Interdisciplinary Process Driven Performative Morphologies: A Morphogenomic approach towards developing context aware spatial formations

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Abstract

Architectural praxis is in continuous state of change. The introduction of information technology driven design techniques, constantly updating building information modeling protocols, new policy demands coupled together with environmental regulations and cultural fluctuations are all open-ended dynamic phenomena within which contemporary architectural constructs have to efficiently perform. This dynamic meta-context brings about with it a vital thrust on developing digitally driven adaptive design processes and techniques for the production of performative architectural morphologies. Conceiving the built form (at variable scales) as an ambitious exercise in digitally driven bottom-up associative, context driven formations of inter-dependent, ubiquitously communicating spatial components rather than focusing on the development of a top-down form centered approach thus attains a vital interdisciplinary process driven research and design position in the contemporary.
This research article exemplifies upon one such novel information integrated, contextual data driven generative design process: Morphogenomics, being experimented with at Hyperbody, TU Delft, under the author's guidance. Morphogenomics deals with the intricacies of morphological informatics, specifically outlining the relationship between contextual information and its associative linkage with the generation of performative morphology. The research article puts forth a logical underpinning of spatially distributed ubiquitous

communication and parametric computational frameworks by means of two research cases:

a. The development of Performative Skin systems (at a component scale)

b. The development of a distributed network city along the A2 highway, Netherlands (at an architectural and urban scale).

1. Introduction

Contemporary research investigations into evolutionary and developmental biology (Broughton, Coates and Jackson, 1999) have revealed intricate data as regards issues of adaptation, efficiency and robustness as well as the phenomena of redundancy and differentiation (Hensel and Menges, 2006) via which natural living systems acquire competitive performance. Understanding principles of natural growth, self-organization and adaptation within variable contextual settings and the application of this extrapolated knowledge via digital means into constructing context driven performative spatial systems (Rosenman, 2000) has thus become an intensely researched field.

Morphogenomics, one of the several exploratory research fields (such as Bio-mimetics, evolutionary algorithms (Coello Coello, Van Veldhuizen and Lamont, 2002) etc) specifically deals with understanding the intricacies of morphological informatics. It is closely linked with the term Morphogenesis (from the Greek morphê – shape and genesis – creation), which deals with the study of the development of form during its early cellular stages in developmental biology. Morphogenomics, however, focuses upon the informatics constituent behind the emergence of diverse morphologies. This informatics constituent specifically involves studying the structure, behavior, and interactions of natural and artificial systems that store, process and exchange information. This information intensive real-time communication process thus serves as a dynamic medium for mapping the morphological genome onto architectural space and structure.

Tools and methodologies in the computational domain pertaining to the simulating the extrapolated understanding of such natural processes have been extremely efficient in forming the backbone for our understanding of such dynamic phenomena. Hyperbody, TU Delft, through its own initiative of understanding the informatics oriented behavior of natural systems has been experimenting with computational techniques such as real-time multi-agent interaction (Oosterhuis, 2006), sensing and actuating systems, generative geometry and swarm simulations over the past six years. The Performative skin systems and The Distributed Network City are some of the prominent research and design ventures undertaken by

Hyperbody specifically focused upon multi-scalar associations between contextual data and built form. Associative data models, which model everything having a discrete independent existence as an entity, and relationships between them as associations are thus used as a computational methodology throughout these two research cases for developing parametric associations between the proposed architectural systems and their adaptive behavior.

The following sections elaborate upon two research and design experiments, which focus upon the usage of associative and parametric geometries, the development of self-organizing generative systems as well as embedded sensing and actuation mechanisms enabling real-time spatial adaptation.

2. Research case a: Performative skin systems

The Performative Skin research relies heavily on principles of nature catering to issues of evolutionary development as an inspiration for developing a sustainable manner of designing and building in the near future. A variety of iteration and differentiation based processes operating in natural systems tend to develop highly adaptive, self-organizing formations (Johnson, 2001). These formations apart from displaying highly performative traits concerning structural, environmental and metabolic criteria are also equally interest provoking when understanding them in the context of polymorphic topologies. A real-time adaptive process of evolution in time, corresponding to internal genetic regulations and external environmental factors in nature thus served as an imperative inspiration for this research. A shift in thinking pertaining to designing systemic componential skin formations, which can adapt and evolve in relation with their contextual settings via ubiquitous information exchange as opposed to developing non-sentient façade systems, is thus initiated through four research projects under the Performative skin system's research agenda.

Adaptation, a vital theme for the skins research also forms a critical process in the field of Evolutionary Biology which is specifically concerned with the origin of species from a common descent and descent of species, as well as their change, multiplication and diversity over time. Adaptation as a process can be defined as the change in living organisms that allow them to live successfully in an environment. It enables living organisms to cope with environmental stresses and pressures. Adaptations can be structural, behavioral or physiological:

- Structural adaptations are special body parts of an organism that help it to survive in its natural habitat (e.g., skin color, shape, body covering).

- Behavioral adaptations are special ways a particular organism behaves to survive in its natural habitat (e.g., phototropism).

- Physiological adaptations are systems present in an organism that allow it to perform certain biochemical reactions (e.g., making venom, secreting slime, and homeostasis).

These three features, namely structural, behavioral and physiological adaptation, in the architectural domain formulated the crux for developing the bottom-up performative skin systems. A component based approach is embarked upon where akin to cells in natural systems, components can be seen as intelligent building entities endowed with abilities of structural, behavioral and physiological adaptations. In the case of building components, adhering to a performance driven agenda (per component) the aforementioned three aspects of adaptation are seen as the following:

- Structural adaptations is seen as a by-product of the inter-dependence between geometry, material and fabrication based affordances in order to produce structurally stable component variations (e.g. Creating morphological variations of the same component in terms of shape, size)

- Behavioral adaptations is closely associated with the domain of responsive interaction which the component should inherit in order to successfully survive and communicate with its context in both active and pro-active ways (e.g. kinetic abilities, information exchange abilities, ambient abilities, sensorial abilities)

- Physiological adaptations in the case of building components is directly linked with the manner in which the component can deal with issues of self sustainment (e.g. energy conservation, retention and dispensation abilities, power generation, distribution and circulation abilities)

Four distinct research experiments: The stomata membrane, Hyper Human Heart, Habitual inversion and the H(eye)light, each built upon the above mentioned adaptation principles catering to contextual data pertaining to wind, water, light and interior interaction were thus initiated (Biloria and Sumini, 2009). In this research paper, I shall elaborate upon one of the four experiments: The Stomata Membrane, from the perspective of adaptation outlined above. The research projects took shape by making use of the following iterative process.

