RESPONSIVE TEXTILES

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SUMMARY

The goal of this research is to investigate kinematic textile membrane strips configurations that serve as responsive second building skins. The movement of these adaptable material systems will be defined by a dynamic response to the environment, balanced with the direct response to the user's influence on the façade.
With use of the integration of sensors and actuators, as well as computation and material responsive enhancers, the end result of the research is aimed to be a self-actuating system that interacts with its surroundings and that is characterized by its behavioral adaptability.

Therefore the user does not control the technology, but represents a change in the containing environment, and form is therefore not afflicted upon the material from the outside, but it represents, together with its behavior over time, an emerging phenomenon arising through the programming of a reactive environment.

The focus falls on tensile architecture in motion, exploring basic responsive capabilities to address local environmental conditions. The goal will be the abilities of the system, and not its image, which represents a shift in perspective: formal becomes behavioral and motion takes over image, as self-actuation means property change and its entails the ability of the material to convert energy to motion. This foreseeable scope will translate into a system that includes the inherent instability given by the multitude of parameters able to transform the morphology of the form, remaining open and indeterminate. The system will perform a continual adaptation and self-organization with a dynamic and changing context.

1. INTRODUCTION

1.1. Research goal

While documenting the possibility of adaptive reactive geometries, the formulation of the assignment and the research expectations is possible:

As part of the research of adaptive multifunctional textile facade systems, how can textile envelopes be configured as responsive user-interaction oriented arrangements? How should the façade respond to user control, what should be the balance between emergent behavior and direct response to user desires? What are the parameters of the façade behavior?

