

Data-Driven Architectural Design to Production and Operation

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Abstract: Data-driven architectural production and operation explored within Hyperbody rely heavily on system thinking implying that all parts of a system are to be understood in relation to each other. These relations are established bi-directionally so that data-driven architecture is not only produced (designed and fabricated) by digital means but also incorporates digital, sensing-actuating mechanisms that enable real-time interaction between (natural or artificial) environments and users. Data-driven architectural production and operation exploit, in this context, the generative potential of process-oriented approaches wherein interactions between (human and non-human) agents and their (virtual and physical) environments have emergent properties that enable proliferation of hybrid architectural systems and ecologies.

Keywords: Data-driven Design, Generative Systems, Design Information Modeling, and Emergent Design Processes

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1 Introduction

In contrast to mechanical reproduction¹ contemporary digital production implies inter al. that the work of art and architecture become digital addressing, therefore, principles² such as data-driven representation, generation, production, and operation. Thus, as more recently convincingly argued by Carpo³, the historical understanding of buildings as physically built identical replicas of architectural intent (formalized in design) which eventually in the 20th century became serially, mass produced identical copies, is challenged by the contemporary data-driven parametric multiplicity and variation. Such multiplicity and variation allowing versions of architectural intent to be virtually or physically implemented and experienced through inter al. spatial reconfiguration has been explored within Hyperbody (fig. 1) with the understanding that multiple versions of the built space may be achieved through kinetic transformation.

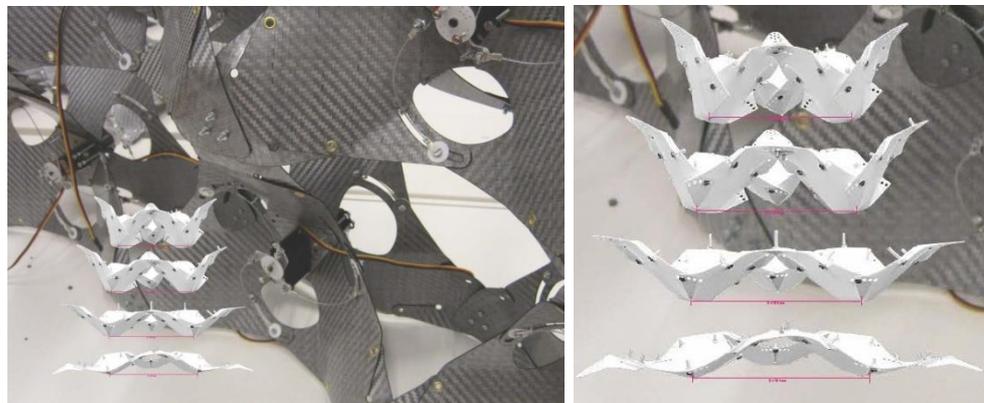


Figure 1: Physical change and variation explored within Hyperbody (2010)

Furthermore, experimentation with parametric multiplicity and variation has been addressed with focus on generative design and data-driven production, which were explored to critically reveal what these techniques may offer architectural production as well as outline what challenges remain in their application. The relationship between generative processes and data-driven production has been focus of current architectural research and practice largely due to the phenomenon of emergence explored inter al. within self-organization, which is defined as a process, in which the organization of a system emerges bottom-up⁴ from the interaction of its components. Self-organizing swarms⁵ for instance, are employed in generative design processes, which deal with ample amounts of data featuring sometime conflicting attributes and characteristics. Those attributes and characteristics are incorporated in behaviors according to which design components such as programmatic units swarm towards locally optimal spatial configurations⁶. In this context, architectural design becomes procedural instead of object-oriented and architectural form emerges in a process in which the interaction between all parts of the system generate the result. Thus, the architect becomes the designer of the process and only indirectly of the result.

1 W. Benjamin, *The Work Of Art In The Age Of Mechanical Reproduction*.

2 L. Manovich, *The Language of New Media*. Cambridge: MIT Press.

3 M. Carpo, *The Alphabet and the Algorithm*. Cambridge: MIT Press.

4 M. De Landa, *Deleuze and the Use of the Genetic Algorithm in Architecture*, Rahim, A. (ed.), *Architectural Design - Contemporary Techniques in Architecture*, Academy Press.

5 H. Bier, *Building Relations*, ed. by Bekkering (Rotterdam; Architectural Annual 2005-06: 010-Publishers), pp. 64-67.

6 H. Bier and T. Knight, *Digitally-driven Architecture* in H. Bier and T. Knight (eds.) 6th Footprint, Delft.

2 Discussion

Self-organizing swarms operate as multi-agent systems⁷ consisting of simple agents that interact locally with one another and their environment based on simple rules leading to the emergence of complex, global behavior. Their use in design is of relevance because of their ability to embody both natural (human) and artificial (design related) aspects. Swarms are, basically, set up as parametric models incorporating characteristics and behaviors representing the natural and artificial systems themselves, whereas simulations of behaviors⁸ show operation of such systems in time.

