Morphogenomic Urban and Architectural Systems

An Investigation into Informatics Oriented Evolution of Form: The Case of the A2 Highway

Computation

Evolution

Flocking

Information

Morphogenesis

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THIS RESEARCH PAPER EXEMPLIFIES UPON A NOVEL INFORMATION INTEGRATED GENERATIVE DESIGN METHOD: MORPHOGENOMICS, BEING EXPERIMENTED WITH AT HYPERBODY, TU DELFT. Morphogenomics, a relatively new research area, which deals with the intricacies of morphological informatics. This paper furthermore discusses an ongoing Morphogenmoics oriented design-research case: the development of a Distributed Network-city along the A2 highway, Netherlands. The A2 highway, development is a live project seeking urban development on either side of this busy highway. Hyperbody, during the course of this research initiative developed a series of real-time interactive computational tools focusing upon the collaborative contextual generation of a performative urban and architectural morphology for the A2 highway. This research paper elaborates upon these computational techniques based Morphogenomic approach and its resultant outcomes.

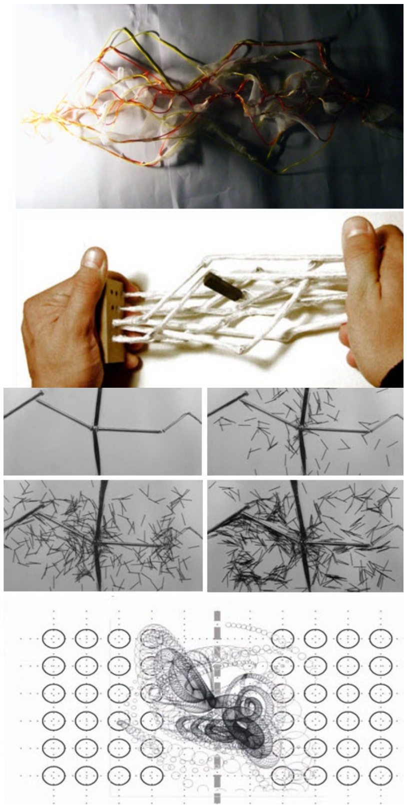


FIGURE 1. ABSTRACT MACHINES DEVELOPED PER DESIGN TEAM

1 Introduction

Morphogenomics, a relatively new research area, deals with 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 communicative process thus serves as a dynamic medium for mapping the morphological genome onto architectural space and structure. Such an informatics based network of information serves as a determining factor for deciphering architectural nomenclature, while allowing digital manipulation of form in the design process, and enabling mass-customization in digital manufacturing.

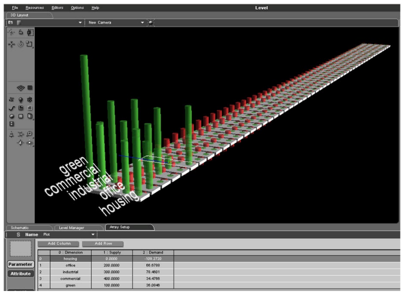
This paper, in line with the afore-mentioned research strand of Morphogenomics exemplifies upon an ongoing design-research case: the development of a Distributed Network-city along the A2 highway, Netherlands at Hyperbody, Faculty of Architecture, TU Delft. Within Hyperbody, 22 students from ten different 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 within which the Hyperbody based five design firms creatively operate.

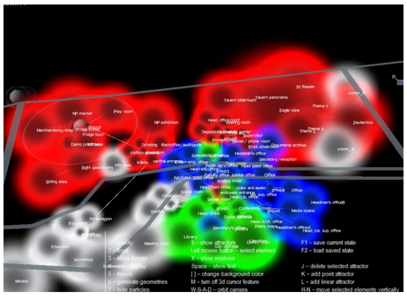
In order to aid this intensive collaborative design-research effort Hyperbody developed a series of computational tools for simulating real-time interactive behavior such as: a dynamic updating data-base with a corresponding data visualization and real time data manipulation web based interface, A swarm CAD tool for global and local spatial as well as programmatic layout (operating on the logics of swarm behavior), an L-Systems based urban and architectural pattern generation tool and computational tools for generating performative structural solutions for complex geometry. Information pertaining to each of the five design groups, collaborative decisions pertaining to breeding programmatic variants along the A2 highway, and the Morphogenomic process behind the translation of abstract thought/mechanisms into computationally enriched urban and architectural morphologies with the help of the aforementioned tools will thus form the crux of this research paper.