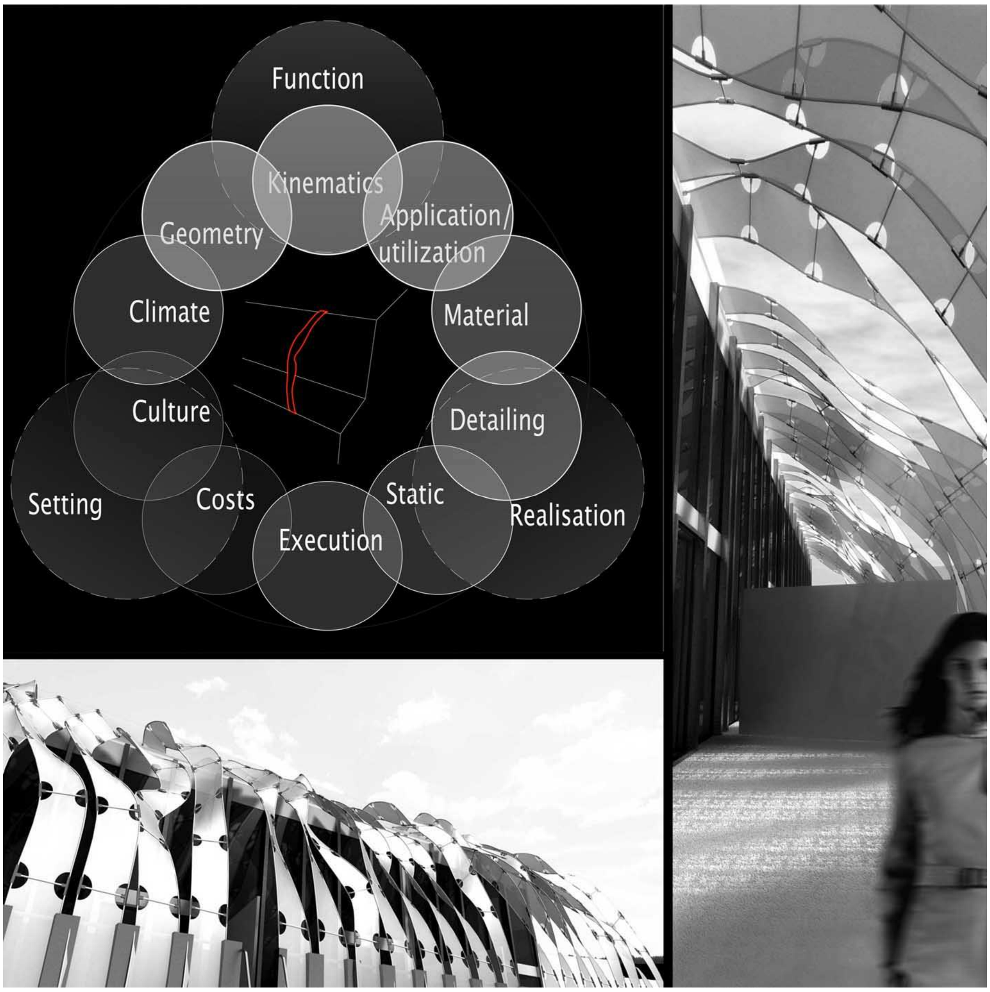

Figure 1: System visualizations

Second skin envelopes are used more and more in recent projects, and commonly serve singular purposes, such as shading. In more recent approaches, facades are also thought of as responsive systems, that adapt to user requirements and that are directly controlled, through sensors and actuators, by the users in order to achieve specific states that respond to diverse needs. (Privacy, shading, rain protection, wind protection) In most cases, these needs are determined after the designers analyze the building context, the natural environment and the user expectations. This set of requirements is fixed and known throughout the design process and is considered not to change during the life span of the building. The only changing parameters are the natural environmental ones, however this change is expected and the results in the change of the facade are foreseeable.

Therefore the question has to be formulated: could a facade system be designed, that responds to a set of predefined requirements but also has the ability to take in new input and adapt to a changing context? Could such a facade respect the typical boundary conditions (busy urban areas and their traffic and accessibility consequences, big city user density, small built areas, versatility of space usage requirements) and respond to the usual needs of a building (fire resistance, wind resistance, shading necessity, visibility rules, etc.) ?

As represented in Fig. 2, the investigation can start by primarily dividing the inquiry into the following topics: user movement and interaction, façade element configuration, behavior of the façade in different weather conditions and effects on the building.

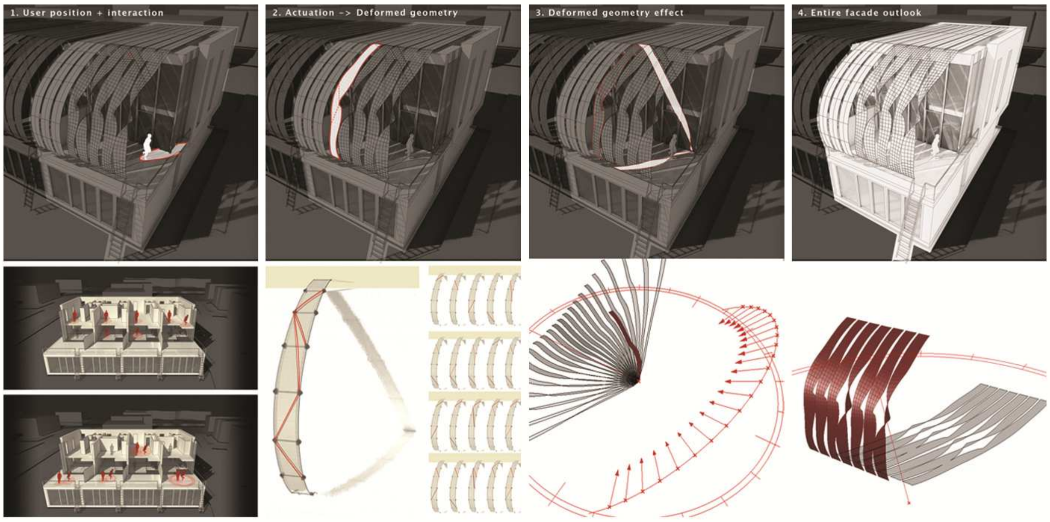

Figure 2: Fields of study

1.2. Search space delimitation: boundary conditions and building typologies

What are the usual building typologies that come into question for such projects? Here a few diagrams that represent some common profiles of buildings in large cities that might benefit from a multifunctional adaptive facade system:

1. Retracted upper stories (for the creation of a terrace)
2. Basic cross section
3. (Double) curved geometry
4. Interior Courtyard type
5. Retracted lower stories (for the creation of a visible access area)