Intelligent (artificial) agents are conceived (in computer science) similarly to natural agents as autonomous entities able to perceive through sensors and act upon an environment using actuators. Interactions between human and artificial agents may follow principles as described in the Actor–Network Theory (ANT) implying that material–semiotic networks are acting as a whole whereas the clusters of actors or agents involved in creating meaning are both material and semiotic. ANT, therefore, implies agency of both humans and non-humans, whereas agency is not located in one or the other, but in the heterogeneous associations between them.

SUN SIMULATION

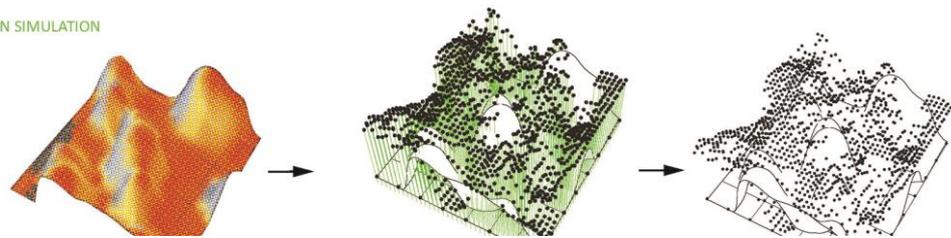


Figure 2: Generative design explorations developed with MSc 3 students (2013) by informing the point cloud with multiple simulations (in this case solar radiation for different seasons)

Such heterogeneous generative processes implemented in simulations are discussed by De Landa⁹ in relation to his interpretation of Deleuze's idea on matter and form implying that form emerges from within matter itself, hence philosophy of immanence (not transcendence) in which matter itself has the capacity to generate form through immanent, material, morphogenetic processes. Simulations based on generative systems such as shape grammars, cellular automata, multi-agent systems, etc. are defined, in this context, as forms of knowledge visualization and means to generate designs from simple rules and local interactions. In order to be able to incorporate such simulations into the design process, comprehensive specification of operation rules of respective systems in relation to the corresponding design to production and operation process is required. This is in addition to or instead of defining the geometric and physical constraints, which are obvious parts of conventional parametric approaches.

Simulations in relationship to architecture have been explored within the Hyperbody design studios with respect to their ability to support the generative development of architectural production: Data-driven production processes and their intrinsic connection to physical, mathematical, biological, etc. sciences increasingly enable architecture to surpass mere

7 Ibid.

8 M. De Landa, *ibid.*

9 M. De Landa, *Philosophy and Simulation: The Emergence of Synthetic Reason*, Continuum Publishing Corporation.

technological application in order to address, as argued by De Landa, system, population and topological thinking. While, system thinking implies that all parts of a system are to be understood in relation to each other¹⁰, population¹¹ replaces typological thinking as it rejects the focus on representative types in order to emphasize individual variation, and topology¹² studies space and transformation.

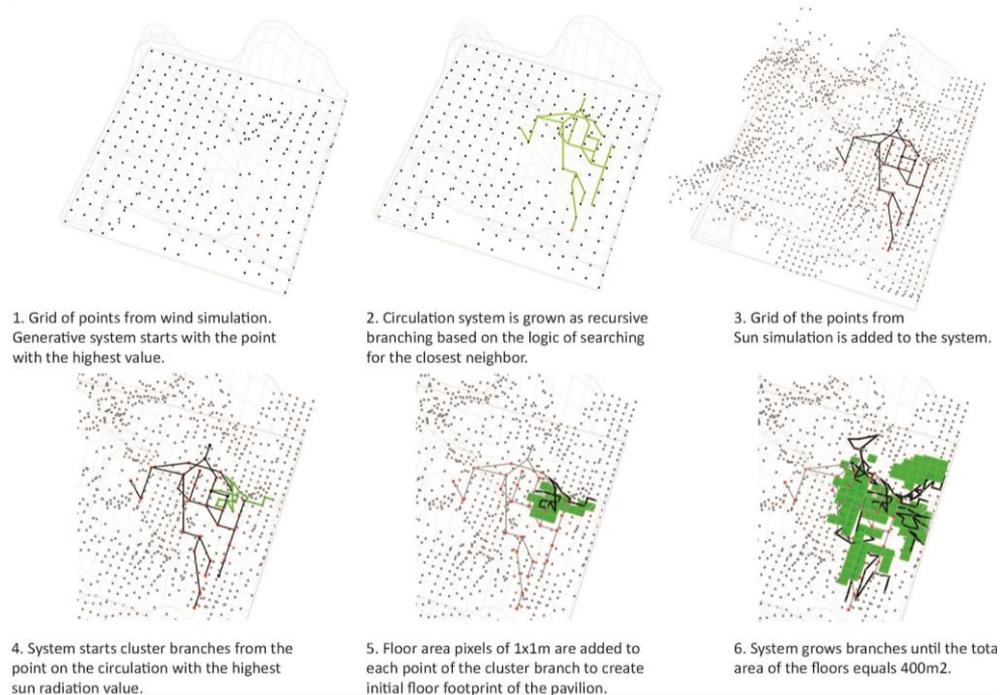


Figure 3: Diagrammatic snapshots illustrating generative systems within the informed point cloud (2013)

In this context, the architect employs artificial agents that produce populations of architectural artifacts, all different in size, shape, and behavior. Thus architectural production becomes the result of multiple interacting natural (human) and artificial agents. Such agent-based processes imply that same or similar (virtual and physical) agent systems may produce under similar conditions multiple (or endless) variations of architectural artifacts due to the emergent properties of the system.