2.1. Structural adaptation: from abstract machines to computational logic

In order to understand the interdependence between material properties and its computational connotation as regards the degree of physical adaptation that a chosen component could go through, experimentations from the analogue counterpart were firstly initiated. The creation of topological genetic-body plans, which could give rise to a variety of morphologies embodying different metric structures, thus became the goal for deciphering computational logistics behind the design research experiment. An analogue componential system was hence

developed on the basis of topological and morphological linkages via establishing inter-dependence between geometry, material and fabrication based affordances for producing structurally stable component variations. In this case, a double layered skin system (Figure1) was developed, which could be physically adapted by means of sliding each component over the other in order to register changes in the depth (between the two skin layers), overall curvature variation, minimum and maximum flexibility per component, amount of sunlight/shadow etc. These structural adaption basics, extracted from the analogue component system served as a blueprint for physical-kinetic adaptations, instrumental for setting up a responsive mechanism to environmental factors (wind, light, sound) as well as interior based user interactions.

Figure 1. Abstract machine developed as an initial notational diagram for extracting structural adaptation principles.

The notational values in terms of ratios of topological alterations in one dimension e.g. x and its resultant affect on other dimensions e.g. y and z directions (in the form of sliding, folding, pinching, stretching, rotating) are used for setting up a parametric rule system for mapping out the maximum and minimum structurally feasible adaptation per component.

2.2. Behavioral adaptation: Information mapping for developing contextual associations

After developing a basis for structural adaptations via analogue abstract machines as the basis for topological, material and structural inter-relations, detailed information maps outlining associative relations between multiple parameters were developed. Parameters concerning environmental data such as rainfall, sun direction, solar angle, moisture content, wind

direction and speed etc were derived from weather databases as well as Ecotect based simulations developed within the Hyperbody group. The information diagrams as a first iteration elaborated upon associative linkages between dynamic environmental parameters and a component's parts (layers), its topological transformation, its attributes and its functions (Figure 2). A diagrammatic representation of how a component's morphology will vary over time in relation with its contextual data as well as graphical portrayals of the resulting interaction scenarios of a population of these components is thus elaborated upon at this stage.
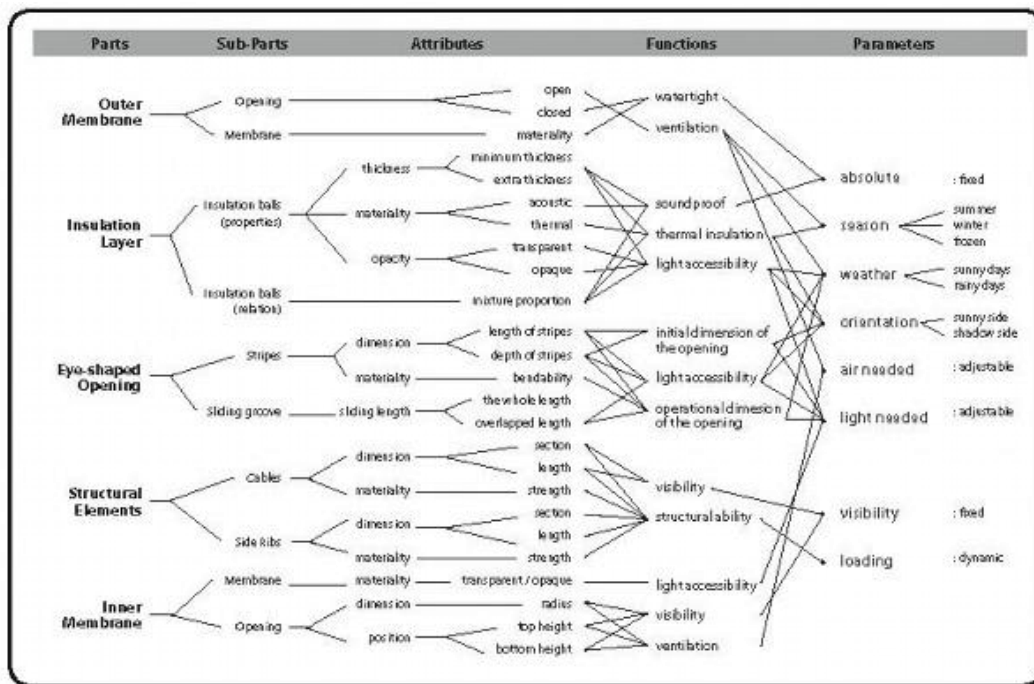

Figure 2. Associative information diagrams.

The second iteration of the information modeling concerns environmental data mapping pertaining to specific geographic locations. This process enables any given surface condition to be analyzed and mapped for a pattern which outlines the most favorable catchment zones for wind, sunlight and water and thus suggest a suitable substrate for populating structural adaptation driven components (Figure 3). A parallel information mapping system takes into consideration the nature of functional program beneath the skin and based upon the differential environmental as well as time based-occupancy scenarios of the program develops a gradient based tiling pattern on the façade. This gradient and its varying intensity at different time frames provide a suggestive framework for selecting structural (scale, size, opening pattern) as well as behavioral (kinetic adaptation in time) adaptation principles (Figure 4) in combination with the type of component best suited for the surface under speculation (wind, water, air based).
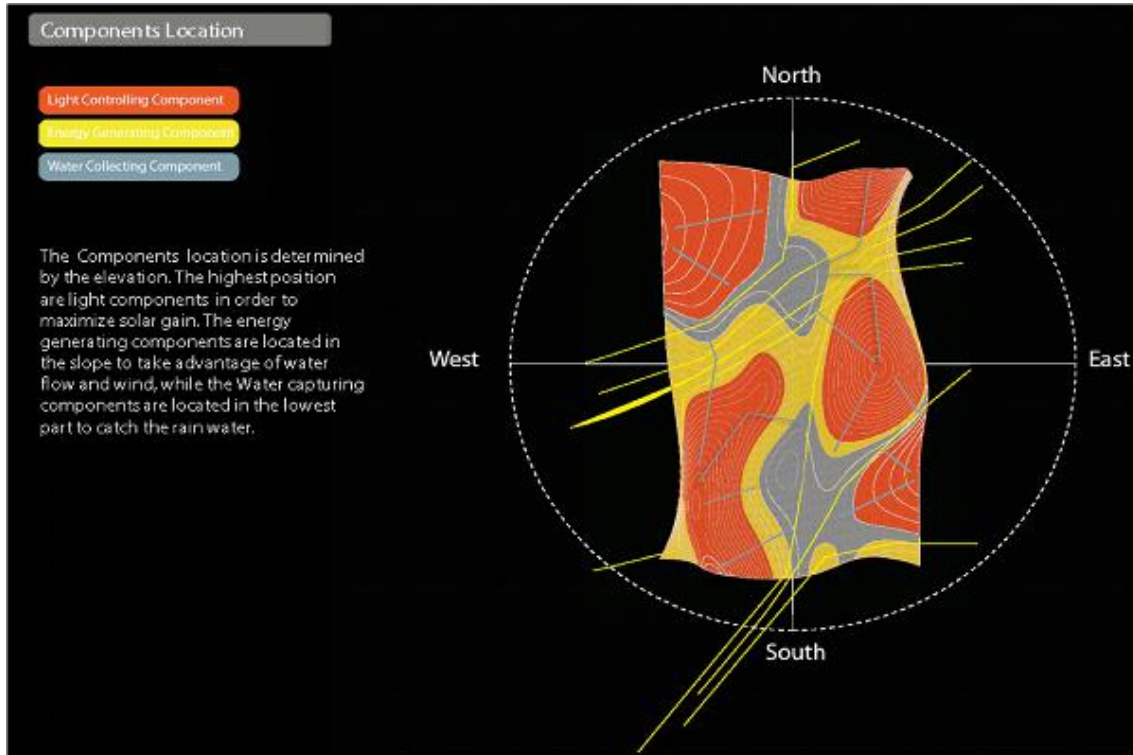
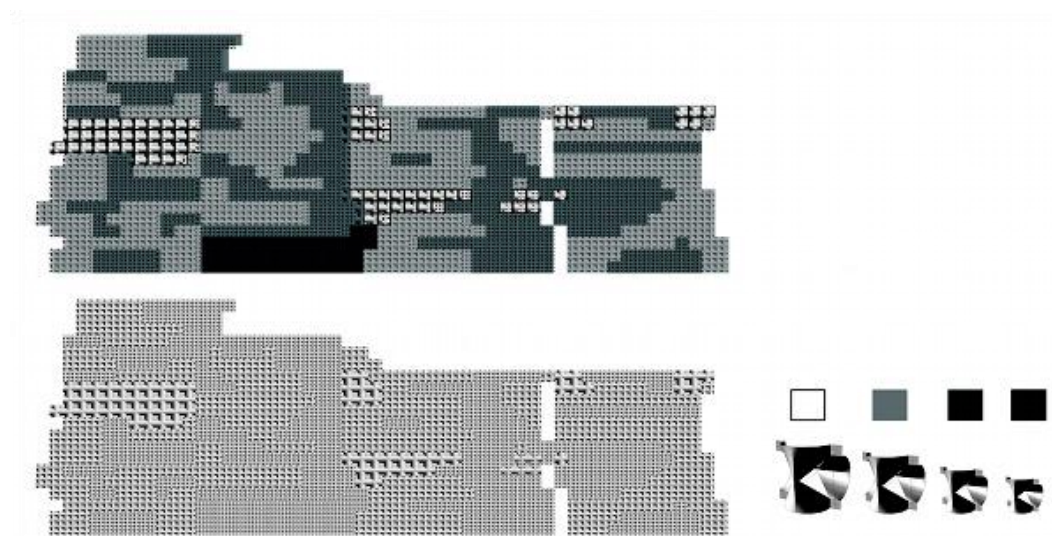**Figure 3.** Information mapping of environmental data on a given morphology.