2 Background research

Contemporary research investigations into evolutionary and developmental biology have revealed intricate data as regards issues of adaptation, efficiency and robustness as well as the phenomena of redundancy and differentiation via which natural living systems acquire competitive performance. Specific fields of interest such as Biomimetics which delve into understanding such natural mechanisms and the application of the extrapolated knowledge into constructing performative structures have since been at the heart of contemporary architectural and engineering research. Tools and methodologies in the computational domain pertaining to the understanding and simulation of such diverse natural growth, development and hybridization processes have been extremely efficient in forming the backbone for our understanding of such dynamic phenomena. Genetic Algorithms (GA) are probably the best known example of such computational processes (Van de Zee and de Vries, 2002) explained.

Hyperbody through its own initiative of understanding the informatics oriented behaviour of natural systems has been experimenting with computational techniques such as real-time multi-agent interaction, complex systems and swarm simulations over the past six years. L-systems another computational technique were first used to model the growth processes of plants (Lindenmayer, 1968), but were then applied to describe the morphology of a variety of patterns including urban and building designs (Hart, 1992). These have also been extensively experimented with in the course of our Morphogenomic research and design initiative.





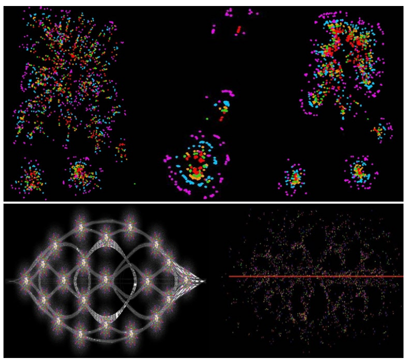


FIGURE 2. THE A2 HIGHWAY DATABASE AND PLOT TABLE SHOWING THE SECTOR BASED DISTRIBUTION AND THE PROGRAMMATIC INPUT PER DESIGN TEAM ALONG THE LENGTH OF THE A2 HIGHWAY.

FIGURE 3. A2 HIGHWAY SWARM CAD SCREEN SHOT AND ITS APPLICATION

FIGURE 4. ITERATIVE SWARMING GENE POOLS LEADING TO THE GENERATION OF URBAN SYSTEMS

3 The Morphogenomic process

3.1 ABSTRACT MACHINES

Parallel to this computational view of understanding natural dynamics, issues pertaining to philosophy and theory, specifically the understanding of Deleuzian notions of population, intensive and topological thinking were incorporated during the first phase of analysis and interpretation of the site (A2 Highway) and the designer's intent.

The notion of an abstract machine (Figure 1) defined by Deleuze as abstract, singular, creative, real, non-concrete, actual, non-effectuated consolidated aggregate of "matters-functions" served as an effective mode of communicating each of the five design team's psychological intent and aspirations. The creation of topological genetic-body plans (essentially non-metric), 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.

3.2 REAL-TIME INTERACTIVE PROGRAM DISTRIBUTION DATABASE

The second phase in order to add a realistic dimension as regards thinking in terms of development affordances and design constraints per sector, led to the development of an interactive computational tool termed as the A2 highway database and plot table (Figure 2). This tool is specifically built as a real-time updating database pertaining to the program distribution over the entire site or in other words for deciphering environmental (catering to functional demands and supply ratios) constraints per sector.

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. However, one crucial feature of this tool was the inter-dependent and thus relational linkage between the data-sets entered per design team. The notion of collective/collaborative functional program development was thus embedded within the interactive simplicity of the tools operation.

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.

