Next Generation Building 1 (2014) 65–82
10.7480/ngb.1.1.1535

Performance driven generative design systems: Agent based model driven design methodologies in architectural education

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The research paper elaborates upon multi-performative generative design strategies by means of associative computational simulations incorporating social, environmental, spatial and structural dimensions. The interdisciplinary research driven design approach presented in this paper is exemplified via design experiments conducted at Hyperbody, TU Delft's graduation studios. These experiments consciously fuse Agent based modeling (ABM), Associative and parametric design techniques, Swarm intelligence Models and Environmental analysis to evolve a comprehensive, performance driven design methodology. A looped process of iterative information exchange between analytical, aesthetic, fabrication and real-time interactive behavior based modes of experimentation for evolving performance driven architectural formations is thus proposed. This inter-performing data-driven approach devoid of its reliance on architecture styles and typologies is thus deemed a democratic methodology to understand our built environment and to bottom-up produce sustainable architectural morphologies. An interdisciplinary mode of operation to invent a new take on pre-processing via integration rather than post-design optimization of architectural space for the sake of sustainability is thus seen as a vital outcome of the research and design methodology.

Keywords: Generative design, Environmental simulations, Associative modeling, Agent based model, Form-finding.

1. Underpinnings

Operating at a post-graduate level with a program spanning the entire Masters education (MSc1 to MSc4), The Chair of Hyperbody (Faculty of Architecture, TU Delft), has been carefully developing an effective performance driven design educational agenda. The agenda focuses on imparting a unique architectural education, wherein urban, architectural, componential as well as fabrication techniques interface with cutting-edge computational and environmental design tools and methodologies. Instead of inculcating the attainment of a glorified form, the underlying methodology involves initiating a process involving iterative knowledge building computational experiments covering agent based modeling, parametric design, environmental design and structural analysis.

Design driven computational methodology typically adopted for such projects thus involves a combination of performative design processes with a set of generative simulation. These encourage developing a relational mode of thinking for cultivating a variety of emergent (Johnson, 2001) spatial morphologies embodying different metric structures and embodied parametric relationships. The methodology involves a networked interconnection between the following Meta research components: Urban Context, Localization, Programmatic Dispersion, Geometry/Topology, Structural and Environmental Optimization, Material properties and Fabrication Protocols (Figure 1). Agent based modeling, however, forms the basis of this generative methodology and plays a vital role for all the research components.

1.1. Agent based models

Agent based models typically consist of autonomous rule based interacting agents with embedded levels of local intelligence and are situated in space and time (Gilbert, 2008). An important aspect to consider in such simulations is the active involvement of the designer as regards setting out the rule sets, the diversity of agents and the kind of agency which is imparted to the agent populations. This aspect involves an inductive modeling process which each designer has to be actively engaged with. In other words: Agency, Structure and Behavior, prescribed as starting characteristics per agent become three most important areas to be considered while designing agent based modeling strategies. Models typically involve setting up simultaneous interactions amongst different agent populations in an attempt to understand spatial implications, density patterns, recurring interaction nodes etc. in space and time This not only helps in analysing the variable impacts of existing urban conditions on the site but also help in the generation of an experimental

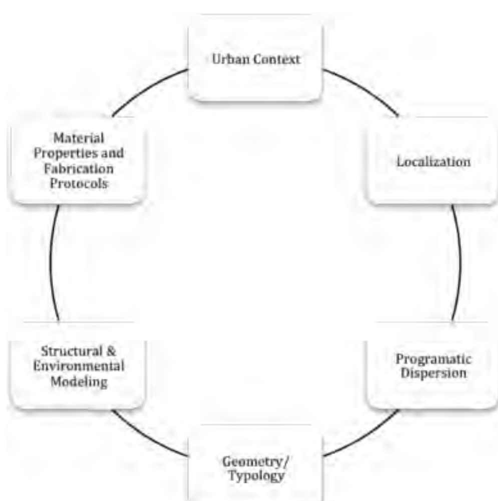

Figure 1. Methodological Stages

information field wherein changes to the weightage per parameter can help one understand the resultant spatial implication on the site. This promotes ABM's as predictive systems alongside the analytical nature associated with them and is extremely fruitful for extrapolating emergent parametric interrelationships within a dynamic context. What also comes to the fore, owing to this emergent nature of ABM's is their non-dependency on a system's stable state. ABM's, essentially operating as decentralized ecologies of agents rely more on the system's robustness and exhibit a real-time complex adaptive state owing to their diversity, connectedness and interactions. Since such systems obviously tend to be computationally intensive, strategies for optimizing such routines need to be cleverly designed.

Towards this end, two sets of agents are typically considered: higher order and lower order. The higher order agents embody an agency covering a broader contextual background, directly connected with global data sets and updating and revising their behavior with respect to time. These have an impact on lower order agents, which act as followers or trackers in the form of multiple nested sub-swarms. The agents are embedded with focking behavioral (Reynolds, 1987) instincts (alignment, cohesion, seperation, directionality etc with respect to themselves and with other agent populations) which helps them to interact with different agent typologies and be attracted to or repelled by different density zones and contextual parameters within the urban simultaneously. Subsequent to this process, multi-swarm optimization, typically involving self-organization based on spatial obstacles, noise proximity, traffic allowance, field of vision etc. of individual agents is usually embarked upon (Biloria, 2011). Behavioral attributes such as density control, wherein incoming agents evaluate the density of the area based upon determinant factors like sensitivity to existing agent density and the number of similar or different flocking agents become vital during this stage. Such emergent computational simulations can iteratively articulate the fate of a flock's self-organized growth or eventual fading out and dying due to entropy, resulting in value embedded inter-dependent agent clusters based on overall agent saturation levels.

2. Performative Design Experiments

The following sections shall elaborate upon the aforementioned research components in an attempt to trace the generative strategy involved for developing performative design solutions.

2.1. Urban Context

One mode of understanding the urban, via Experiment A (E.A.) involved considering the entire site as a dynamic information field and thus involved mapping every square meter of the site for input of measurable parameters such as noise, light, wind, humidity levels etc. (Figure 2). The relational model of the parameters, as is existing on site, is configured as an interactive system within an user interface (using Processing as a software). Owing to this relational nature, one can further his/her understanding of the impact of individual