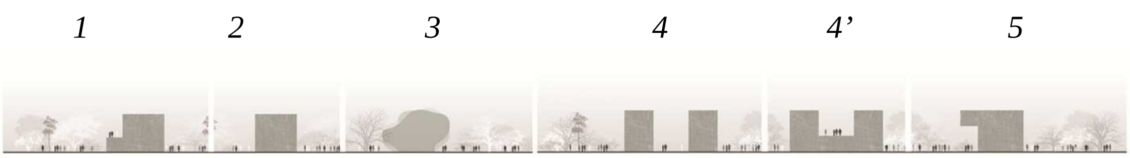

Figure 3: Feasible building typologies

1.3. Realistic approach:

The project strives to apply and integrate a textile façade system to a residential building, with the goal of creating shading that allows user interaction and control, while at the same time obeying rules implied by visibility needs, fire resistance, wind resistance etc.

Figure 4: Building frame

2. ABSTRACTION

The issue of an adaptable multifunctional textile envelope that should serve as more than a shading system is raised.

With the purpose of search space delimitation, this work will only investigate textile façade systems with a strip-like configuration. The length of the elements must suffice to apply to two stories and the connection to the roof and console must not represent an impediment to the elastic system kinetics, these self-imposed boundary conditions are to be seen as conventionally set limitations.

3. INVESTIGATION PROCESS

Seen analytically, such façade strips might have the configuration seen in Fig. 5 that was used as a guideline for the model building phase. The sample configuration has vertical, horizontal and diagonal elements with semi-rigid joints. For some of the actuation options, some of these elements were not built, a total of 10 different configuration variations being used for the first model phase, as shown in Fig. 7. and exemplified in Fig. 6. The connections to the roof or handrail were not yet defined, as the goal of this phase was to generally determine the actuation mode with the greatest kinematic amplification.

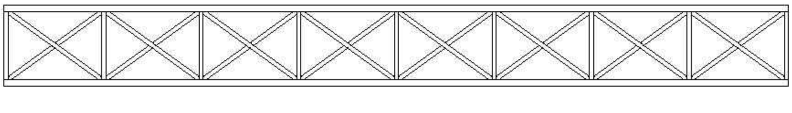

Figure 5: Configuration guideline

3.1. Actuation possibilities:

As initiation of the investigation process, an option list is developed, that categorizes the movement types possible: As a main diagram, a separation is made between reactions, or effects of the movement, and actuation, or cause of movement, this being the basic structure by which system options could be differentiated.

Actuation can be external or internal: external actuation could be separated into translation and rotation and internal actuation can be divided in contract, expand and bend.

3.1.1External actuation:

As a convention, external translation actuation is defined as movement of either a single point, a linear element or possible combinations of these moving elements (such as a point and a linear element, two points, two linear elements and so on). The movement takes place in the initial plane of the element, prior to the movement.

- Movement of one point
- Movement of the horizontal frame element
- Movement of the side bar
- Movement of two linear elements.
- Combination of a point and linear element movement

External rotation actuation refers to the circular movement of one linear element or several, outside of the initial element plane.

- Rotation of the side bar
- Rotation of the horizontal frame element

External actuation is applied on the outer frame of the textile strip.

3.1.2 Internal actuation:

Internal actuation is structured into contract, expand and bend.

Contract: The first type of internal actuation can be applied to either a diagonal line in the configuration, a vertical or a horizontal one. The components do not have to start or end on the external frame of the textile strip, and do not have to actually consist of material elements; the movement refers to a line included in the configuration. The actuation translates into diminishing the length of the specific line, by bringing the two limit points closer together.

- Horizontal line
- Vertical line
- Diagonal line

Expand: This second type of internal actuation is the inversion of the contraction movement and can be applied to the same components: vertical, horizontal or diagonal. The limit points are taken farther apart.

Bend: The third internal actuation option is “bend”, which refers to curving a material element in the configuration, be it vertical, horizontal, or diagonal.

- Horizontal element
- Vertical element
- Diagonal element

The investigation process will start with the analysis of examples of each actuation possibility (model building, pictures, 3d models) and the classification of the effects in the geometry.

3.2. Reaction options

Reactions can be either global or local, as follows: global translation, global rotation or local contraction, local expansion, local bending.