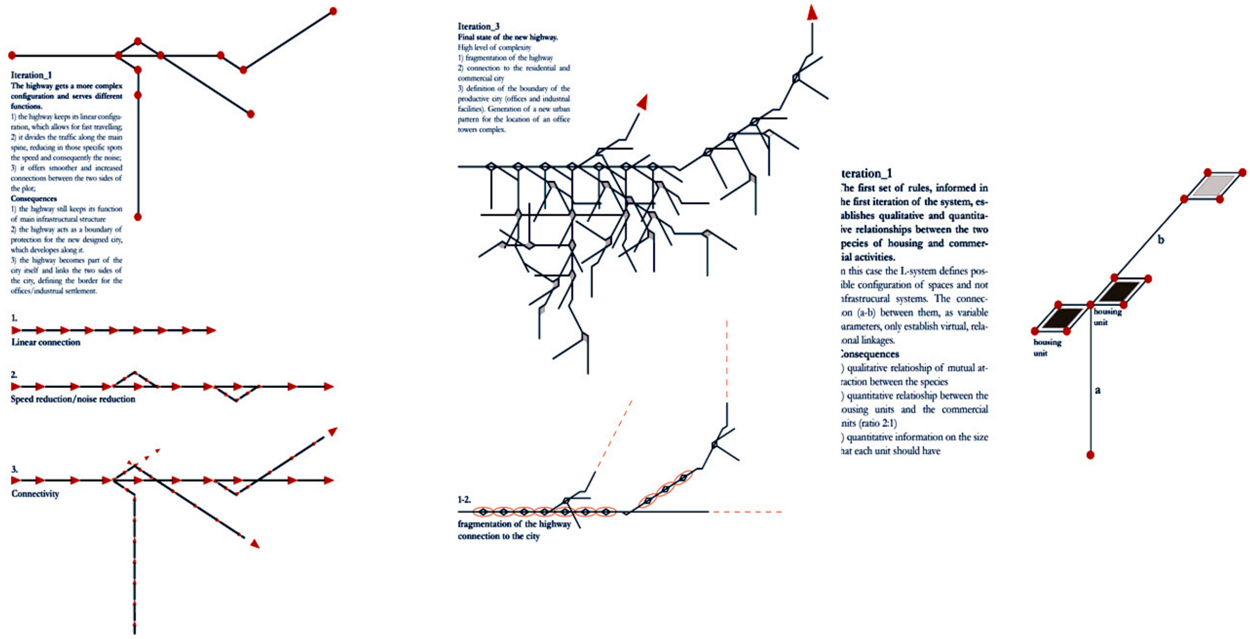
The exercise in this phase for all the groups was thus visualized as collaboratively attaining a stable functional distribution (match the supply and demand ratios, indicated by green signals), and thus collaboratively setting up specific breeding environments per sector.

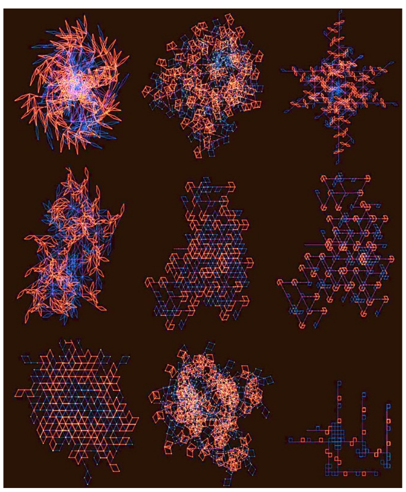
3.3 BREEDING URBAN MORPHOLOGIES USING MULTI-AGENT SWARM BASED COMPUTATIONAL APPLICATIONS

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. 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 3) was introduced to the design groups at this stage.

This tool and its principle: the behavior of a group of agents that may be able to perform tasks without detailed representations of the environment and other agents was successively used for generating a variety of clustering and self organizing patterns. Each functional unit (housing, commercial, industrial, office and green), in this phase attains the dimension of an 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. An example of the resultant output (Figure 04) of this principle exemplifies how this process enabled a design team to develop emergent





urban patterns while providing them with computational logistics to defend these ecologies of mutually interlinked species (functional variants).

3.4 GENERATING URBAN MORPHOLOGIES USING L-SYSTEMS AND TURTLE GRAPHICS

Apart from the above mentioned Swarm and Multi-agent systems based applications, L-Systems combined with Turtle graphics interpretations were also effectively experimented with during the third phase of the Morphogenomic process. A combinatorial approach for experimenting with the co-evolutionary generation of two L-systems respectively: one for the design of the 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 5).

The highway based L-system performs two operations: firstly, creating a clear bifurcation of the highway into the surrounding landscape, thus strongly establishing a set of transversal connections between the highway and its surroundings and secondly, fragmentation of the highway for solving noise related issues along the highway stretch. The principal branch thus confirms the linearity of the highway and allows for fast travelling, while the secondary branches reconnect the landscape and aid in the reduction of speed-noise generated by the cars. The fragmentation process which switches the main route of the highway into multiple paths thus provides a system of transversal connections between either sides of the highway, enabling it to become an integral part of the urban tissue.