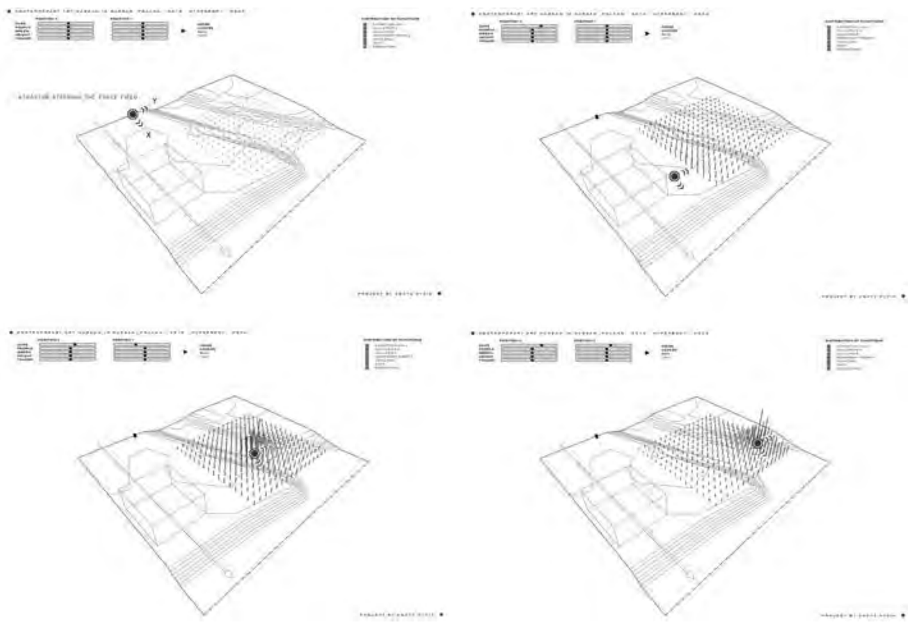

Figure 2. Processing based interactive visualization of social and environmental data per square meter of the site with the help of vertical bar based intensity display per parameter

parameter weightage modifications by changing individual value of any parameter, which automates the weightages of all associated parameters in order to see the resultant affect on agent organization patterns in time.

The varying intensity per parameter, in this experiment is visualized by means of height variations of vertical bars, which are actuated in real-time as and when agent populations navigate through the dynamic information field.

In another experiment, Experiment B (E.B.), the urban context is mined for predefined attractor points in the form of existing land-use functions (residential, public facilities, retail, mixed used, wasteland, open spaces, etc.) with varying degree of weightage and embedded starting points for different agent typologies. Each agent type thus scans every other agent from a specified flock and infrastructure obstacle boundaries. They either follow or move away from other flocks depending on the logics (here logics being the degree of attraction between various flocks, the power of separation, cohesion, alignment and obstruction) fed during the simulation. By doing this each agent successively gets a higher order in the network. Simultaneously each attractor point calculates the number of agents influenced by it.

This exercise gives rise to various network typologies like hybrid, distributed, centralized, etc. (Figure 3). The more the agents cluster around a specific spot, the more the probability that they reach a threshold and furthermore gain a higher popularity rating. This triggers the “KILL” command (thus culling swarming) and creating an interconnected cluster in 3D space depending upon the cluster distance provided by the designer

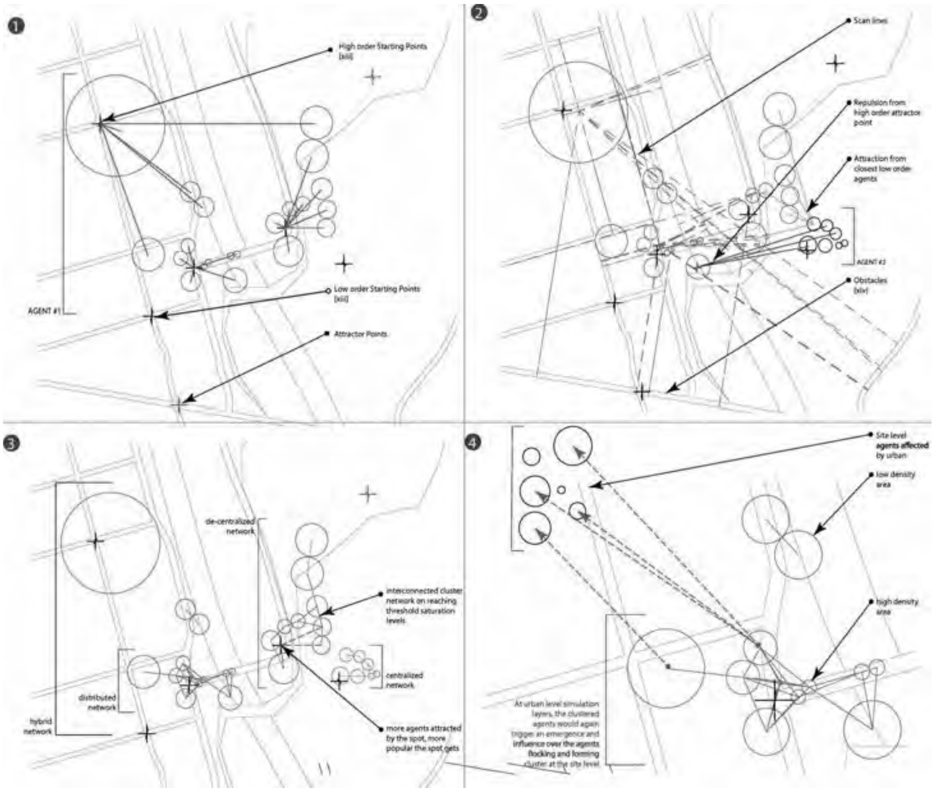

Figure 3. Multi Agent simulation rules (urban context)

for different agent flocks. These clusters can further be classified into high density and low-density areas. For a potential spot, the smaller the minimum distance of connectivity between differential agents, higher the density that area will have and vice versa.

2.2. Localization

At the local site level in E.B., agents operate on top of the urban network conditions derived from the urban context simulations. The local site level agents are programmatic agents and the connective topology of the programs are determined based on the building limits imposed by city planning authorities. In this example, the site is a myriad of functions and open areas, which interface historical and cultural aspects. This calls for different layers of network interactions, namely: Infrastructural, Transport, Functional and Landscape (Figure 4). Post urban simulation evaluation hint towards various infrastructure development trends for instance at an urban level, automobile connections showing trends of better connection with existing primary highways. Hint of creating new bridges dedicated to pedestrian influx to the site perimeters and new traffic infrastructure diversion for secondary and tertiary roads etc. (Figure 5). Furthermore, the agency per agent ecology