Figure 4. Information mapping using the tiling technique on a given morphology.

2.3. Digital design and scripting routines

Digital design and scripting routines work as an intermediate membrane to weave structural and behavioral adaptations into a comprehensive working system. Structural notations registered through analogue component models coupled together with differential component

patterns & behavioral kinetic adaptations are thus assimilated in an associative three-dimensional digital model.

Scripting routines for setting up parametric relations (derived from the information mapping process) between each constituting part per component were developed using Grasshopper (a plug-in for Rhinoceros) as well as using Virtools (a game design software) and Generative components. The parametric relation set-up also dealt with the generation of an integral structural system (Figure 5), which based on the nature of individual structural adaptation as well as the surface curvature variation (as a top down design feature), generated a space frame for hosting wind, water and sun based components. The space frame, conceived as a hollow steel bone structure with integrated telescopic actuators, was generated bottom-up to be modular in nature in order to facilitate the insertion of optimized mechanical components, in accordance with the information mapping findings.
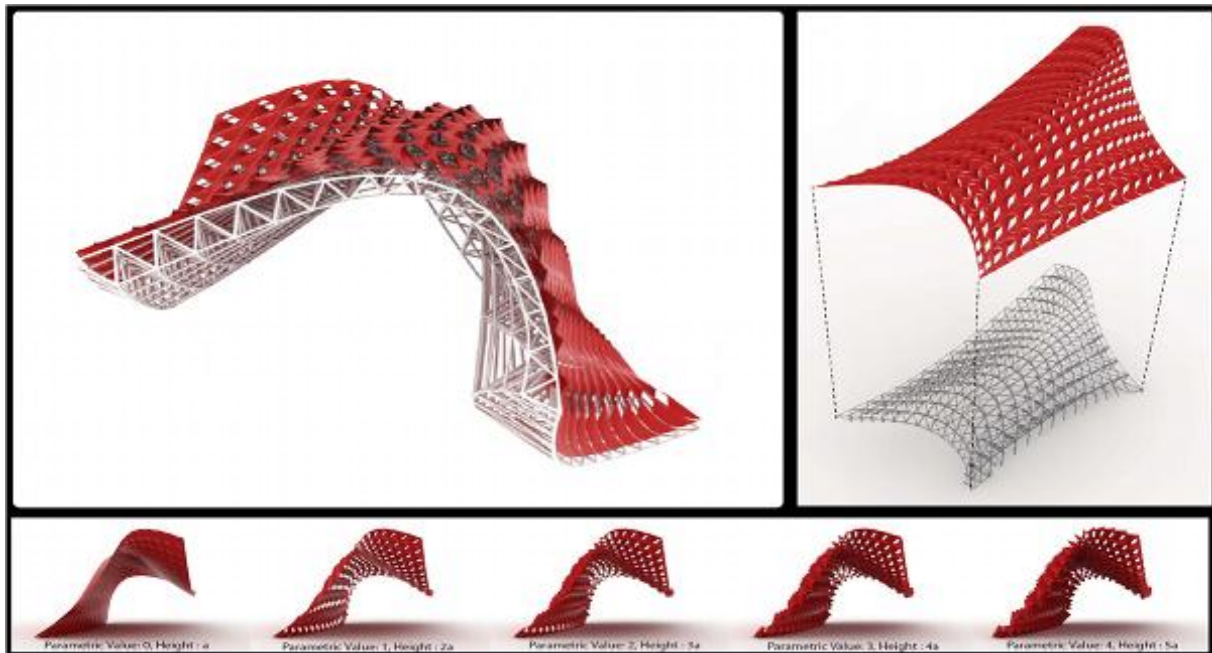

Figure 5. Results of the integrated skin and structure generation script.