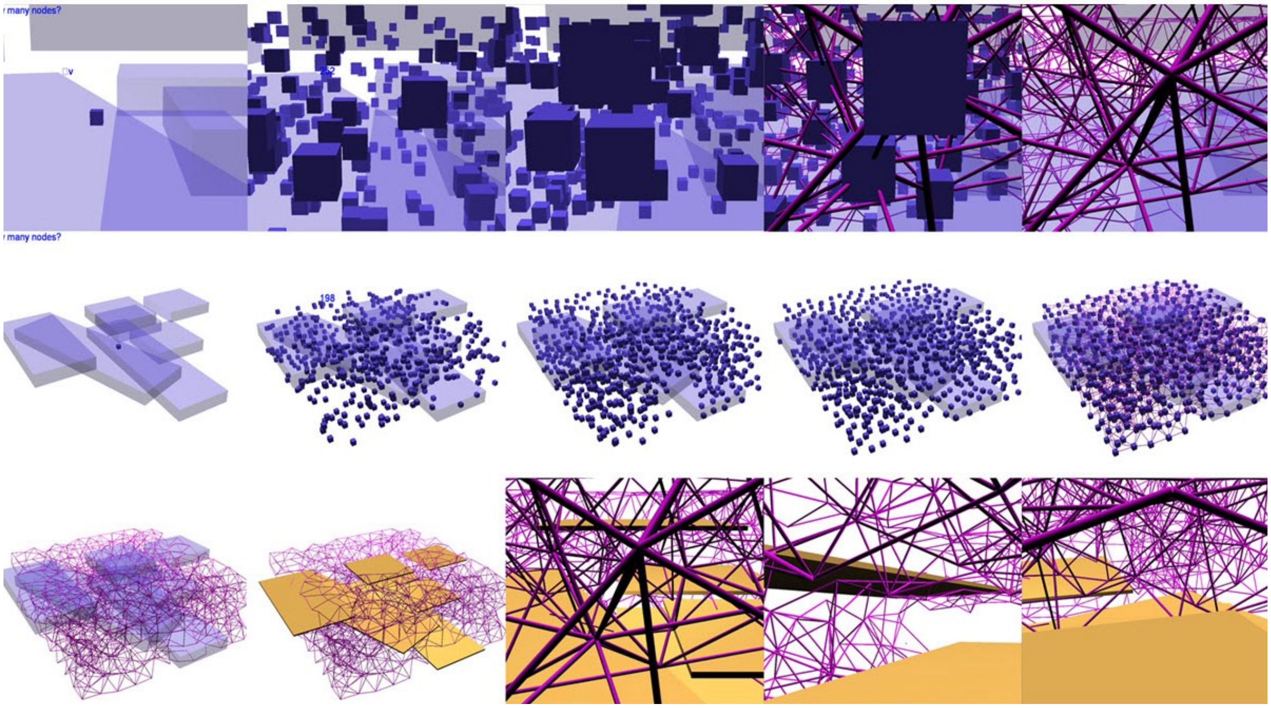
Operating upon this branched fragmented L-system, the residential L-system, in the first operation, establishes qualitative and quantitative relationships between these branching patterns and breeds surfaces from the intersections of these differential branching line networks. The meaning associated with the network of lines in the highway based iterations eventually transcends its initial association linked with representational infrastructural systems, to virtual, relational linkages between the different programs. At a second stage, parametric relations are established amongst the derived elements (surfaces) for the generation of urban patterns of different functional species (Figure 6). A highly interdependent mutually interactive L-system structure giving rise to urban morphologies is thus visualized.

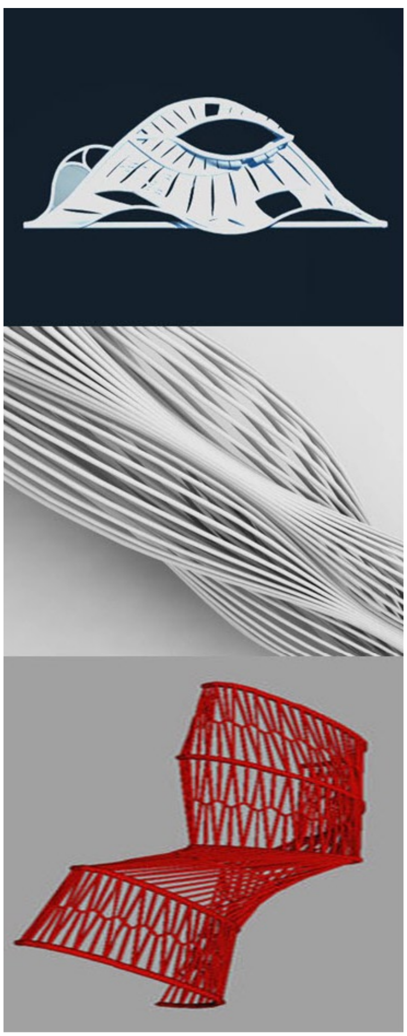
FIGURE 5. L-SYSTEM BASED HIGHWAY AND HOUSING INTERDEPENDENCY

FIGURE 6. L-SYSTEM BASED URBAN CITY CONFIGURATIONS VARIANTS

4 Architectural interventions within the urban morphologies

After arriving at urban morphological patterns, the design groups focused on architectural