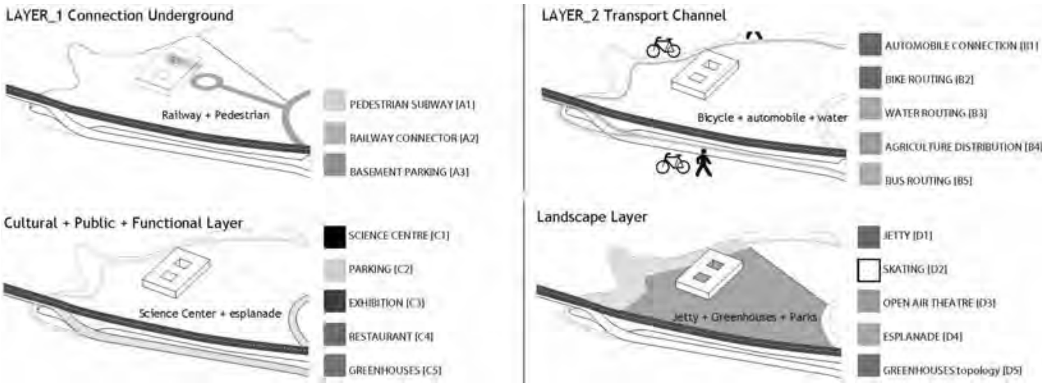

Figure 4. Network layers

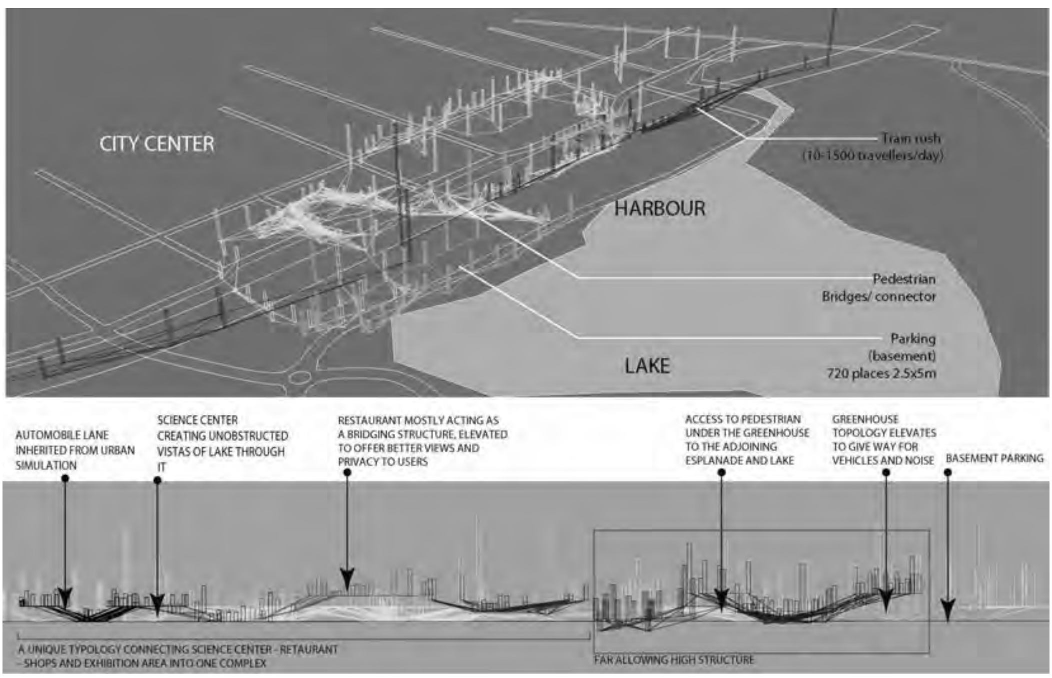

Figure 5. Self-organizing Multi-agent system results

at a local programmatic level start hinting at the location attribute with respect to these infrastructural connections. These local agents, at this simulation stage are affected by attributes such as proximity of infrastrcuture for easier connectivity, generation of binding features for connecting programs, z direction displacements including bridging structures in accordance with regulations and thus the generation of connecting landscape elements and throughfares etc. As a result of these first set of simulations, boundary conditions of different functions, the heights and the overall spatial distribution typology of different spatial agencies are thus extracted (Figure 6).

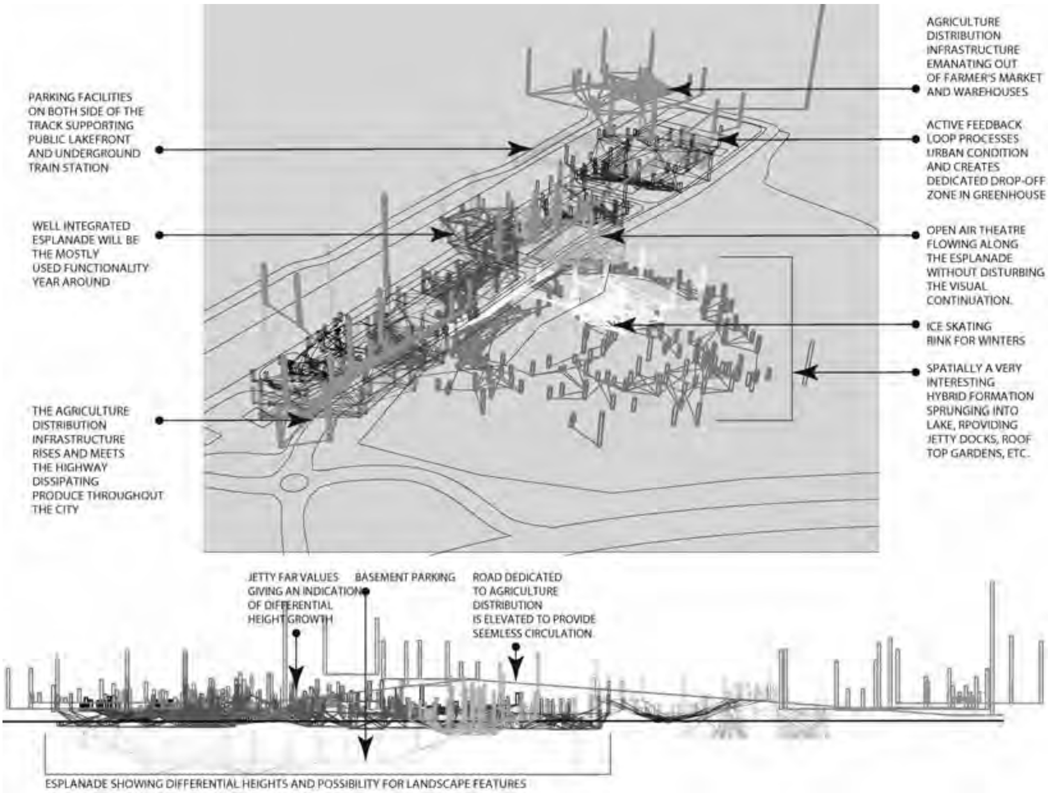

Figure 6. Local level Self-organizing Multi-agent system results

2.3. *Programmatic Dispersion*

Rather than considering the programmatic arrangement as the organization of platonic programmatic elements, in E.B. programs are considered as a self-organizing system of programmatic masses, which aggregate based upon weighted connections and parameters to specific anchor programs (these being the programs which would act as primary focal spatial nodes as per the architectural requirement). In order to meet specific programmatic requirements such as circulation, area calculation, accessibility and transparency levels. A second degree of simulation was coded using Processing (open source software platform). The behavioral parameters embedded for this simulation being the program area, internal connections, crossover degrees, physical affinities, noise allowance, accessibility thresholds, transparency and height of the functions (Figure 7).

The Processing sketch was executed multiple times with random seeds in order to achieve a manually optimized design regarding program distribution and form development. The next step was to make sense of these dispersions, after choosing a good random seed, the extracted geometry is judged based on the overall shape and geometry. The chosen geometry/iteration is then exposed to circulation connectors based on minimal distance algorithm and environmental forces to produce better aesthetically articulated shape and efficient topology.