A process involving dividing, setting points, adding curves, adding vectors, and adding surfaces constituted the scripting logic. This scripting routine worked as a looped sequence engulfing the information mapping sequence as an initiating routine as soon as any 3d manipulation to a surface condition is initiated. A variety of components for regulating light, water, and wind based energy generation and their combinatorial population are subsequently developed as digital representations at the end of this phase (Figure 6). The kinetic adaption per component as a real-time response to dynamic contextual datasets, derived from the behavioral adaptation phase thus work as a component specific feature within this research experiment.
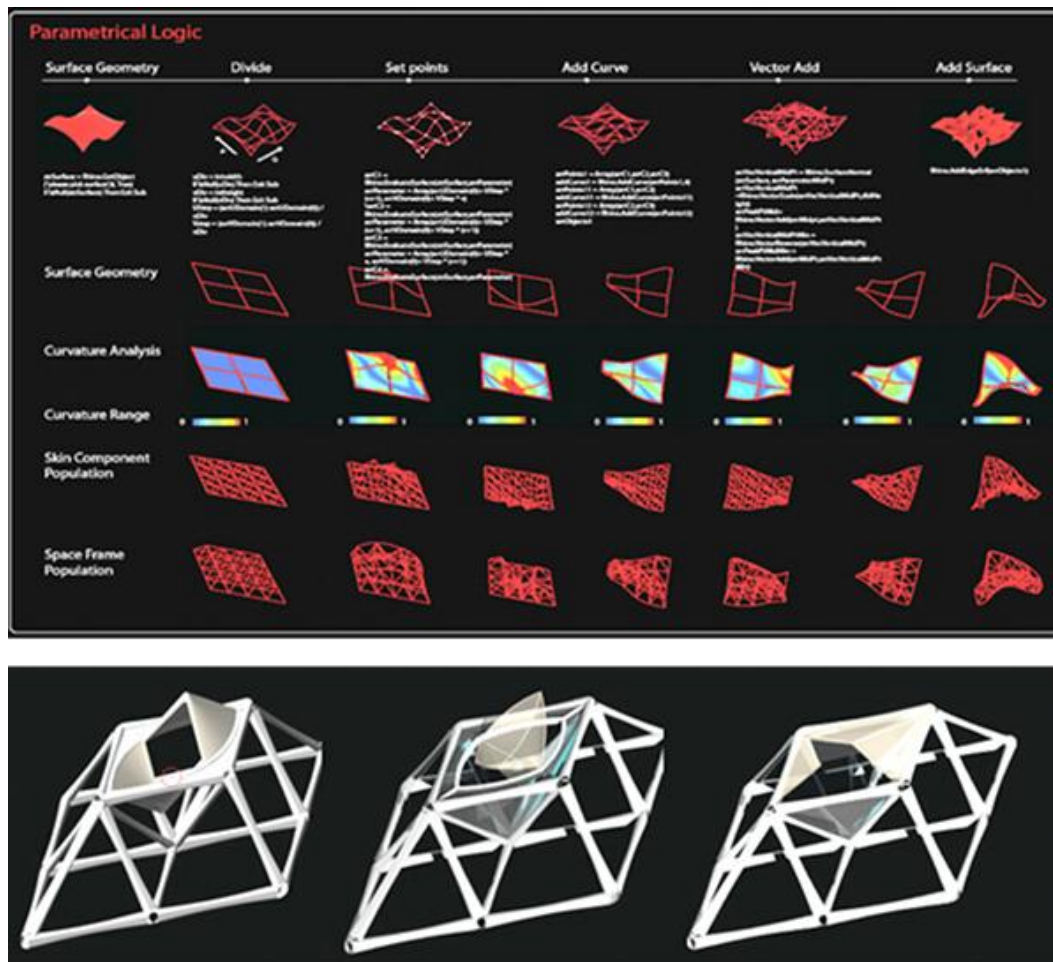
Figure 6. The water, wind and sun capturing components (below) to be embedded within the parametrically derived structural thus operating as an integrated whole (above).

2.4. Physiological adaptation via embedded Interaction design and ubiquitous communication

The digital component generation phase coupled together with varying performance based combinatorial digital population of these components went through a further iteration involving physically embedding sensors, actuators and control systems within the components for physically actualizing the proposed behavioral interaction concepts. Apart from developing elaborate information data flow sequences for the skin system, kinetic adaptations per component geared towards storing, transporting or regulating environmental factors (sun, wind and rain) were carefully choreographed using micro-controllers programmed by using MaxMSP & Jitter.

The Stomata membrane served as an excellent experiment for developing a self-sustainable performative skin system. The wind, water and light based components (shown in Figure 6) develop ubiquitous communication protocols via a carefully thought information exchange strategy: The wind based energy generating components in the Stomata membrane skin system host a rotary mechanism, which apart from being strategically positioned in accordance

with curvature variations of the surface (in order to take advantage of wind pressure) host an optical moisture detector (humidity sensor) and a light sensor. The energy resulting from the rotary motion caused by wind based current flow is harvested to power central battery units. This power is further distributed within the entire skin system for powering motors and linear actuators in all other components. The light sensor, in the form of a photo array, a CCD or a CMOS determines a value corresponding to ambient light conditions and compares this value with a pre-determined comfort level based light value per program. The comparative value is communicated to embedded micro-controllers per light controlling component (made of laminated double glass panels connected with telescopic actuators) in the entire skin, thus initiating kinetic adaptations for controlling aperture openings (Figure 7).
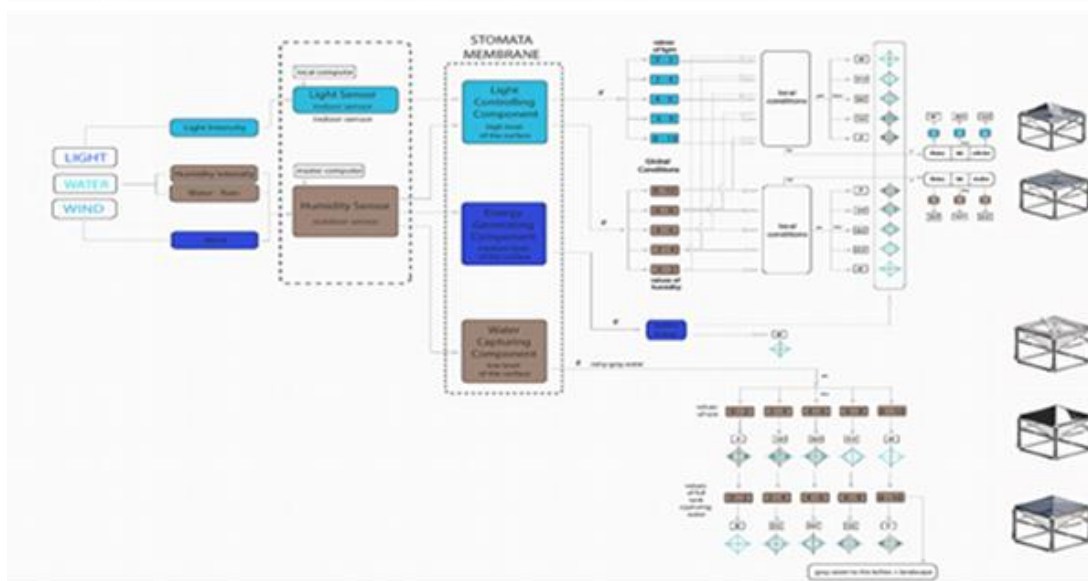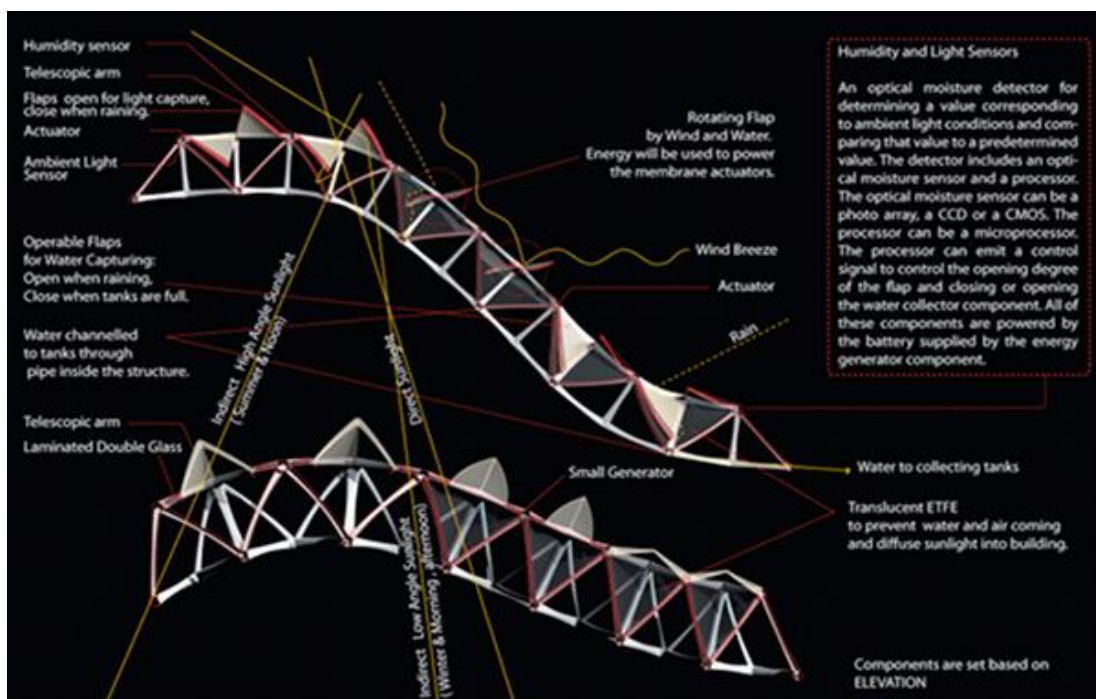