After the development of the main analysis procedure, the examples will be compared with the secondary standards and further structured. An important aspect of this step is checking the options against the above described boundary conditions and establishing their fitness in reference to these standards. The goal of this continued classification is the expansion of the geometry option list.

3.3. Association options: physical models, examples, 3d models

3.3.1. Physical models:

The investigated geometries differ from the point of view of the actuation type (and therefore also from the point of view of actuation effects on the outlook), but for the sake of the extensive coverage of the search space, the differentiation will go on to a more detailed level. For each actuation mode possible, a series of 10 possible structural configurations and for each of those 2 possible membrane layouts are built and analyzed (the type of membrane used also differs from the point of view of its elongation tolerance, some being built of plain weave glass fiber mesh, other of elastic textile material). Each of the 16 built models is then actuated. The models are built in scale 1:10, having a total length of approximately 60cm. The actuation is schematically simulated by either introducing elastic elements that pull joints together, or rigid ones that push farther apart (Fig. 6 and Fig. 7)

The geometries are however only investigated for local actuation modes, as the research is intended as an alternative to a global actuation concept. This work also intends to show the diversity allowed by a system not through the diversity of the actuator types or their complexity but through its intrinsic behavior (determined by the interaction between membrane, outline structure, bending-active elements, the proportions of the stripes and the frame of the built environment on which the stripes are attached).

The local actuation modes investigated are contract, bend and expand. The effects contraction and bending have on the geometry outlook are comparable; therefore the more easily buildable option is preferred, which would then be contraction. (A tension and release system is more energy efficient than a flection or expansion one). The expand motion, although possible conceptually is limitedly viable for the fore defined configurations, as it would require an extremely flexible membrane and large actuators. This possibility has however been tested on the configurations with pre-stressed membrane and the conclusions are, predictably, that the amount of force needed to deform the geometry in such a way makes this actuation mode undesirable from the point of view of actuator complexity.

The investigation will therefore be focused on local actuation, and specifically on the contraction option. The 16 built configurations are subjected to contraction of horizontal elements, vertical ones and diagonal components. The first step is to investigate the effect of single element deformations (each of the 3 afore mentioned possibilities), in different relative positions within the stripe. Combinations of 2 elements follow, either both elements actuated simultaneously or gradually. The last step is combinations of 3 elements, with simultaneously applied deformations or layered phased ones. The results are to be seen in the diagrams and pictures of the models.

The goal is finding the options with the highest degree of kinematical amplification but with the lowest degree of actuator complexity and diversity. Therefore the diagonal contractions, applied in layered phases to configurations with pre-stressed membrane are to be investigated further, first digitally and then with the help of mock-ups. Fig. 7 exemplifies some of the plain weave glass fiber mesh models, locally actuated and linearly and rigidly connected to the roof edge, in front view. The lower connection allows freedom on the OY and OZ axis and permits the rotation of the strip.