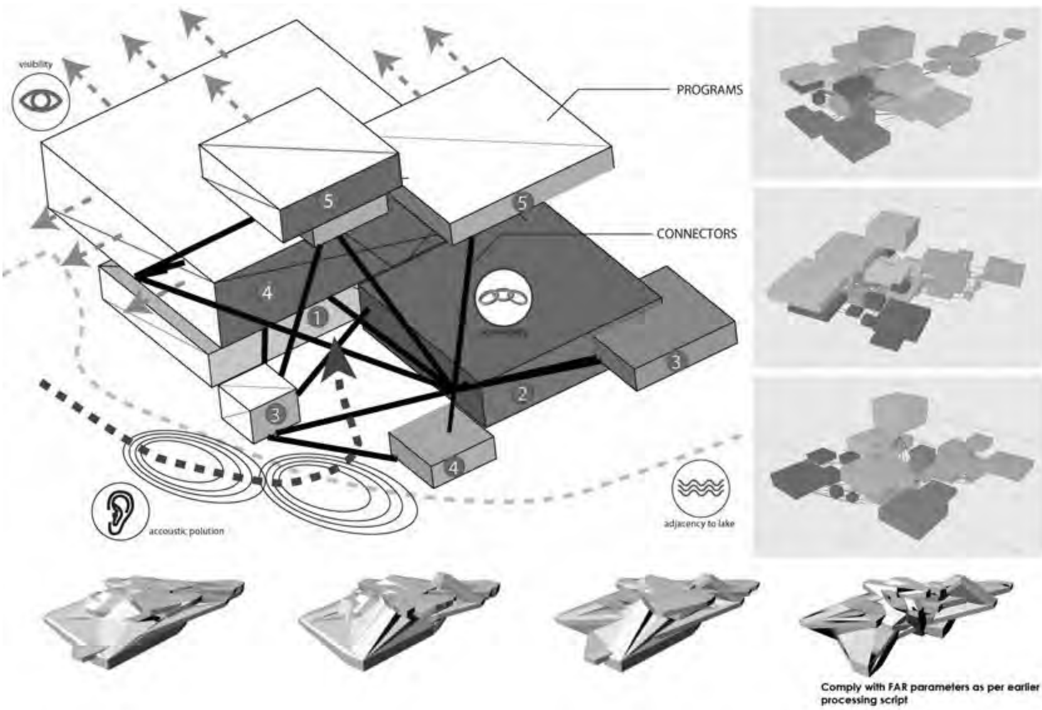

Figure 7. Programmatic Dispersion generative outcomes

In E.A., however, the agents to be simulated were seen literally as architectural program. Each program is represented in the simulation by a circular disc, the area of which corresponds with the square meters to be occupied by that program per se. The ecological view point implied that each program for instance an exhibition space would have a particular affinity towards site based environmental parameters (global level) but at the same time would have to find its position within the local information field with respect to subordinate programs such as toilets, reception areas, storage spaces etc in accordance with a weightage criteria scripted per program agent. In this case, the aforementioned site based dynamic information field per square meter of the urban area was established as the experimental ground. The self-organizing agent system thus went through an iterative process of global and local optimization to develop three-dimensional patterns/formations outlining the placement of program and connective infrastructure simultaneously. Multiple iterations based on an entire day's cycle as well as based on associated variation of each contextual parameter-based value are initiated via the interactive user-interface, thus establishing a tabular comparative chart per formation (Figure 8).

2.4. *Geometry/Topology*

In E.B. the allocation of programmes are determined by the trajectory of the Sun. A script was written using Grasshopper in which spaces adapt to the concept of a solar fan whereby meeting the performative requirements of the building. The solar computational

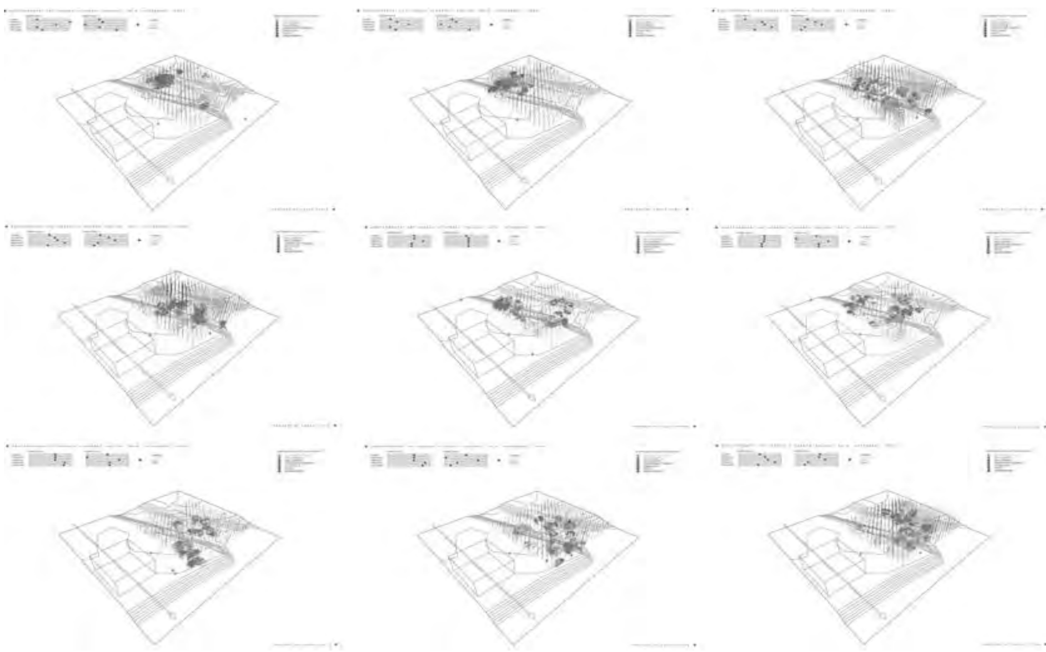

Figure 8. Sample of the catalogue of program agents based self-organization formations in time based on differential parametric values

abstraction especially plays a pivotal role in fulfilling the buildings lighting and solar requirements. In this case, the geo-coordinates impose harsh dark winters and comparatively lower sun angles. Here the script takes into account the base curve, the latitude, total sun exposure (range of months and daily hours), spatial definition inherited from previous simulations thus generating abstracted negative non-orthogonal vector shafts creating unique situations (Figure 9). These shafts give the building shallow plans and enhance diffused light penetrations much needed in harsh weather conditions.

In another experiment (E.C.), a completely different strategy involved the simulation of structural agents to generate geometry. Within a given contextual setting, comprising noise, sunlight, wind and visibility parameters, the assigned agency in this case is directly linked with the maximum and minimum distance which the agents of a particular flock can maintain between themselves while at the same time diverse flocks of agents with differing distance parameters, depending upon their proximity to each other were allowed to physically interconnect to create three-dimensional geometries. Processing, as a software tool was used to set up the entire experiment with a bounding box set up over the selected architectural intervention site into which the agent population is released. The resultant agent behavior involved densification of the structural/cohesion linkages around zones, which needed to block noise levels within the context as opposed to widening of the connections in places where light intake could be attained. A series of tests were iteratively conducted throughout a 24-hour cycle and a catalogue of formations representative of agent based structural geometries was thus created (Figure 10). These are suggestive of

