Behavioural Surfaces

Project for the Architecture Faculty library in Florence

Tommaso Casucci1, Alessio Erioli2
1University of Florence, 2University of Bologna.
1http://synth-e-techmorph.blogspot.it/, 2http://www.co-de-it.com/
1tommaso.casucci@gmail.com, 2alessio.erioli@unibo.it

Abstract. Behavioural Surfaces is a thesis project in Architecture discussed on December 2010 at the University of Florence. The project explores the surface-space relationship in which a surface condition, generated from intensive datascapes derived from environmental data, is able to produce spatial differentiation and modulate structural and environmental performance. Exploiting material self-organization in sea sponges as surfaces that deploy function and performance through curvature modulation and space definition, two different surface definition processes were explored to organize the system hierarchy and its performances at two different scales. At the macroscale, the global shape of the building is shaped on the base of isopotential surfaces while at a more detailed level the multi-performance skin system is defined upon the triply periodic minimal surfaces (TPMS).

Keywords. Digital datascape; Isosurfaces; Material intelligence; Minimal surfaces.

BEHAVIOURAL SURFACES
The introduction and use of digital tools in Architecture implies an impact measurable not only in terms of a technological shift, but mostly and foremost as the necessity of a paradigm shift towards an increasingly complex and richly responsive system that is able to dynamically interact and simulate complexity as opposite to merely represent it. This capacity allows us to implement new processes and systems (joining behavioral and geometrical aspects as the basis for morphology and organization) from their analysis and to extend them through simulation to a wider range of scales and effects. The interaction is increasingly intense and fast, up to the tipping point where the ability of technology to change us has reached and surpassed our ability to feedback on it. Ultimately, this means that new extended computing power, advanced control on massive databases in design processes require a new kind of sensibility derived from the ability to understand and interact with complex phenomena.

Architectural and design problems become more focused around the perpetual and dynamic assessment (analysis and design) of a system’s behavioral properties (physical, geometrical and performative, but also effects and affects), as well as the network of environmental relations through morphogenetic processes instead of the description of building models where geometries are statically
overlapped on material processes. Such processes are intended to exploit and embed material intelligence within the system, where behavioral properties of matter are seen as an integrated part of geometry organization, guided by the balanced interplay of extensive and intensive differences in the system itself.

According to Neri Oxman, “material properties are considered intermediary agents mediating environmental impetus with material response, such that inanimate matter might contain the information for its behaviour and evolution” (Oxman, 2011). Research at the nanoscale from the observations on matter through Scannig Election Microscope (SEM) revealed how material organization is highly thriving on curvature and minimal surfaces. As Stephen Hyde puts it: “shape determines functions and the energetics of functions dictate the optimal structure required” (Hyde et al, 1996). While growing up in scale and complexity, allometric growth causes the genesis of forms that steer away from the pure geometry of minimal surfaces but still material processes put their principles at work within a more complex global organization as a form of localized material optimization.

Thriving on these premises, the project explores the qualities that can emerge from the modulation of surface condition driven by intensive datascape describing environmental conditions. The project consisted in the articulation of the basic principle explained above focusing on the system behavior and performance organization at two different hierarchical scales, thus developing two different yet connected algorithmic exploration of surface definition processes. At the macroscale, the global shape of the library (including both the internal flow and spatial distribution as well as the outmost skin) is defined on the base of isosurface systems generated by the pervasive vector field of flow patterns simulated on the building site; at a more detailed scale, a particular kind of triply periodic minimal surface is chosen as a topological model to articulate the porosity pattern of the outer skin according to the distribution of internal forces and solar radiation values.

The design process involved a digital tool pipeline including several existing software (such as Rhinoceros®, Grasshopper, Autodesk® Maya, Autodesk® Ecotect) in order to stream information from the
analysis of physical data to the geometrical and performative setup of the system and its simulated material properties.

The case study project is a design proposal for the new Architecture Faculty library in Florence. Although the proposal is an academic case study only and not aimed to construction in a close time range, we hope it could be a first step for further exploration in coupling material behavior and geometry in architectural design.

The building site is a large area containing an existent panopticon building used until recent times as convent first and penitentiary later on. The project recovers the pre-existing spaces of the panopticon as storage, HVAC spaces and archive for physical books and provides a new built structure to host study areas, meeting rooms, an auditorium and exhibition space.

The design process can be summarized in three steps:
1. Building the environmental analysis datascape
2. Morphologenesis of the global structure
3. Surface to multi-performance membrane behavior

**Building the environmental analysis datascape**

The first phase of the project was focused on the analysis of specific environmental conditions on the building site both at the actual state and in future scenarios (built upon the projections extracted from existing databases – for example projections made by the local transport authority about the number of people traveling on public transport in ten years from now). On this phase a large quantity of relevant data was collected from both existing databases (when available) and direct measurements on building site and structured to set up a pervasive, three-dimensional vector field describing a global environmental datascape. In particular a mapping of the connectivity network (which city areas were reachable within a certain time frame) was built based on road system, transportation mean and capacity and traffic condition.

From such map the users flow and intensity at the expected area access points were extracted, while attractor points for neighbour cultural facilities were also defined. All the data was then converted and translated to a common model in Autodesk® Maya in order to describe the distribution of each analysed condition on the site, locating attractors as a set of potential charges and force fields attractors, using particle sources for the access points. Each of these entities are related to specific analyzed conditions and were parametrized accordingly.

The field was then generated using Maya n-particles flow simulation, to explore the trajectories produced from the interaction of the distributed charges and the 3D digital model. The 3D vector field generated from the simulation was the pervasive datascape used as input in the following isosurface generation process.