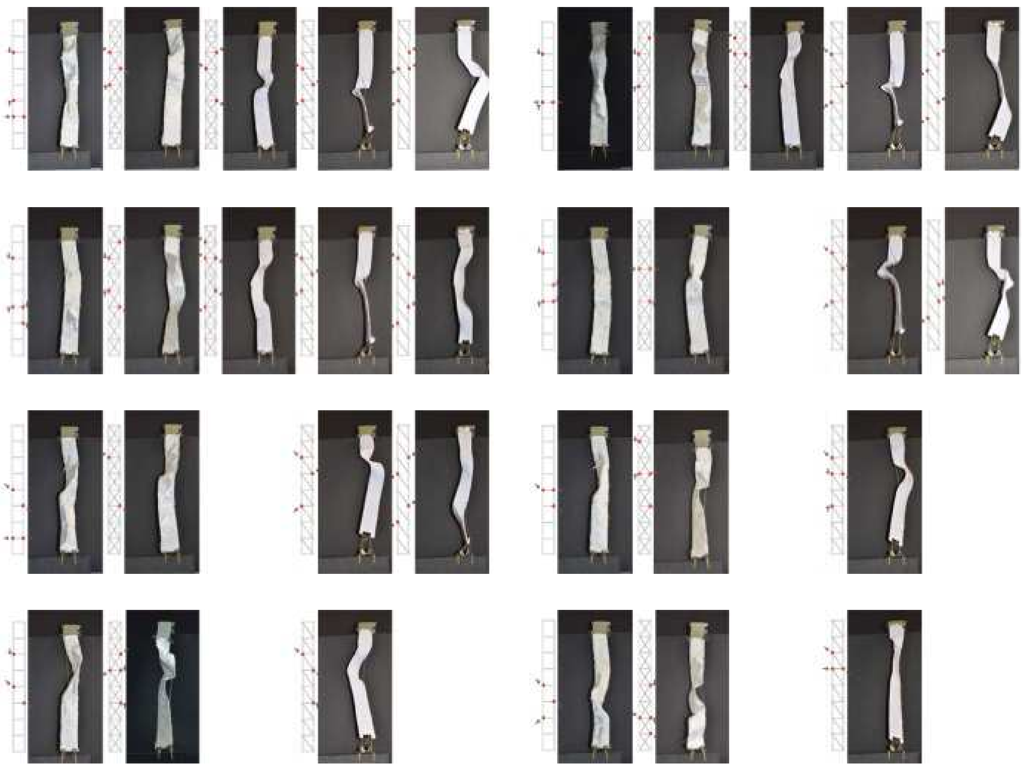

Figure 6: Examples of actuation types, physical models 1:10

3.3.2. Digital models: Digital representation of deformed geometries

Results acquired with the help of the physical models (scale 1:10) are used to guide the modeling of the digital simulations and to identity the parameters that influence the relaxation. The stiffness of the structural elements is one of the main factors responsible for the degree of shape adaption. The membrane pre-stress factors as well as the way it is fixed to the structure are equally important parameters.

The following computational tools were used to simulate and parametrically control the behavior of the system:

Grasshopper: In order to simulate the GFK elements, their stiffness and their bending behavior, a convention is made to represent them as trusses. The grasshopper configuration is fed with two curves, that is then transforms to polylines. The number of control points (also division points) is set with the help of two number sliders: one that represents the number of transversal elements between the 2 curves and the other that represents the number of division points between the transversal elements (the higher the number, the closer the polyline follows the initial curve curvature). The trusses are then built, with as many frames as total number of division points (transversal number * number of division in between).

Kangaroo: The Kangaroo components set transforms the lines (members of the truss) into springs, appoints them stiffness and damping values and uses the anchor points to fixate the general geometry. Forces are either defined as vectors, such as gravity or as attraction stress between two points on the different longitudinal elements. Bending of the linear elements can additionally be simulated by a vector based method that computes the shear forces at a node into bending moments. Diagonal elements are created and enumerated, as to have the possibility to create the movement by determining the numbers of the diagonals to be actuated.

In order to check the validity of the resulting deformed geometries, they are also built by bending the elements that represent the GRFP longitudinal beams. Another way used to confirm the validity of the geometries is building models in 1:10 scale and mock-ups 1:5. Fig. 7 first exemplifies the configuration and applied actuation, then the digital results and then the 1:5 Mock-up results. The strips are connected linearly both to the handrail and to the roof edge. The upper connection is to a rail that can be driven forward or backward, as seen in Fig. 8. The bending-active GFRP elements that constitute the frames of the strips, as well as the transversal elements, both insure that the membrane is only slightly wrinkled but not folded and also that the strips spring into the initial shape after the actuation forces are released.

Fig. 8 also demonstrates the two extreme states of the system, i.e. the neutral (right side of the picture) and the storm state (left side of the picture)

