the flare system reflects direct or ambient sunlight and the whole system acts as a unified body of pixel formed by natural light.

4) The façade system of Q1 headquarters in Essen, Germany where the sunshades are fixed on a central vertical frame that open and close depending on the sun's rays .The motorized, kinetic metal feathers (shades) open and close based on user input sensor data. There are several case studies that exemplify the existence, as well as significant evolution in the responsive surface/facade design, fabrication techniques and working principal, rendering the architectural design possibility of the proposed design model. Unlike the actuator based interactive surface this research is focused on generation of an integrated system of building façade relying on reciprocation between environmental stimuli as well as

individual user control in mutually exclusive form. The refinement of technology in actuator-based systems can mitigate any existing discrepancy.

5. CONCLUSIONS

With this ambitious computational research work, it has been tested and studied that responsive architectural primitives can be framed with an ecological perspective, wherein the architectural abode would not only provide spatial dimensions for habitation, but also shall respond and change in topology with the constantly changing environmental parameters. Parametric design formulates this essential design condition, which enhances responsive design possibilities in simple living conditions. Although realization of the complex façade model would comprise installation of complex electro-mechanical systems, difficult maintenance, high construction cost and highly skilled labors yet the performance based advantages in the proposed design model could be manifold such as integration of optimized day lighting; user controlled façade system, improved solar insolation, efficient ventilation and unique architectural design style of the envelope.

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