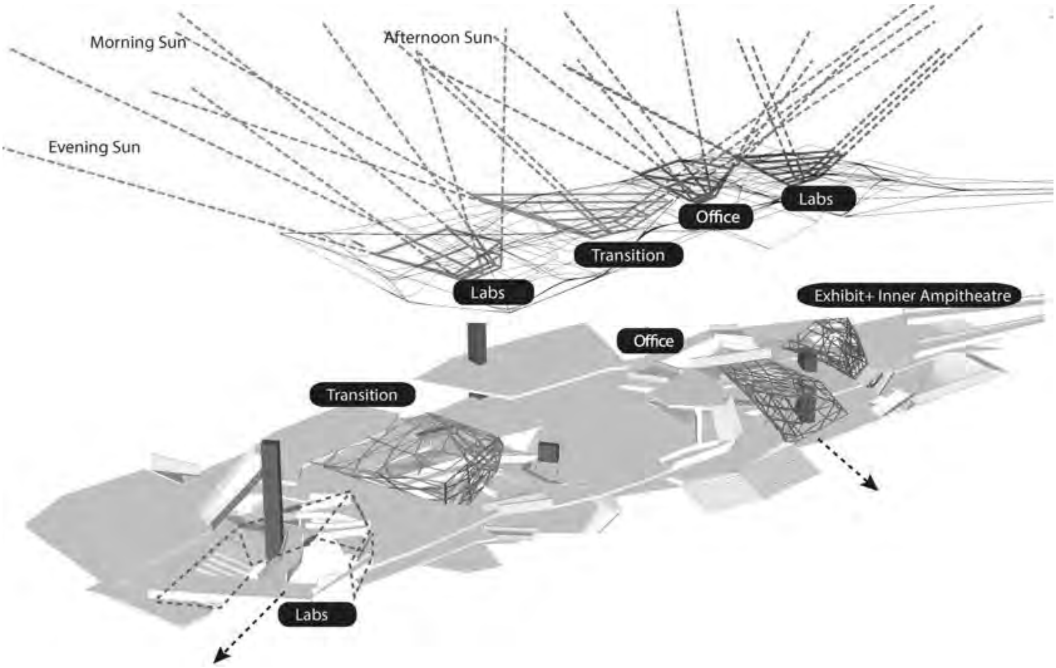

Figure 9. Solar fan simulation result

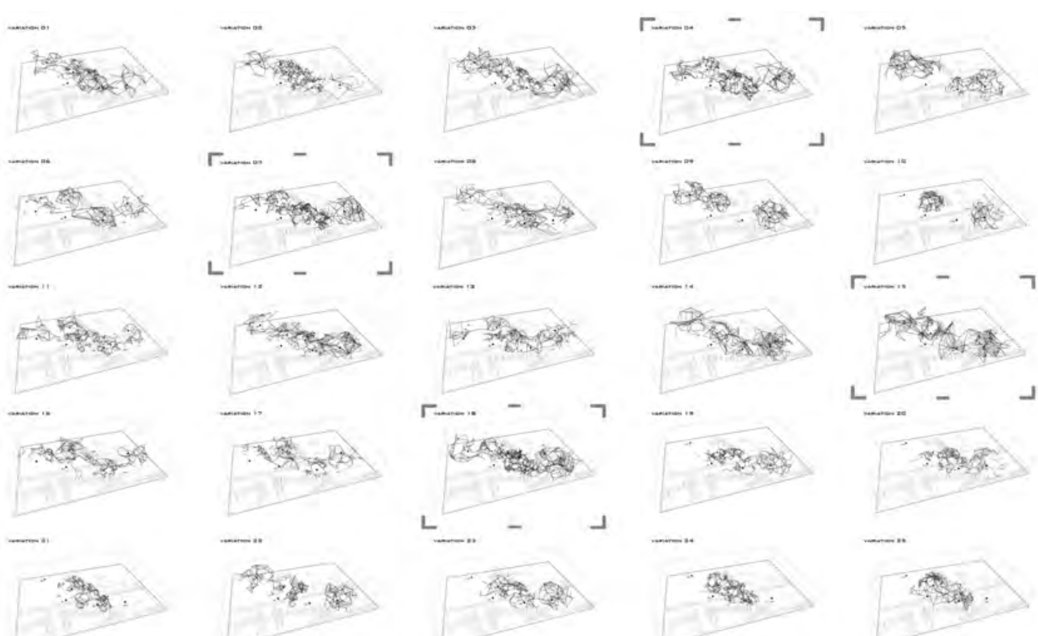

Figure 10. Catalogue of structural agent based formations for a 24hr. cycle

zones of specific performances and it is within this performative structural layer that programmatic dispersion simulations can be subsequently run.

2.5. Structural and Environmental Optimization

In the case of E.B., a solar fan application based geometric exploration guides a structural mesh generation system, which takes into account the abstracted solar geometry and encapsulates the underlying spaces. This is further refined using mesh refinement algorithms to generate a more cohesive structural vocabulary by the designer. Furthermore the structure is evaluated using Finite Element Method (FEM) Millipede package in Grasshopper to define beam depth, shapes, sizes and identify vulnerable structural elements (Figure 11).