**Morphological definition of the global structure of the library**

The generation of the library shape at the macro-scale is based on the extraction of isosurfaces describing equipotential conditions inside the vector field derived from environmental analysis.

Isosurfaces are defined as surfaces that represents points of a constant value within a volume of space, in other words, they are level sets of continuous functions whose domain is 3D-space. In our case the isosurface system was generated through the use of marching cubes algorithm in Rhinoceros®.

During the generation process, a set of parameters was defined to control the final output, the
isosurface meshing methodology, the isosurface threshold value and the range of selected values from the original vector field.

The exploration of all possible variations produced a broad set of different outcomes in the final meshed surface among which a solution was identified using two selection criteria based on usability and spatial heterogeneity. Usability was interpreted as connected to the presence of planar horizontal conditions (approximated within an adjustable tolerance) within the continuous surface, searching for the one that possessed the higher percentage of such conditions. Spatial heterogeneity is a necessary prerequisite for functional differentiation in general and a condition coherent with the different activities in a distributive and functional program of a library; in this case the criteria was used to locate, among all cases, the one in which spatial het-
The convoluted morphology of the surface aims to enhance structural performances thanks to the combination of curvature and material system morphology at a finer scale, just as it happens in shell structures: their typical efficiency is due to surface curvature and to the spatial configuration of the material distributed along the surface itself. Instead of a mono-optimized linear hierarchy where each element is singularly optimized for minimal use of material in very specific conditions, the goal was to produce a redundant structure with interdependent hierarchies with trans-scalar feedbacks in which each element participates to the definition of the whole system performances and redundancy assures resilience. In redundant structures surplus in number of nodes and connections provide the system with high adaptability and reliability (predictable failure modes) in case of unpredictable stress conditions, due to the elements morphology and system design and to the fact that each node is not strictly indispensable to the stability of the entire system. This form of material intelligence is very frequent in biology: “Biology makes use of remarkably few materials, (...) and they have much lower densities than most engineering materials. They are successful not so much because of what they are but because of the way they are put together” (Jeronimidis, 2004).

**Surface to multi-performance membrane behavior**

In order to achieve multi-performance membrane behavior on the outer surface, mechanical and porosity properties are expressed through a minimal surface based microstructure.

Minimal surface are defined in mathematics as surfaces whose principal curvatures at any point have always equal magnitude but are opposite in sign; triply periodic minimal surfaces (TPMS) are a family of minimal surfaces whose structure is based on a tri-dimensional crystalline organization: they are particular cases of equipotential surfaces dividing space between the atoms of a crystal. Their high genus combined with uniform curvature endows...

...erogeneity was better matching with the library’s functional mapping. Since the two criteria do not generally converge on a single solution the one that was more efficiently (even if not optimally) satisfying both criteria was finally chosen.
them with high-level mechanical performances combined with porosity control. Three dimensional patterns based on triply periodic minimal surfaces can be observed in the microstructure of sea urchins. Their impressive mechanical properties and lightness are due to material organization despite the weak material (calcium carbonate) constituent.

Multiperformance is then pursued through parametrical proliferation of a subclass of TPMS, Schöen’s manta surface: it is based on the repetition of a genus 19 cubical cell, which is compliant for quads based proliferations such as the one in this project. The mesh inherited from the previous step is rationalized through Catmull-Clark subdivision: this pro-

Figure 9
Topological variation of the components.
cess enhances the curvature-based properties of the initial mesh and outputs a quad-based only mesh, which fits Manta’s modular topology.

Several patterns were tested to evaluate the global behaviour derived from the interaction of a great number of elements. Interesting effects begin to emerge around vertices connecting more than 4 edges. Variations in density and tessellation were explored in order to test specific conditions (surface curvature values or stress values on the surface).

Porosity on the exterior membrane was tuned (through phenotypical variations of the cells) according to direct solar radiation values derived from solar analysis on the global surface rationalized for proliferation, in order to ensure a heterogeneous and regulated pattern of climatic and lighting conditions in the library interior spaces. In areas where direct solar radiation values are low, the passage of direct solar rays is fostered; conversely where these values are higher the passage of direct light is blocked, favoring bounced light instead.

Maintaining the topological conformation of the Schoen’s Manta surface, the parametrical variation of the fundamental region determine the modulation of lighting condition in the interior spaces of the library.

The final intricacy of the global proliferation around the convoluted surface creates also a self-shading pattern that it is expected to cause positive influence on thermal load patterns and performance over the entire building. It was not possible (but it would certainly be a necessary step in further developments) to make specific tests in order to prove the amount of thermal benefit provided, however the similarity in collective self-shading techniques (provided both by convolutions on an individual’s shape as well as collective growth patterns) in species such as cacti provides an observable qualitative proof of efficiency.

CONCLUSIONS

The thesis project is a case study about the application of material system properties through morphology and organization, articulating geometry, organization and efficient behavior at several system scales within a process of integration with environmental conditions. Environmental forces (in the form of a pervasive datascape) drive and constrain the initial generation upon which then a process of multi-performance optimization through morphological organization and parametric proliferation is operated. The thesis explored in particular two different yet connected and consistent condition-driven surface definition processes at different scales (one through marching cubes algorithm, the other through triply periodic minimal surface definition), which resulted in different spatial organization capacities and behavioral performances of the system and its constituent parts.

Isosurfaces, commonly used in Computer-Aided Engineering and meteorology for volumetric data visualization, were used to define isoconditions for the global shape of the library according to the environmental datascape while triply periodic minimal surfaces were used to acquire multi-performance membrane behavior out of the initial surface, manage porosity and modulate light perception and climatic conditions in the interior spaces of the library.

REFERENCES


