Sensitive skin design: a generative approach

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Abstract. This paper presents a framework of study of an iterative evolution of a modular component designed in an attempt to simulate material constraints and motional response with the perspective to be multiplied into a dynamic system. The main scope of this project was to investigate the process that maps a territory of possibilities, among which lies the potential architectural solution. In order to explore this field a parametric model has been developed. The simulation of the materials nature has been embedded in the algorithm on a geometry constraint basis in an attempt to simulate the behavior of the system comprised by elements in tension and torsion. A multiplication process of the module was introduced at a following stage of the research focusing on regular tessellations and circle packing on the plane. Responsive performance has been studied on a selected specimen of the evolution given a hypothetic context scenario according to which the scale of the design was set at a façade component level. The resulting responsive permeable skin was presented as a potential design solution among the successive approximations of this algorithm. Along the course of the research the parametric tools were used not only as a medium of synchronous output visualization but also as a mechanism to simulate material properties, structural constrains, environmental data, and worked as stimuli of inspiration driving the overall design process.

Keywords. Parametric design; generative design; simulation and visualization; responsive skin.

INTRODUCTION
The emergent significance of parametric control in design is indisputably present in an increasingly numerous architectural conceptions. Quoting Achim Menges (2006), “parametric modeling has been understood as instrumental for its ability in improving workflow, its rapid adaptability to changing input and its delivery of precise geometric data for digital fabrication and performance analysis”. A broad field of innovative practice in architecture is being carried out through parametric design as a result of a process-oriented approach. Several research studies on the application of such methods in architecture have already been carried out presenting morphogenetic design techniques through experimentation on form, materials and structure not as separate elements, but rather as complex interrelations in polymorphic systems resulting from the response to varied input and environmental influences (Menges, 2006).

In the generative process presented in this paper parametric modeling was also used in
order to articulate the development of prototypical forms which were later evaluated on the basis of their performance in a simulated environment (Frazer, 1995). Simulations are essential for designing complex material systems, and for analyzing their behavior over extended periods of time. A computer simulation of the motion of the structure and the display of the structure as an animation of moving parts can identify problems in its initial geometric and kinematic conception. It can also assess the effect of the changing geometry of the structure on space definition, building morphology, and functionality (Liapi, 2000). In the sciences, ‘model’ means more than the geometrical description of an object that we commonly use this term for. A model is an abstraction of a process, and can be refined as understanding of a process develops, so that complex problems can be accurately modeled (Stathopoulos and Weinstock, 2006).

According to Kepes (1956), a pattern in nature is a temporary boundary that both separates and connects the past and the future of the processes that trace it; “Patterns are the meeting-points of action. Noun and verb must be seen as one: process in patterns, pattern in process”. Seeing the parametric design process as an evolution of geometry in time a pattern is what both separates and connects the archetype and the multiplicity of its iterations. The concept of the pattern is kept as a reference at each stage of the design methodology in an attempt to entwine the consequential steps of the evolution of the form;

“Architectural form is conventionally conceived in a dimensional space of idealized stasis, defined by Cartesian fixed-point coordinates. An object defined as a vector whose trajectory is relative to other objects, forces, fields and flows, defines form within an active space of force and motion. This shift from a passive space of static coordinates to an active space of interactions implies a move from autonomous purity to contextual specificity.” (Lynn, 1999)

**PATTERN AS A PROCESS; DEFINING THE UNIT**

On a first level approach the parametric model used was oriented accordingly in order to examine the combinations and possibilities of the comprising elements of the cylinder with the model working like a conceptual sketch; (Schenk, 1991; Asanowicz, 2007). “As a design medium a sketch represents something to be interpreted and understood in different ways and to be made more concrete later as further decisions are taken.” (Park and Gero, 1999)

The experimentation begun by analyzing a cylinder into two sets of generative parts into the topology of two coaxial circles connected with straight lines along their circumference in equal intervals. The parametric representation of the cylinder provides an infinite number of distinct cylinders by setting the radius and the height as variables. The visual feedback of this change of variables may depict a series of results of a predefined static geometry. Also it could imply a key frame in a sequence of a dynamic relation between geometric elements (Lynn, 1999) of distinct material and structure in a “post-geometric” design approach according to Aish (2005), since the various material interpretations of the same geometry are integrated in the descriptive system of the geometry itself. In this way the possibilities for obtaining new forms from the same description include the constraints of the material comprising the form.

Therefore, a parametric model was designed in an attempt to reproduce material constraints and dynamics between components on a first level of qualitative research. The CAD software used in the exploration of this was Rhinoceros 4.0 and the parametric modeling was carried out in Grasshopper™ graphical algorithm editor.

Firstly, the definition for the model focused on representing rigid linear elements of fixed length and circular elements of variable circumference, that is to say in terms of material constraints rigid rods in compression connecting elastic circles in tension.