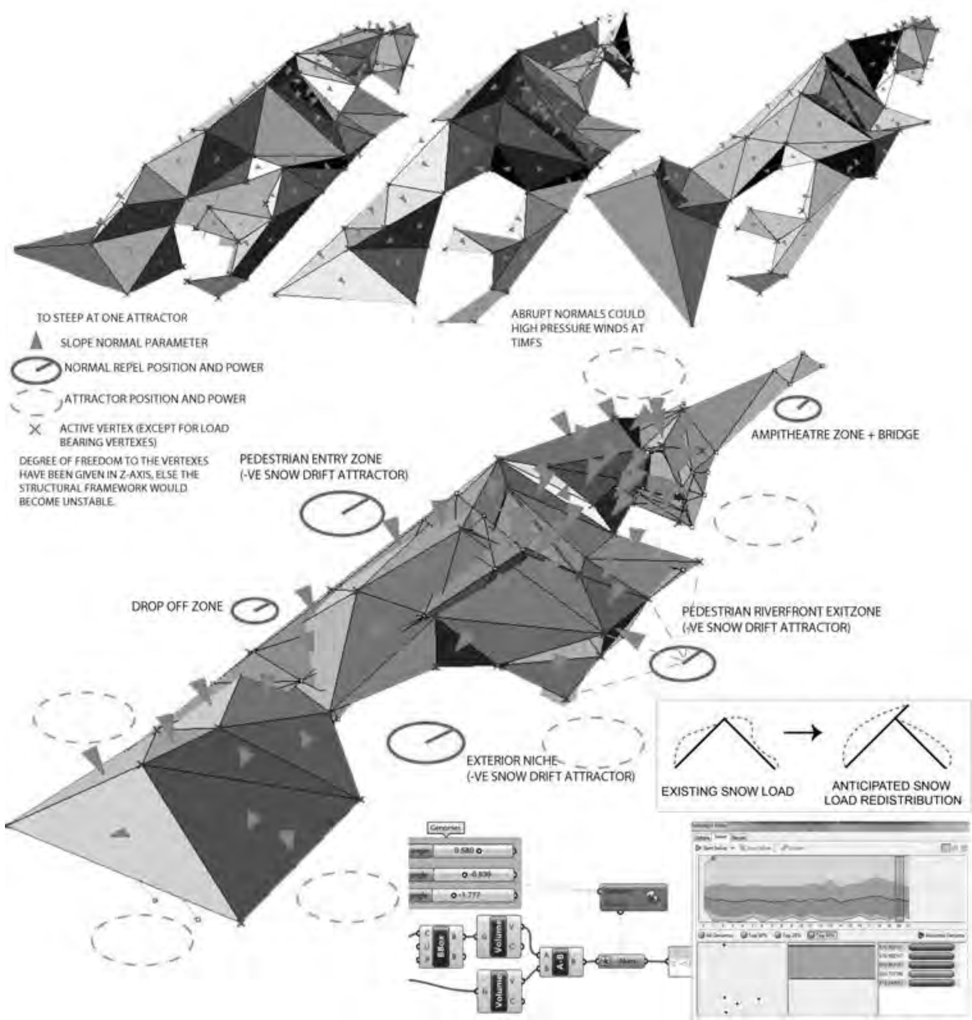

Figure 11. Snowdrift load based structural and spatial optimization

During this phase Genetic algorithm based optimization routines using Galapagos (Rhino Plug-in) are conducted for optimizing roof profiles (in this case for heavy snow drift conditions caused due to strong wind conditions and translated into slope angle simulations). The following criteria became crucial: roof slope normal inherited from mesh generation algorithm (GA), negative snowdrift attractors (to avoid the snowdrift to occur in pedestrian routing fields), attractor positions where snow can be drained and the active vertexes whose degree of freedom in movement is evaluated during every GA run based on the FEM analysis without compromising the overall structural stability.

Wind conditions and the manner in which effects of wind turbulence could start refining the developing architectural aesthetics became vital. The structural results are thus further cycled via another feedback loop wherein the project has to mitigate wind turbulence using the classical aerodynamics principles (studied via AutoDesk CFD simulation). The GA optimization's main objective in this case is to either deflect the wind creating low pressure regions behind the building's external boundary edges or else make the edge conditions act as wind breakers (Figure 12). For the main building however, owing to the wind dispersion via variable air turbulences, a study of air vents and wind spoilers pointed towards the development of air intake channels based components and volumetric junctions inside the building for redirecting the wind and for producing energy simultaneously. After analyzing various aerodynamic components, a pressure releasing component was finally chosen, which would be proliferated in a pattern on the facade. This component would trap the exterior air flow and channelize it into vents for further being used either

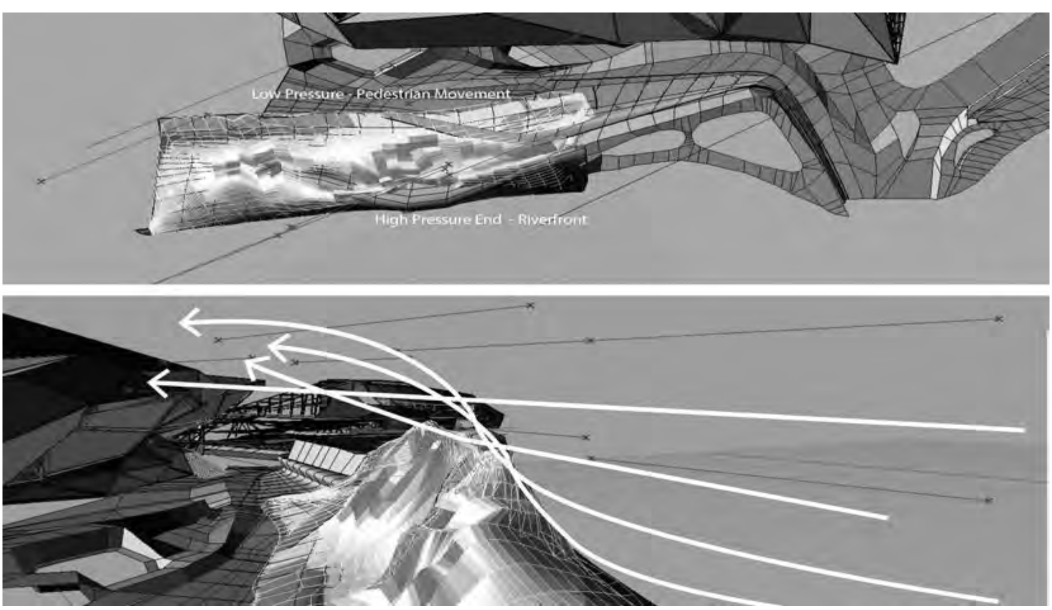

Figure 12. External building boundary level wind forming optimization

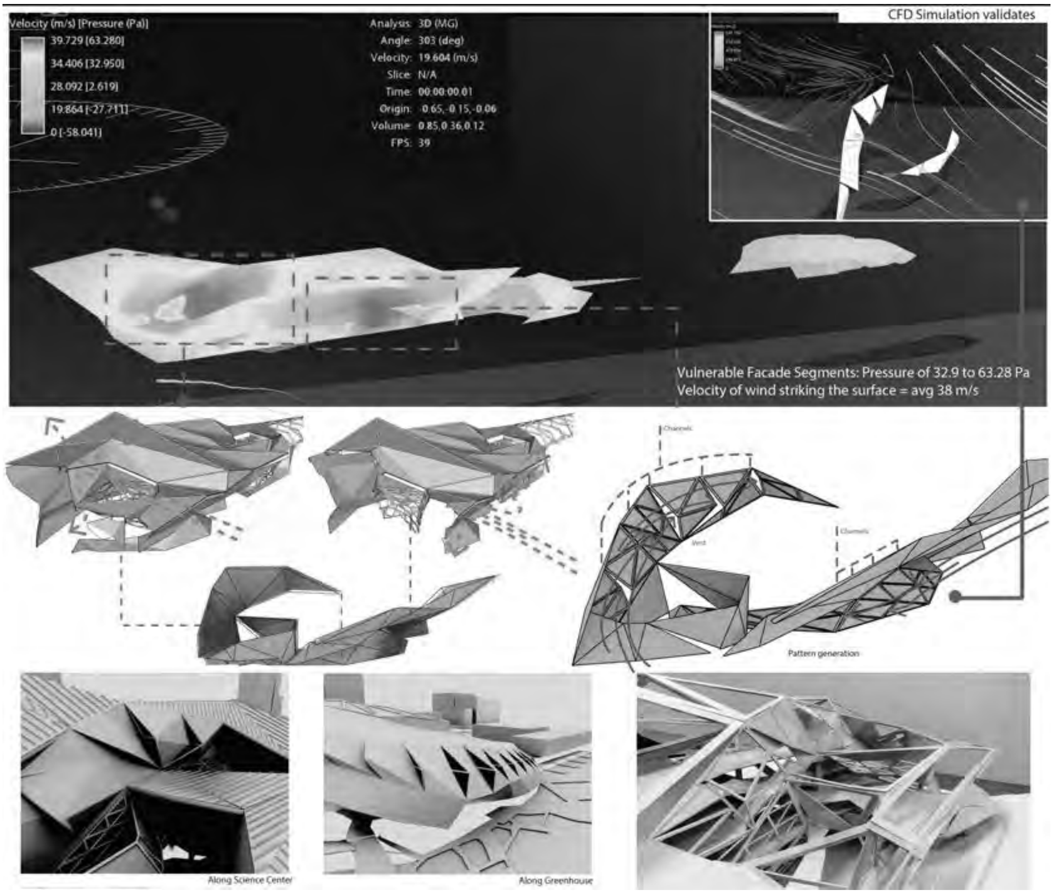

Figure 13. Aerodynamic component taxonomy

to generate energy using turbines or to just release it externally. The ultimate goal being; to recover the load loss, “giving pressure” to the system for better smoothness, continuity and for reducing turbulence (Figure 13).