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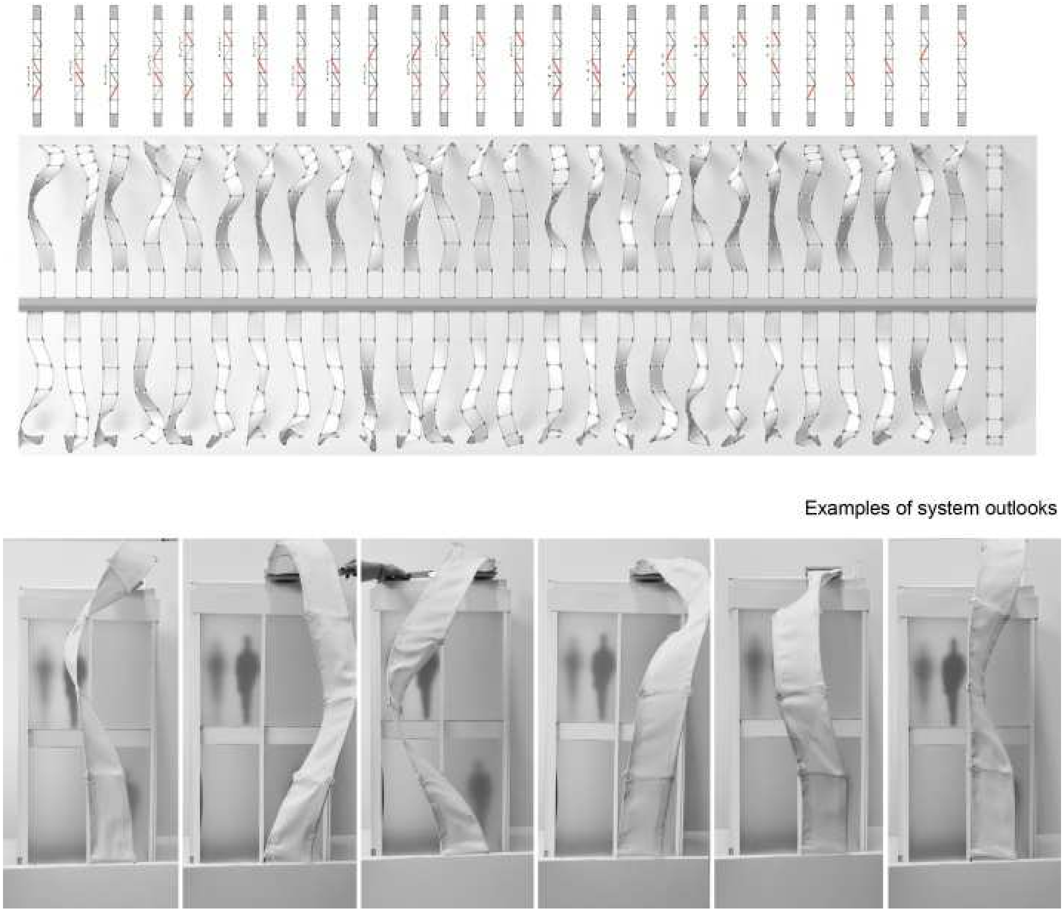

Figure 7: Comparison: digital and physical models 1:5

Figure 8: Mock-up side views

3.4 Computational investigation:

After determining the parameters and limitations that define the geometry (given either by the actual physical constrains of the system, or by the material specific properties) and determining a set of general rules of response to a basic set of natural environmental changes (sunlight, wind, rain) and the consequences of these rules on the system, the computational process begins. This long list of parameters and general geometric rules allows for a multitude of associations, which translates in a diverse set of system configurations. A library made up of all possible deformed geometries is created.

Instead of deciding on an image, and then controlling the appropriate parameters in order to achieve that image, the system is only given general impulses in specific locations. These impulses are given through data sent to the actuators by either one "brain" or by several centers of computation.

The entire algorithm was programmed in Rhinoscript, with additional Grasshopper and C# definitions. The information exchange between the main algorithm and Ecotect (used to evaluate weather conditions effects on the geometry) was also automatic.

The weather information is a critical part of the façade development process. All the geometries in the created library are evaluated for the current weather conditions. These are fed into the algorithm as criteria after being extracted, with the help of Grasshopper[1], Geco[2] and Ecotect[3] from a weather file. Weather information, such as wind speed, wind direction, solar irradiation, humidity levels and temperature are compared to predetermined values that represent average, highs and lows for the place of construction of the façade and the specific time of year. According to their values and position in a predetermined order of importance, each weather criterion is assigned an importance factor or a weight. Each geometry is then evaluated for each weather criterion (for some criteria the evaluation function is an overly simplified version, to be used as a place holder), and the separate grades are factored by the respective criterion's weight in order to get the final grade for each geometry, for the current weather conditions.