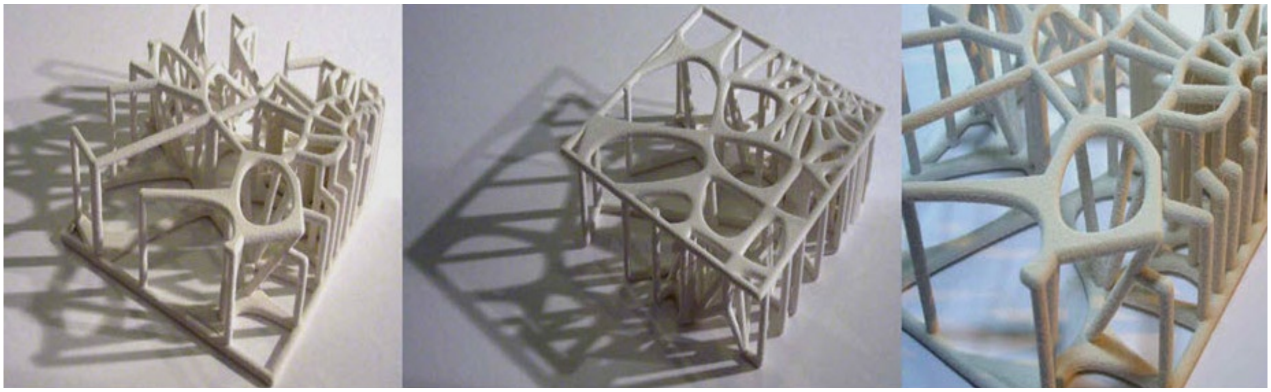
and structural issues pertaining to a chosen portion per sector. These local level interventions thus lead to morphological fine tuning leaving one with a set of abstract voluminous architectural entities while developing a connective infrastructural and functional logic in the whole site. Once a mutually agreeable solution (amongst the design groups) was arrived at, each designer started to articulate/model a series of these abstract architectural bodies crucial for elaborating upon their design language. The students were provided with a set of computational tools for translating these volumes to a 3d point cloud and swarm based morphology (Figure 7). This morphology is also meant to provide the students with clues pertaining to the structural morphology of the designed/evolved spaces.

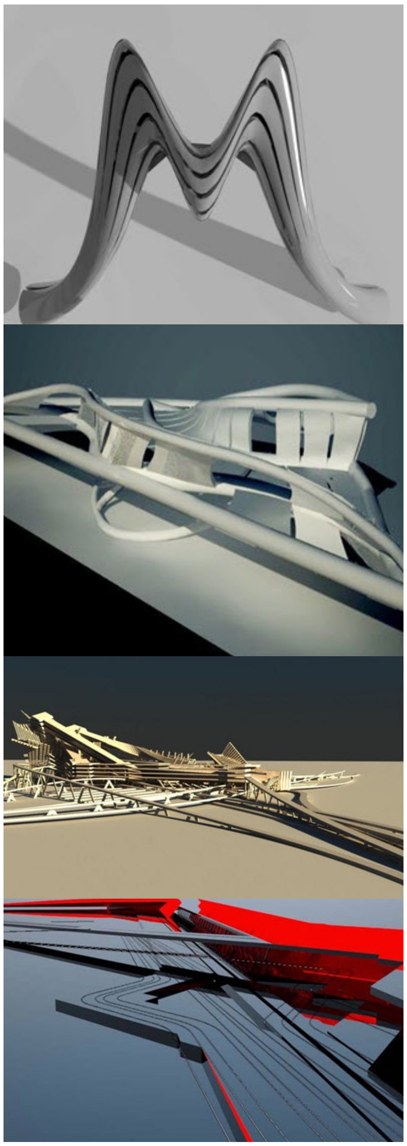
Computer aided manufacturing processes for physical modeling and analyses of the urban morphologies were subsequently carried out. The morphogenomic urban output in terms of patterns per sector were either CNC milled or were stereolithographed per group and were assembled together to understand how the entire urban fabric operates. 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 in this file to factory based approach. Experiments with colored as well as mono-chrome rapid prototyping also formed an essential part of the exercise (Figure 8). The limitations and affordances of different manufacturing processes also allowed the design groups to re-appropriate their design outputs (form finding process) for efficient selection of the appropriate production technique.