In the case of E.C., a different strategy is utilized; the structural framework generated via the structural agents is sampled to identify inherent three-dimensional structural connectivity and related opening patterns. Maximum and minimum opening dimensions within the generated structural system are thus identified as well as node junctions (or intersection points) for identifying the number of structural entities (e.g. beams) that intersect at specific angles per node are also identified. This analyzed three-dimensional pattern is interfaced with three-dimensional components; whose scale, depth, degree of opening as well as the angle of the opening (in accordance with the sunlight, noise and humidity parameters) are generated using scripting routines. The external faces of these tetrahedral components are developed as cupping systems in which 3d façade elements

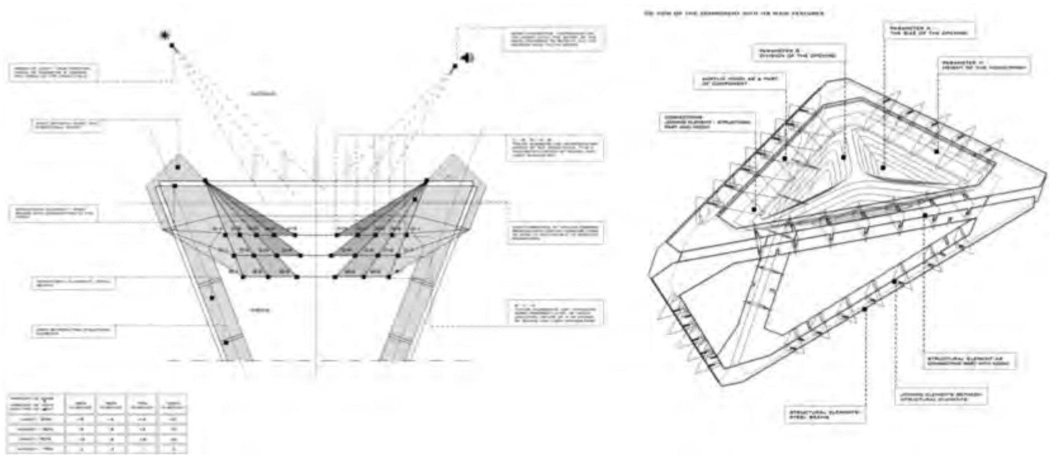

Figure 14. Tetrahedron component system displaying the cupping system, which can be customized parametrically based on sunlight and noise parameters

can be parametrically attached at variable depths as well as at variable angles as a direct response to the degree of permissible sunlight and the permissible noise level per function hosted by the tetrahedron component (Figure 14). Once this parametric system is established, the component population phase using scripts developed in Grasshopper is initiated to get an outlook of the generated morphology. A fully customized componential system, with contextual performance driven opening patterns, is thus achieved.

2.6. Material properties and Fabrication

The fabrication-based requirements are typically derived from the environmental performance criteria as well as industry based manufacturing protocols. These are interfaced with computer aided numerically controlled manufacturing tools and techniques to develop precision driven prototyping routines. For instance, in the case of E.B. the component will be fabricated using thermally insulated epoxy resin shell with a fibre transparent cover that would allow the light to enter but trap the wind (Figure 13). The transparent cover will thus allow light derived heat energy to be stored while trapping the cold exterior wind. The toplogy of the component is also developed carefully to release the pressure difference through inbuilt solid channels in the component. The choice of material comes from the logic of engagement. In the example characteristics of wood (Glulam) in conjunction with other materials like steel and concrete are used to create new and optimized hybrid material solutions. The primary structure is also chosen to be Glulam composite due to the local availability and manufacturing skill available in Finland. When compared to steel and concrete-wood composites, this composite was found to have higher air insulation, while steel and wood composite work out best in tension and for joints. Reusability and reclamation coefficients are also higher with the choice of this material palette.

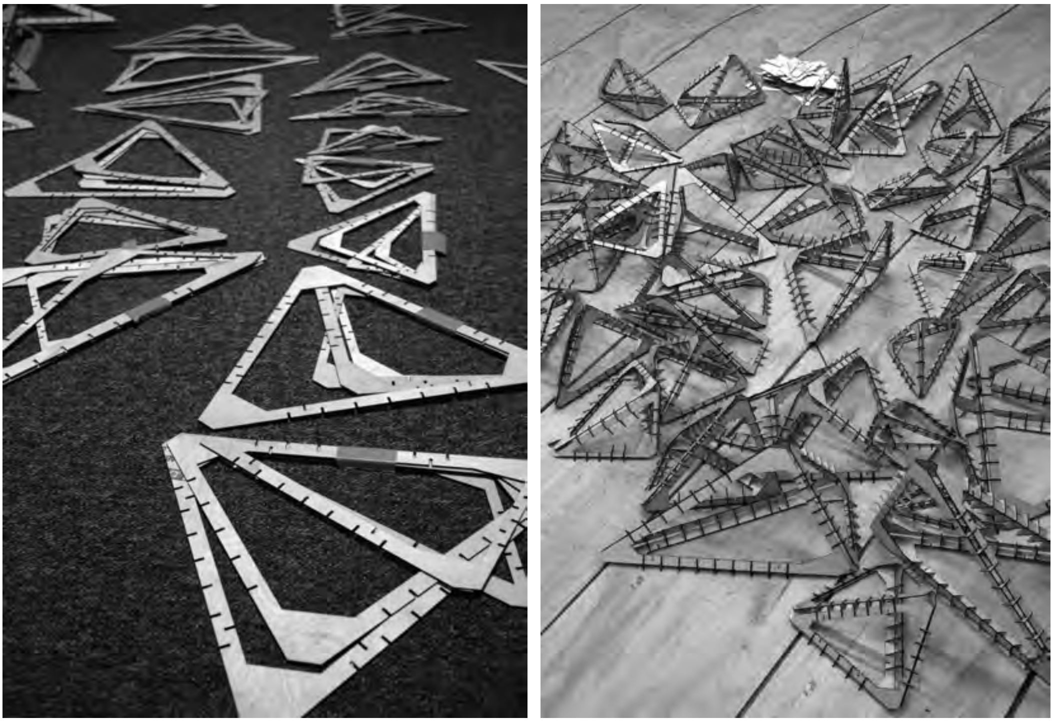

Figure 15. Individual laser cut beam profiles per tetrahedron structural frame before and after assembly stage

In the case of E.C. a rhino script specifically developed for unfolding the tetrahedron components into two-dimensional laser-cutting profiles is then initiated (Figure 15). The script not only unfolds the structural 3d profiles (beams and nodes) but also generates connectors to bind

Apart from this, the receiving notch of the external face per tetrahedron where each façade cup has to be positioned is also embedded within the cutting profiles. Each profile is logically numbered and is eventually assembled manually to create the tetrahedron profiles. The manufacturing of the façade cups follows a different procedure. For this purpose a mould corresponding to the component including its opening sizes is milled using a CNC mill. This mould is then subject to vacuum forming with which a transparent façade shell is created (Figure 16). This shell is eventually coloured in accordance with the design aesthetic needs and is placed within the notch already cut and assembled to receive it.