Figure 7. Prototype with embedded sensing and actuation systems being controlled in real-time.

The humidity sensors specifically relay information about the level of moisture content and the amount of water to micro-controllers in the water capturing components. This value is directly related with the amount of opening to be created in the water-capturing component (made out of Neoprene poly-chloroprene connected with telescopic actuators) in order for it to channel and store rainwater in underground tanks. This stored gray water is then used for flushing toilets, for watering plants and for washing purposes. The water capturing component's kinetic adaptations are also inversely connected with the level of water stored within the underground tanks and are therefore capable of over-riding opening instructions being relayed by the humidity sensors as and when needed (Figure 8). Apart from relaying information to water controlling components, the humidity sensor readings are also relayed to the light controlling components micro controllers. The information pertaining to rain and increased moisture when received by the micro-controllers thus result in shutting the laminated glass panels. The stomata membrane, by means of real-time information communication between its constituting components performs complex physiological adaptations in order to serve as a fully self-sustaining spatial system.
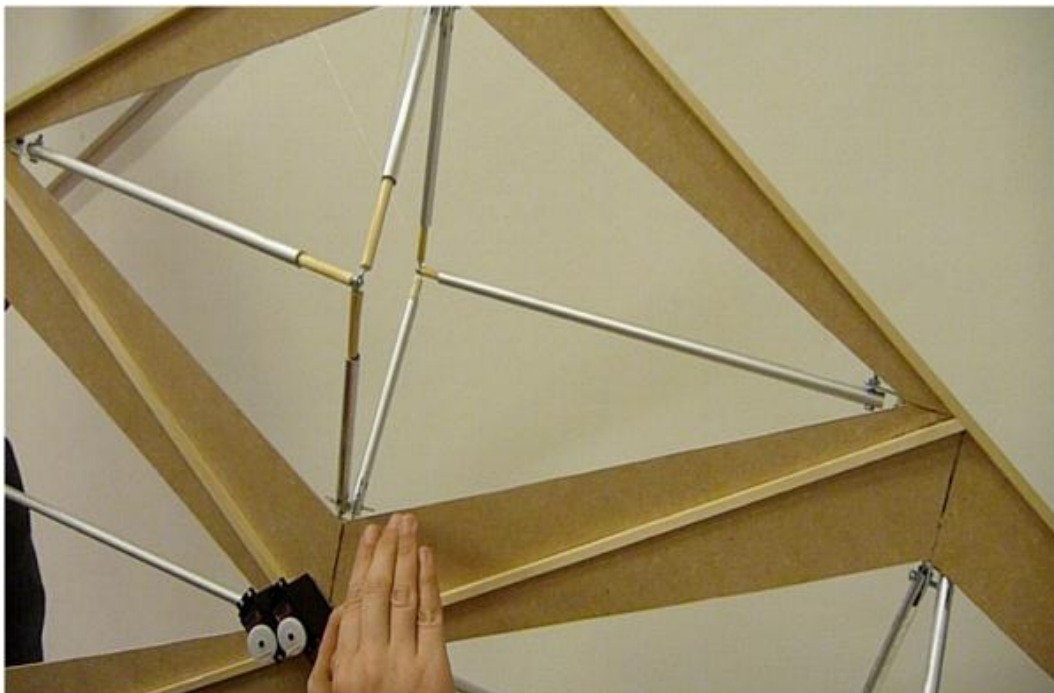

Figure 8. System architecture (below) and a three dimensional configuration of the water, wind and light modulating components (above) on a doubly curved surface.

The second category of experiment, despite of dealing with the nature of real-time information exchange, owing to scalar variation and the need for optimization as an inherent quality of the system deals with a different approach towards bottom-up design formation. The scale in this case goes beyond the component and engulfs the urban and the architectural. This also implies

a change in the nature of interaction within the formulated system as well as the nature of collaborative interaction between research and design teams.

3. Research experiment b: The Distributed Network City

This section exemplifies upon a design-research case: the development of a Distributed Network-city along the A2 highway, Netherlands at Hyperbody, Faculty of Architecture, TU Delft. Within Hyperbody, 22 students from ten different countries along with Hyperbody researchers were organized into 5 groups (5 Design firms), each working collaboratively with the other in order to produce generative urban and architectural morphologies along the A2 Highway. The visions of the governmental organizations in charge of the A2 development were abstracted as a set of global rules/constraints.

The nature of interaction for such collective-interaction in real-time required Hyperbody to develop a series of computational tools such as: a dynamic updating data-base with a corresponding data visualization and real time data manipulation web based interface, A swarm CAD tool for global and local spatial as well as programmatic layout (operating on the logics of swarm behavior), an L-Systems (Lindenmayer, 1968) based urban and architectural pattern generation tool and computational tools for generating performative structural solutions for complex geometry. The nature of tools as well as the complexity of tasks as regards multi-optimization routines for performative 2d and 3d pattern generation for this experiment was thus more complex in nature. The scale of the project demanded that the entire A2 site be divided into equal sectors per research group. The analysis per sector would thus become a local investigation and any design development process per sector shall only be approved after comparing its socio-economic impact on the entire A2 site.