5 Conclusion

This Morphogenomics research and design project 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 emergent generation of data driven urban and architectural morphologies (Figure 9), inherently interlinked with their contextual settings formulated the crux of this design-informatics oriented initiative.

The computational tools developed during this process provided one with the opportunity to efficiently connect and alter the project database as well as to precisely communicate three dimensional data to appropriate manufacturing tools. A critical level of understanding as regards the inter-linkage of philosophical, socio-cultural and computational





thinking as a driving force behind the generation of meaningful morphologies was thus brought forth through this exercise.

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7 References

Broughton, T., P. Coates and H. Jackson. (1999). Exploring 3D design worlds using lindenmayer systems and genetic programming. In Bentley, P.J. (ed.) *Evolutionary Design by Computers*, chapter 14. Morgan Kaufmann.

Burry, M. (2003). Parametric Design, Associative Geometry. In *Blurring the Lines*. London: John Wiley & Sons.

Coello Coello, C.A., D.A. Van Veldhuizen and G.B. Lamont. (2002). *Evolutionary algorithms for solving multi-objective problems*. New York: Kluwer Academic.

Coenders, J. Bosia, D. (2006). Computational Tools for Design and Engineering of Complex Geometrical Structural. In *GamesSetAndMatch II*, ed. Kas Oosterhuis and Lucas Feireiss, Rotterdam: Episode publishers.

Frazer, Frazer, Xiyu, Mingxi, Janssen (2002). Generative and Evolutionary Techniques for Building Envelope Design. In *Proceedings of the 5th International Conference on Generative Art 2002*.

Gurer, E. and Cagdas, G. (2006). A Multi-Level Fusion of Evolutionary Design Processes, In *Proceedings of the eCAADe 2006 Conference: Communicating Space(s)*, Ed: V. Bourdakis, D. Charitos, University of Thessaly, Volos, Greece, September 6-9, 2006, pp. 904-907.

Hensel & Menges. (2006). Differentiation and Performance: Multi-Performance Architectures and Modulated Environments. In *Architectural Design AD* . 76 (3), 60-69. London: John Wiley & Sons

Janssen, P.; Frazer, J. and Tang, M. X. (2005): Generative evolutionary design: A framework for generating and evolving three-dimensional building models. In *Innovation in Architecture, Engineering and Construction* Volume1, ed. S. Sariyildiz and B. Tunçer 35-44. Rotterdam: Delft University of Technology Chair Technical Design & Informatics, The Netherlands.

Johnson, S. (2001). *Emergence, the Connected Lives of Ants, Brains, Cities and Software*. London: Penguin Press.

Lindenmayer, A. (1968). Mathematical models for cellular interactions in development i & ii. In Journal of Theoretical Biology. Elsevier

Oosterhuis, K. (2006). Swarm Architecture II. In *GamesSetAndMatch II*, ed. Kas Oosterhuis and Lucas Feireiss, Rotterdam 14-28. Rotterdam: Episode publishers.

O'Reilly, U..-M. and M. Hemberg (2007). Integrating generative growth and evolutionary computation for form exploration. In *Genetic Programming and Evolvable Machines* Volume 8, Issue 2 (June 2007) 163-186. Netherlands: Springer

Rosenman, M.A. (2000). Case-based Evolutionary Design. In *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, 14, 17-29. Cambridge University Press.

Sass, L. and Botha, M. (2006). The Instant House:A Model of Design Production with Digital Fabrication. In *International Journal of Architectural Computing*. Issue 4, volume 4, pp. 109-123. Multi science

FIGURE 7. (OPPOSITE TOP) 3D POINT CLOUD GENERATION AND STRUCTURAL MORPHOLOGY ESTIMATION TOOL.

FIGURE 8. (OPPOSITE LEFT & TOP) RESULTANT CAM MODELS

FIGURE 9. (ABOVE LEFT)THE RESULTANT COMPUTER MANUFACTURED ARCHITECTURAL INTERVENTIONS