3. Conclusion

The methodology presented in this paper outlines an integrated data driven computational approach wherein typical issues of engaging computational routines for glorified

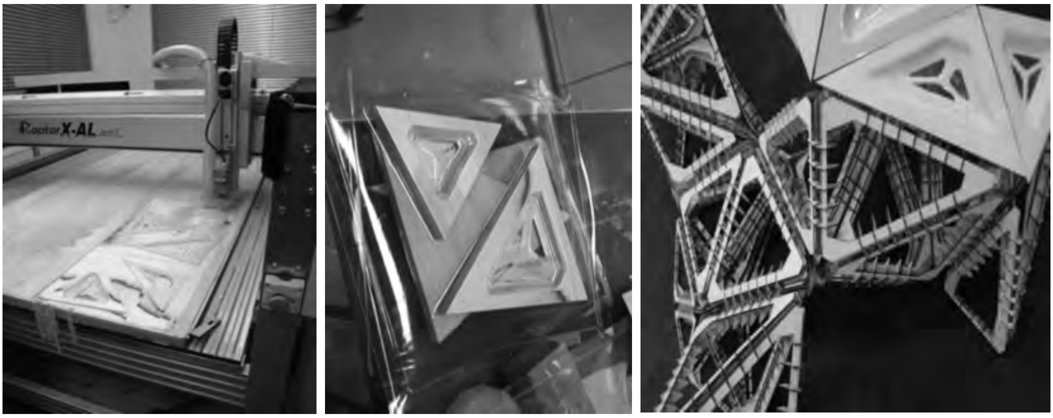

Figure 16. Customized façade caps per cupping system and assembly phase (being manufactured via a process of 3d milling, vacuum forming)

formal attributes takes a back seat. Instead, the collaborative knowledge sharing between different disciplines of environmental sciences, natural sciences, information technology, computer aided manufacturing and architectural design operate synergistically in order to bottom-up generate the logics of integrated spatial systems (Figure 17).

The implementation of layered operation of agent based simulations with designed variations in the degree and relationality of agency deployed per agent cluster results in emergent multi-dimensional formations. Per research component level, itself relies on and at the same time provides an opportunity to the designer to re-evaluate the underlying results of each stage of simulation. As is clear from the examples, almost all research components: Urban Context, Localization, Programmatic Dispersion, Geometry/Topology, Structural and Environmental Optimization, Material Translation and Fabrication Protocols involve a strong co-relation with environmental factors ranging from sun directionality, noise conditions, snow loads, wind conditions etc. This results in a simultaneous, integrated approach towards generating architectural propositons and detail at various scales, which co-evolve from a quantitative and qualitative persepctive. Issues of aesthetics thus take up a new dimension, namely performance driven design, rather than using computational tricks for generating complexity for the sake of the term.

This inter-performing data-driven approach devoid of its reliance on architecture styles and typologies is thus deemed a democratic methodology to understand our built environment and to bottom-up produce sustainable architectural morphologies. An interdisciplinary mode of operation to invent a new take on pre-processing via integration rather than post-design optimization of architectural space for the sake of sustainability is thus seen as a vital outcome of the research and design methodology.

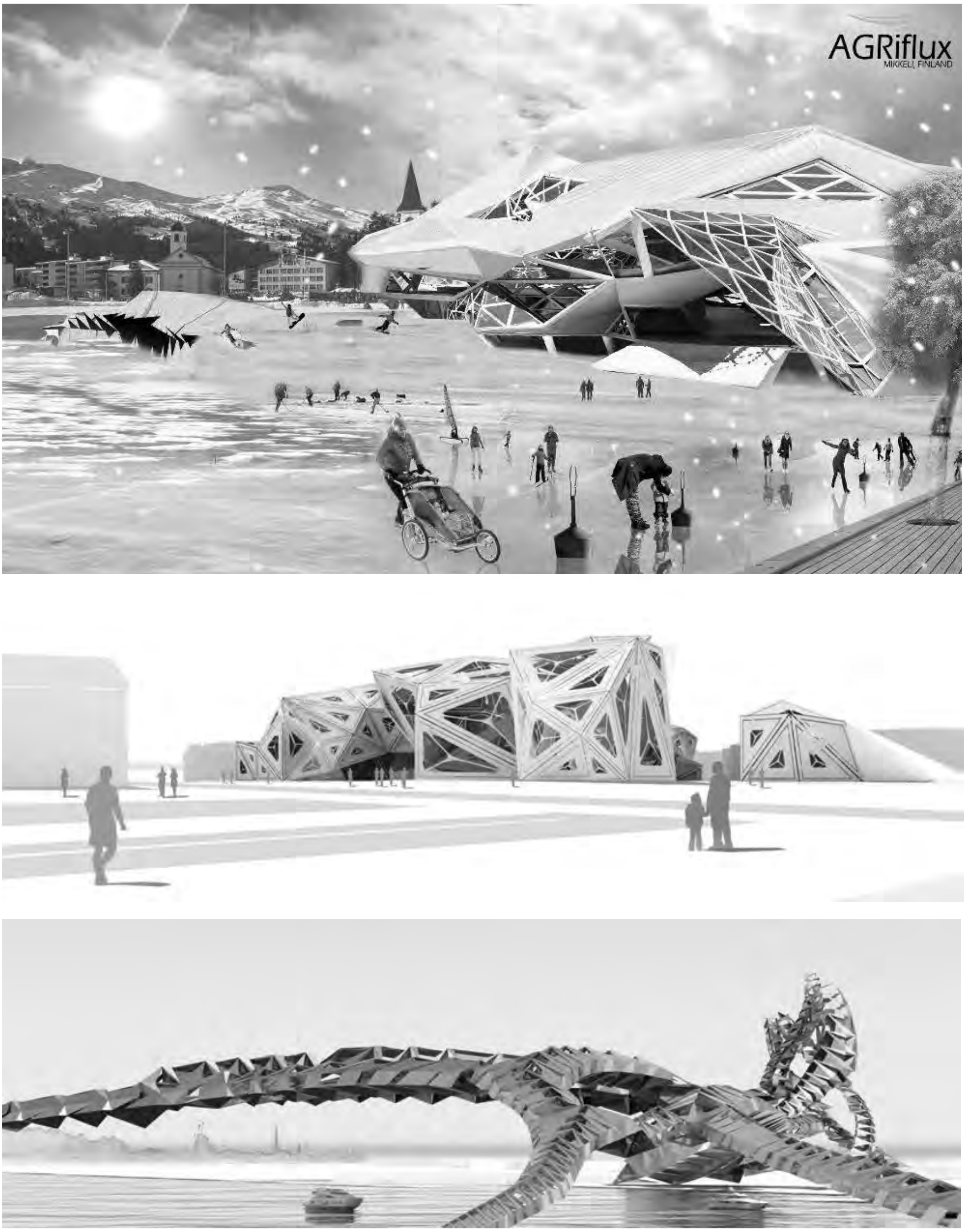

Figure 17. Performance driven design outputs using the proposed computational methodology

4. Image/Project Credits

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