3.1. Abstract machines

In the case of this experiment, the nature of the abstract machine, instead of developing notational procedures via material property based applied experiments, tended intensively towards deriving conceptual complexity via non-scalar yet logic driven systemic thinking. Deleuzian philosophy of population, intensive and topological thinking were incorporated during this first phase of analysis and interpretation of the site. Topological genetic-body plans, which could give rise to a variety of morphologies, embodying different metric structures thus became a logical underpinning for deciphering computational logistics per design team (Figure 9). Conceptual underpinnings such as dynamic networks, bundling, flow, density etc with an understanding of the urban potential were conceived as physical experiments with embodied computational potential.
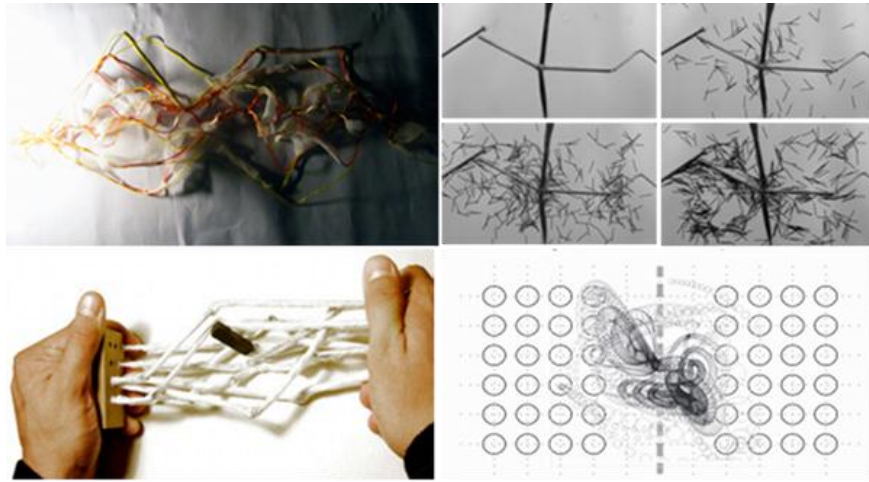
Figure 9. Abstract machines developed per design team.

3.2. Real-time Interactive program distribution database

The scale and the nature of this experiment, which demanded a careful balance between stake holder based demands and the contextual affordance per sector, thus lead to the development of an interactive computational tool termed as the A2 highway database and plot table (Figure 10). This tool is specifically built as a real-time web based updating database with a graphical interface pertaining to the program distribution over the entire site or in other words for deciphering environmental (catering to functional demands and supply ratios) developmental constraints per sector.
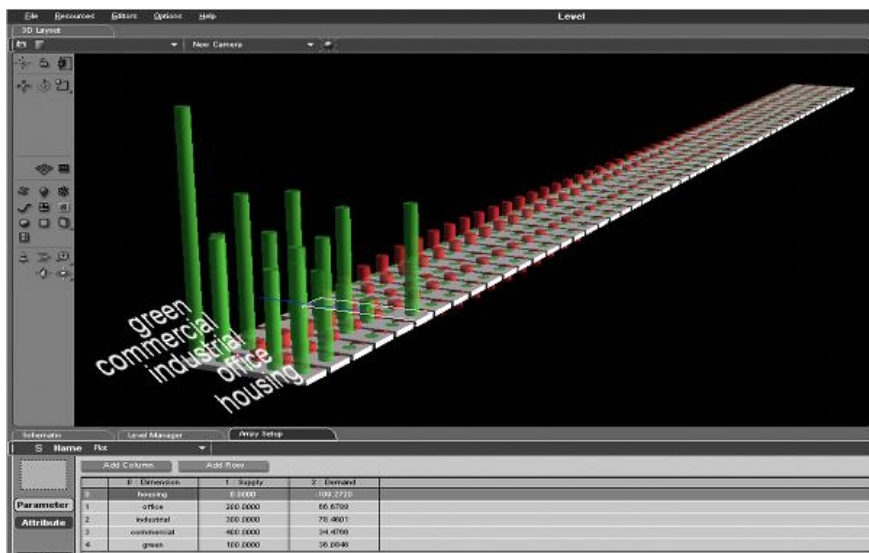

Figure 10. The A2 highway database and plot table showing the sector based distribution and the programmatic input per design team along the length of the A2 highway.

Each design team was provided with their own web based interface (of this database) pertaining to their sectors, within which they started inputting values corresponding to their

functional and envisioned demands. Global rule sets, which correlate the ratios between demanded functionalities/activities of the site (housing, commercial, industrial, office and green), are inbuilt within this A2 database tool and owing to the tools real-time updating nature, any data entered by any group has a direct impact on datasets being handled by other groups as well. The exercise in this phase for all the groups was thus visualized as collaboratively attaining a stable functional distribution (match the supply and demand ratios, indicated by green signals), and thus collaboratively setting up specific breeding environments per sector. This breeding environment can also be seen as a specific ratio outline between differential programs based agents, each embodying their own behavior as regards their relationships amongst each other as well as environmental constraints within which they are embedded. The difference between the two experiments concerning this intermediate stage of logical underpinning for program ratios in a democratic manner, involving multiple design teams is thus apparent. This intermediate stage thus lays the foundations for simulation driven design processes and is thus crucial in an iterative urban pattern generation process.

3.3. Breeding Urban morphologies using Multi-agent Swarm based computational applications

In the third phase, the above mentioned design intent oriented, mutually negotiated contextual environmental setup (per sector) is further processed locally (per group) by the application of evolutionary computational techniques (O'Reilly and Hemberg, 2007). At this stage the interlinked environmental set-ups are populated with respect to their environmental demands (program of demands or rather demanded requirements which the respective sectors should be catering to). A computational tool, namely: the A2 highway Swarm CAD (Figure 11) was introduced to the design groups at this stage.
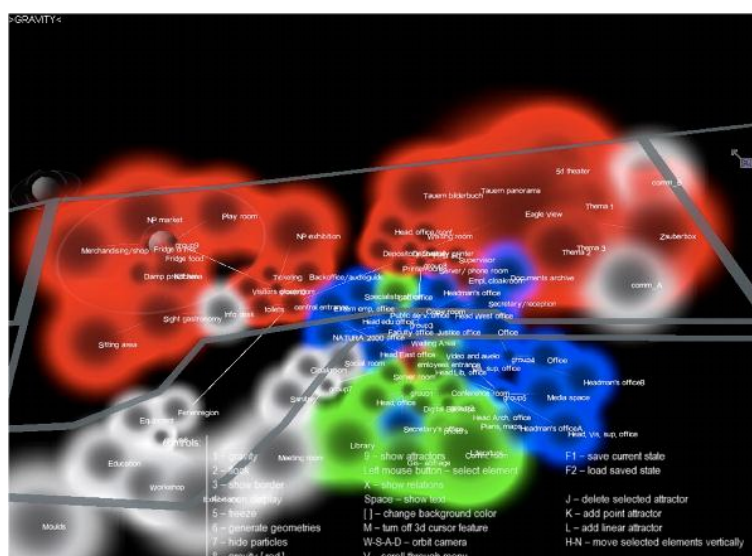

Figure 11. A2 highway Swarm CAD screen shot and its application.