The second variable induced was torsion where different sizes of “aperture” were observed and the distance between the circles decreased accordingly.
A third parameter of axial inclination was added to the so far deriving topology of the hyperboloid by rotating the common axis of the circles and testing it in various positions. The same procedure was carried out in the alternative of one circular rail of constant circumference and one of variable connected by linear elements of fixed length.

The experimentation proceeded by testing the behavior of skew lines of variable length as a simulation of an elastic material in tension connected with circles of constant radii in torsion and inclination, followed by an additional test of circular rail of constant circumference and one of variable connected by linear elements of variable length. This part of the qualitative experimentation on this specific geometry concluded with a final testing of both primary components (circles and lines) of variable sizes in an attempt to simulate the behavior of the system comprised by elements in tension and torsion.

This part of the experimentation is describing a general background for the following research along with the principles defining the geometry for the unit. In this stage the process of parametric modeling worked as a medium of inspiration (Frazer, 1995) for further investigation on the potentials of this specific topology.

**PROCESS AS A PATTERN; ANALYZING THE UNIT**

On a second level the research turned to several natural systems in order to study function and mechanics brought about the principles deriving from

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**Figure 1**
Lower circular rail of constant radius and upper circle of variable radius connected by linear elements of fixed length-tension testing. Cone-truncated cone.

**Figure 2**
Lower circular rail of constant radius and upper circle of variable radius connected by linear elements of fixed length-torsion testing. Hyperboloid

**Figure 3**
Sequential states of module in torsion and orientation. Extendable circles- rigid constraints.
the geometric properties of this configuration. Architecture has frequently drawn inspiration from the inner logic of nature’s morphological processes (Frazer, 1995); this parallel step along the course of the experimentation was triggered by the visualization of oscillating parameters and this animation implying the evolution of a form and its shaping forces (Lynn, 1999) creating a motion effect of a pore dilating and closing. Therefore, the geometry was visually interpreted as a ‘void’ and the systems investigated extended from plants stomata to coral polyps in fluctuation during nutrition.

According to Frazer (1995), in regard to natural ecosystems and their applicability on architecture, an ecological approach to architecture does not necessarily imply replicating natural ecosystems, but the general principles of interaction with the environment. The emergent algorithm for the geometry was elaborated with analogies drawn from nature both in a conceptual and a metaphoric sense in a design hypothesis context (March, 1976) in order to evolve to the next stage.

Having established a conceptual model of the behavior of the module the research proceeded with experimentation on the multiplication of the module. Given the wide spectrum of potential configurations a framework of study was set according to the scope. By maintaining as a reference the

Figure 4  
“Architects learn to use natural forms from observing living structures: trees, bones, shells, petals and microscopic creatures” (Pearson, 2001)  
Stomata and coral polyps as units and in multiplication.

Figure 5  
Mapping of the process.
initial experimentations on the conceptual module a phylogenetic tree (Dawkins, 1986) was designed in order to specify the different qualities of each deriving generation and the potential evolution of each branch. The networking process included the outcome of the so far explored spatial, geometrical and structural constraints on the geometry and its iterations. The combinations concerning the material properties of the components in terms of rigidity and elasticity on a unit level were classified in order to evaluate their prospect in further development.

**PATTERN AS TEXTURE; POPULATION METHODS**

The preliminary research included investigation in texture in architecture and in nature; texture has not been approached as an outcome of additional ornamentation of Classical architecture as Alberti states in “De re aedificatoria” (Book VI, Chapter 2) or a substantial property of the un-processed material, but rather as a link between material performance and design decision. The sense of texture in this case is referring to the design of a multipliable unit as a conceptual “brick” that would accumulate form, structure and logic in “bonding pattern and structure” in the words of Mies van der Rohe (Johnson, 1947).

Under the spectrum of the research context, several experiments on the tessellation of the unit were carried out. The module was tested on triangular, rectangular and hexagonal planar uniform tiling of identical modules and it was extended to a gridding experimentation on spiral planar circle packing [1] containing modules of various sizes for the purpose of study. However, irregular and non-planar gridding of the module exceeded the scope of the study, it was incorporated in the potential systems as to be addressed at a future study.

The parametric definition of the module as a unit was embedded in the design of the multiplication pattern along with its variable attributes of orientation and aperture in an attempt to explore the behavior of the system as a whole. Several structural constraints had to be taken under consideration along with the geometric attributes of each tessellation experiment such as avoiding intersection among neighboring modules when their components are in expansion. For this reason the parameters affecting the units’ geometry were linked to the parameters defining the geometry of the grid which was designed to be structurally independent in order to provide stability for the system. Conceptually the modules were connected to the grid in a way that their ability to move and rotate would not be obstructed. The connecting material part of the surface was conceived as an elastic medium in tension that would constrain the modules allowing motion. The multiplication of the hollow unit produced perforated surfaces of adjustable proportions between the structure of the grid and the module- the material and the void. This structure had the potential to evolve into a metaphoric filter of variable porosity given the modules attributes.