With reference to the wind analysis, a conventionally simplified version is simulated. Geometries are basically evaluated by the area of the surface normal to the wind vector, the bigger this area, the higher the resistance to wind force, factoring in the main wind vector direction and the wind speed that determine the importance that the results of this simplified analysis will have. The higher the wind speed, the more essential the wind factor become (very high speeds mean storms) and so the higher the weight of the results of the evaluation, this being the principle used for the scaling of the weight of each factor (wind speed, wind direction, solar irradiation, humidity levels and temperature).

Analysis of the temperature and humidity factors shows if there is snow, in which case the geometries with the least horizontal surface (on which the snow would gather) are evaluated the highest. This simplified perspective is developed in order to allow the uninterrupted development of the method, an actual snow and wind load static evaluation to be written upon further study and with the help of specialist. In case there is rain, the options

[1] Grasshopper is an algorithm editor for Rhino 3D
[2] Geco is a set of components which connects Rhino/*Grasshopper* and Autodesk Ecotect
[3] Autodesk Ecotect Analysis is a program that performs simulation and building energy analysis

with the largest horizontal surfaces (that would offer shelter) are rated highest. The result is a hierarchic list of all geometries, starting with the fittest one and ending with the one that would behave worst in the current conditions. An initial façade is created, one composed of stripes that find themselves actuated in the form of the fittest geometry.

The user additionally has the ability to interact with the façade and select a desired effect: light/ shadow and size of the desired effect: local/ entire room/ multiple rooms. This selection is then represented as a surface projection. If the desired effect is light, then the geometry that leaves the least shadow on this surface projection is searched and if the effect is shadow, then the geometry that leaves the largest shadow on the surface is to be found. The connection with Ecotect is again created, in order to calculate the shadows of all possible deformed geometries in the current weather conditions and their intersections with the effect surface projection. The order in which the geometries are investigated is the one resulted from the evaluation to the weather conditions, therefore the end result is a façade made up of stripes deformed to states that best behave in the current weather conditions and of stripes that are as close as possible to that goal and at the same time respect the user's choice of façade effects. Material behavior will also be periodically analyzed and sent as input data to the computational brain. Static analysis results could also be performed through strategically placed sensors and be used as input information. The system therefore interacts with an algorithm that learns the users' preferences, material behavior and attrition and that continuously adapts and responds to changes and updates.

Figure 9: Façade results for the same conditions, different user position

3.5. Computational brain

The responsive façade interacts as shown above with the environment and the user simultaneously, process that allows the gathering of data about the resulted geometry outlooks. The weather situations are stored and averaged and the user preferences are also remembered and developed into a neuron that allows the façade system to foresee the desired effects in weather conditions met before. During a certain time interval, for example one month of façade functionality, the algorithm keeps gathering information and therefore completes itself, knowing what the user has been desiring for the mentioned time interval. The initial façade created hence includes not only the fittest option in reference to the current weather conditions, but also a suggestion that the algorithm makes after evaluating what the user had desired in similar situations. This learning phase of the algorithm is permanent; the data base that is used as statistical source keeps growing during the entire life span of the façade.

4. CONCLUSIONS

This study focuses on the vast number of possibilities that a seemingly basic façade geometry offers if its transformation is specific to the employed materials. The kinetic amplification is possible due to the successful collaboration of the membrane material and the fibre reinforced composite bending-active elements, connected with semi-rigid joints.

The present work is to be seen as a conceptual method investigation, in which more detailed functions are to be integrated. The method created represents a structured framework that insures the easy implementation of specialists (electrical engineers, construction engineers, etc.) written functions in the right positions. Therefore the parts of the algorithm used to evaluate snow and wind loads as well as material attrition are to be understood as place holders, overly simplified variations that allow the method to be understood as a whole. Further and more detailed investigations are to be made upon the static characteristics and limitations of the structure, the goal of the present work cornering elastic kinetics being the discovery of the intrinsic transformation capabilities of a constructive ensemble and investigate them analytically.

The algorithm and method created are innovative in terms of extending the adaptability and flexibility of the user-façade interaction. One does not overpower the other; the surrounding environment is never compromised for the sake of user control. All factors with which the façade comes in contact influence it to appropriate degrees and it permanently learns what the user encourages and what façade outlooks are fittest in different scenarios.

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