Swarming, as an influential computational technique for simulating natural systems, specifically movement dynamics (as seen in a flock of birds or a school of fish) was introduced by Creg Reynolds (Reynolds, 1987). The tool developed on this understanding: SwarmCAD is based on the behavior of a group of agents that may be able to perform autonomous tasks without detailed representations of the environment and other agents, much like the manner in which simple rule sets of alignment, cohesion and separation, within Swarm systems result in complex flocking behavior. Each functional unit (housing, commercial, industrial, office and green), in this phase attains the dimension of an autonomous agent with programmed behavioral rules such as its affinity/closeness with other functions, relational ratio based multiplication per agent, volumetric data etc. Dependent upon such programmed behavioral modules, interaction routines are automated for attaining meaningful and logically structured urban morphologies. Urban patterns can thus be seen as self organizing systems with its constituent components akin to members of an organic swarm, working constantly to generate activity, usability, occupational and territorial patterns (Figure 12).
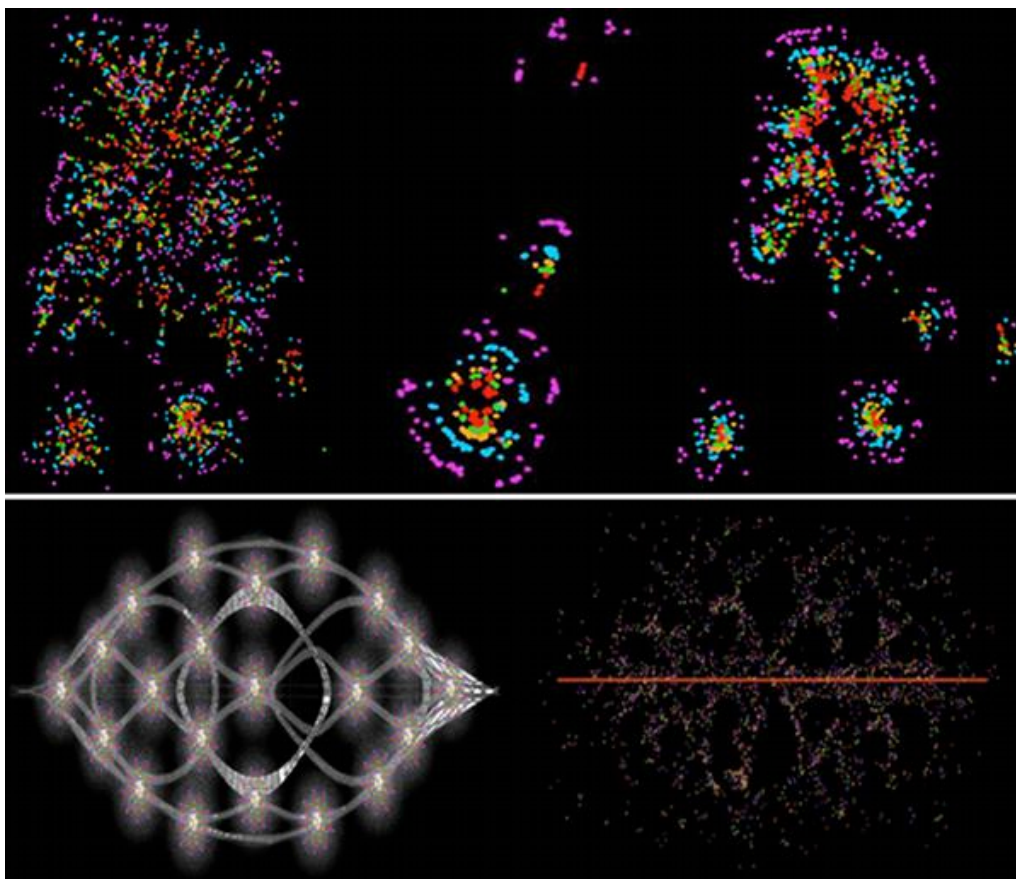

Figure 12. Iterative swarming gene pools leading to the generation of urban systems in iterative time steps, thus leading to hints of infrastructural patterns as a resultant of the emergent function agent organizations.

The aforementioned SwarmCAD based self-organization routines, provided a two-dimensional output as regards the optimal programmatic stagnation zones as an outcome of the multi-agent simulation. On top of this layer, though, a second layer of optimization sequences, which

specifically dealt with criteria such as branching systems driven optimized path formations within the derived pattern were induced. For this purpose, L-Systems combined with Turtle graphics interpretations were experimented with. A combinatorial approach for experimenting with the co-evolutionary generation of two L-systems respectively: one for the design of the existing highway itself and one for the residential city, characterized by residential and commercial units. Inter-dependency between the two L-systems was set up for facilitating an iterative growth of the residential city in relation with the generated boundary conditions of the highway based L-system (Figure 13). A highly interdependent mutually interactive L-system structure, giving rise to urban morphologies is thus visualized.
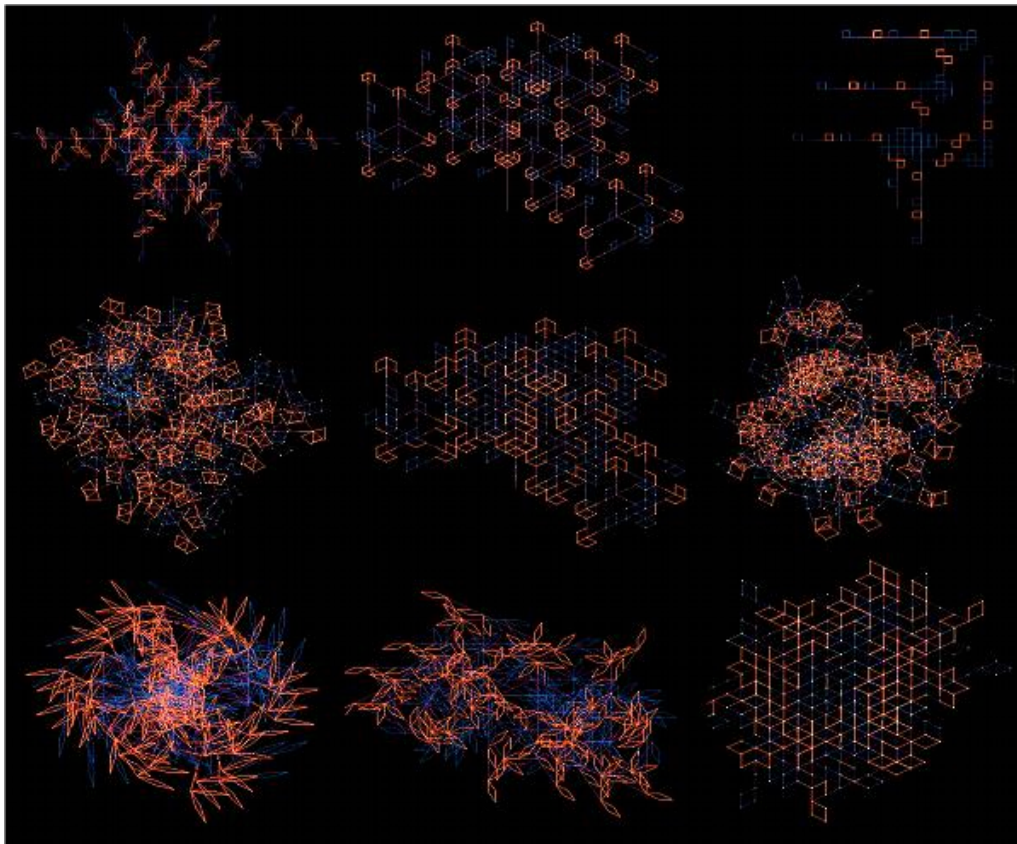

Figure 13. L-system based urban infrastructure configurations with integrated turtle graphics based architectural growth variants.