**PATTERN AS INFORMATION; ENCODING THE RULES**

The previous stage of the research concluded in creating a set of modules that interconnected in a spatial level. The parameters that controlled the
movement of the modules were embedded in their definition, although, a system connecting them was yet to be invented since they were so far considered as independent units in terms of responsiveness.

According to Bateson (1979), as cited by Andersen and Salomon (2010), the sequential repetition of similar parts within a pattern allows one to forecast the next iteration, and once the rules of combination between the parts are established (in music, on a facade, in a text, or on a piece of fabric) any deviation will stand out (and is coded positively as information or negatively as a mistake. Along with this approach an irregularity in the geometric pattern of the grid could be interpreted as a source of information concerning the performance of the system. Therefore, a set of rules for responsiveness had to be defined merging the initial parameterized values of aperture and orientation of each module into a new hierarchy level.

The first approach was based on a homogenous behavior of the system in which all the components were adjusted simultaneously and each module shared the same characteristics in diameter of opening and direction of inclination. The approach was applied in each type of multiplication separately offering distinct textures in each case in the topography of the surface. This systemization could favor a uniform type of adaptation of the system to the external source that triggers the fluctuation of variables, in terms of conceptual design. That is to say, it could be suitable for a synchronous overall control of the modules concerning the input – output relationship.

The second approach was oriented in creating a dynamic relationship between geometrical entities. In order to achieve this attractor points were integrated into the algorithm. The first set of attractor points were used to decrease the aperture of the modules related to them by a relationship of proximity within a field of adjustable power. The second set of attractor points was used to define a vector input along which the modules were aligned to or not according to the variable range of attraction. This experimentation provided interesting results of texture of the surface in terms of anaglyph and perforation patterns.

Information as pattern; responsive expression

The scope of this paper extends to a case study on a first level experimentation basis given a hypothetical response scenario. In order to explore this perspective, a product among the possible results of the algorithm was chosen following a natural selection path among the branches of the phylogenetic map describing the subject of experimentation in terms of materials, structure, gridding and scale.

The scenario’s product for study was defined as a hexagonal gridding perforated façade element comprised of expandable and rigid components connected by elastic constraints. The connection of the modules was simulated by an inflated elastic membrane which was chosen as a design solution in order to permit the movement of the hollow parts. Climatic response and occupant interaction were proposed as performative objectives for their significant presence in several dynamic facades (Anshuman, 2005).

In terms of environmental response this responsive skin was treated like a sun screening device experimenting with the penetration of sunlight to the interior. A necessary stage on this experimentation was to establish a relationship between geometric and non-geometric data. To achieve this parametric definition of the solar path along the year [2] was integrated to the initial algorithm and it was associated with the orientation of the modules using the sun angle as a vector input. A morphological and luminous performance evaluation was performed by simulating the skins texture change according to the sun’s position while producing various shading effects and

Figure 7
Solar response as skin texture.
light penetration level on the interior. The solar study was carried out at several days of the year at distinct states of orientation in order to assess the environmental potentials of the responsive skin system.

In order to engage user association to the system (Anshuman, 2005), a potential motion path was simulated and according to the proximity of the user the aperture of the modules fluctuated using the position of the person as an attractor point. The system was set to an aesthetic evaluation using several possible trajectories of motion at various range levels.

The combination of the two sets of input created a dynamic fluctuation effect on the skin's texture. This effect provided aesthetic and performative feedback producing texture and composing a metaphorical semi-permeable membrane between two distinct environments through various void dynamics.

CONCLUSIONS
This paper presented a qualitative design experimentation on the evolution of a dynamic modular component multiplied and interrelated into a performative responsive system. A field of possible iterations was charted in order to investigate the width of the spectrum deriving from a basic geometry. The framework of analysis could be of value to a perspective future research in terms of process-based design.

The course of the research revealed a wide field of experimentation which exceeded the scope of this study and may be addressed at a following stage; on a modular level the optimization in terms of structural efficiency could benefit from experimentation on material testing in a quantitative approach. In reference to multiplication, proliferation on-non planar

Figure 8
User motion response as skin texture.

Figure 9
Sensitive Skin*; user interaction and solar response. Façade element conceptual design.
surfaces may be explored. Responsive performance may be related to additional environmental input such as sound, wind or humidity and extend to a quantitative optimization method. Fabrication of prototypes could provide a material ground on the concepts discussed during the research. Parametric tools allowed the simulation of the module, the system and the environment as separate algorithms and as a whole in terms of geometry, scale, and material properties, structural restrains and environmental data and providing real-time digital visual feedback and that were integrated in a substantial way into the dynamic process of architectural design.

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