3.4. Architectural interventions within the urban morphologies

After arriving at urban morphological patterns, as mediation between the dual L-System interactions coupled with Turtle graphics to develop 2d and 3d extrapolations of functional layouts, the design groups focused on architectural and structural issues pertaining to specific portions per sector. Infrastructural spines (global level) derived from the L-system procedures were treated as structural entities interweaving and stabilizing the architectural patterns (local level) they would host within them. The local level computational outputs, which were inherently based on the percentage of built-up area and the affordance per-sector concerning

height regulations set forth by the governmental agencies, are subsequently subjected to morphological fine-tuning and individual articulation, while developing a connective infrastructural and functional logic in the whole site. Design language and individual stylization strategies were thus made prominent at this phase of the design iteration.

Computer aided manufacturing processes for physical modeling and in some cases structurally analyzing the architectural morphologies were subsequently carried out. The morphogenomic architectural outputs (Figure14), in terms of characteristic features per sector were either CNC milled or were stereo lithographed per group. The students were thus not only able to compare the morphological variations per sector but were also able to understand the vitality of the informatics component as regards file to factory-based manufacturing processes and the advantages of working in an integrated design framework involving multiple teams.
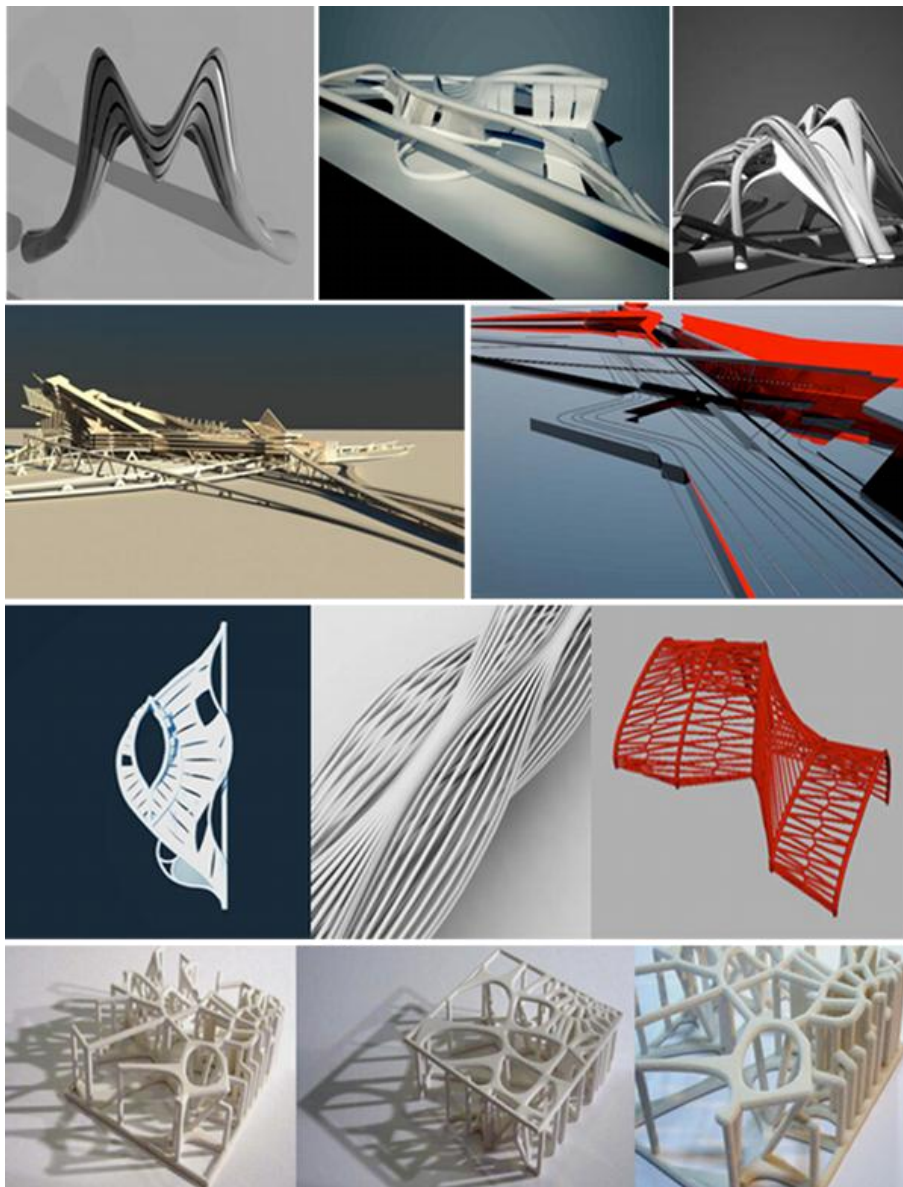

Figure 14. Resultant CAD CAM based architectural interventions displaying the integration of urban infrastructure as structural features.

4. Conclusion

The Performative skin systems and the Distributed City research initiatives proved to be a critical exercise in collaboratively understanding the implications (generation, representation, communication and processing) of compounding the term informatics with the discipline of design. The differences in computational operations based on scalar variations per experiment were evident. The nature of the abstract machine, in the case of the skin components was specifically designed to derive notational sequences owing to the material properties based digital data extraction procedure as opposed to the A2 Highway project in which the main focus revolved around deriving a global computational strategy such as bundling, flows etc as inspirational yet rational underpinnings for each design group. The computational tools developed for optimization purposes per experiment also differ considering the nature of optimization. The Performative Skins research based optimization primarily focused on articulating real-time kinetic adaptations of the entire system (global) from a bottom-up per component level (local level), as opposed to the A2 Highway project, which owing to its scale and the nature of problem at hand works with a dual level optimization with L-systems and turtle graphics in order to sequentially break-down the issues of infrastructural weaving with nested functional agents.

The computational tools developed during the two projects, also exhibit different properties ranging from embedded electronics driven mechanical control to collaborative design and decision-making support systems. The informatics components and the computational procedures, which bind them, thus result in differential morphologies, each serving a performative cause. The domain of digitally driven design processes through these Morphogenomics based experiments not only lay a logical underpinning for generating non-standard bottom-up contextually interactive morphologies but also demonstrate how associative design techniques coupled together with electronic media, control systems and participatory design strategies can help enhance the conception, performance and outlook of our built forms at multiple scales.

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