Such emergent design processes have been focus of design experimentation at Hyperbody with the aim to develop generative systems and incorporate them in performance-driven design processes. These processes address two main aspects: First, generative systems are based on and derived from different types of complex systems¹³ and second, chained algorithms can ease the processes of design information exchange¹⁴ between different stages of parameterization, generation and simulation for performance measurement and evaluation. Different types of complex system are explored and customized based on distinct design objectives and requirements taken for each of the projects into consideration. In other words, generative systems are defined as design mechanisms in which both synthesis and analysis sub-routines are embedded and applied for a multidisciplinary performance-driven design. With this target, for the first step, initial studies were conducted ex-

10 B. Wilson, *Systems - Concepts, Methodologies and Applications*, 2nd ed., Wiley.

11 E. Mayr, E.: *Darwin's Influence on Modern Thought*, 1999 (retrieved 18-02-2013 from http://www.biologie.uni-hamburg.de/b-online/e36_2/darwin_influence.htm)

12 W. Sierpinski, *General Topology*, Dover Publications.

13 J. Holland, *Studying Complex Adaptive Systems*, *Jnl Syst Sci & Complexity* 19: 1-8.

14 S. Mostafavi, *Performance Driven Design and Design Information Exchange*. *Computation and Performance*, Faculty of Architecture, Delft University of Technology, Delft: eCAADe

ploring different complex systems¹⁵ such as fractals, cellular automata, recursive, agent-based, and L-systems. By analyzing the behavior of each of these systems and consequently define their operating rules on one hand the design teams were able to control the bottom-up emergence processes of complex systems and on the other hand they were able to change the behavior of these systems by introducing more conditional or if-then structures in the scripts.

One project is representative and as it aims to integrate the data gathered from the site analysis (such as sun and wind) from macro to micro scale in order to generate the design of a pavilion with emphasis on ecological and environmental aspects. At detail level, the focus was to achieve material and resource efficient design solutions by integrating environmental and structural simulations in chained sets of algorithms as to establish a holistic computational design system.

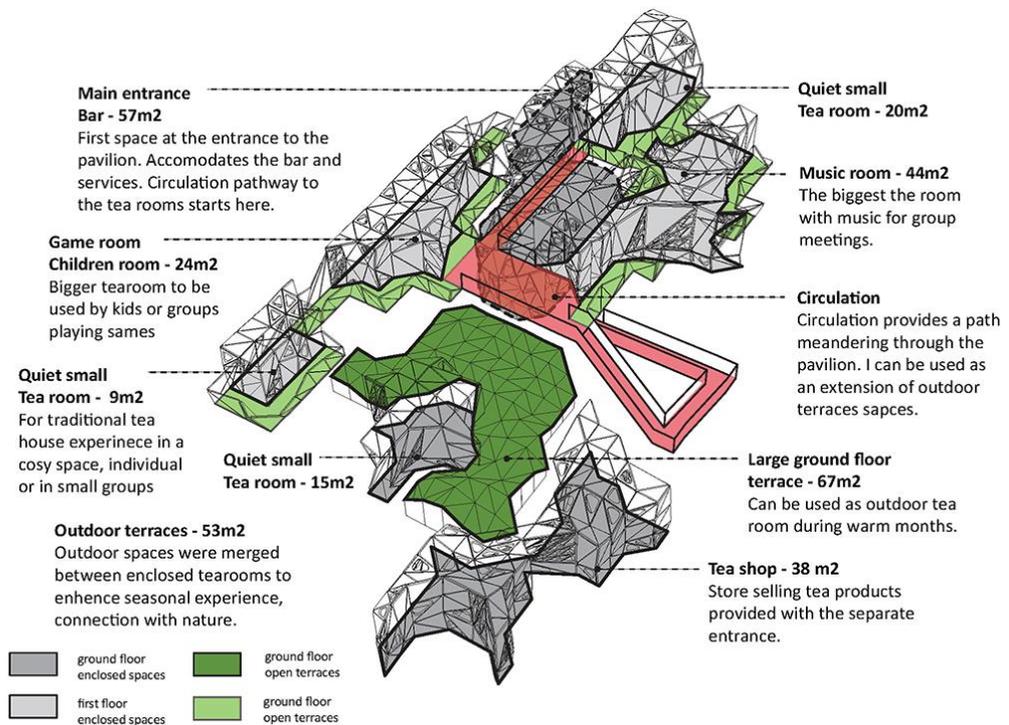


Figure 4: Diagram presenting one of the selected configurations of the Eco-locator pavilion (2013)

Eco-Locator (fig. 2-5) has developed a twofold climatic strategy focused on Computational Fluid Dynamics (CFD) for airflow simulation and solar radiation including on site daylight access simulations. The goal was to provide data sets that would inform the generative system. In this case, the generative system implies a recursive search evaluating site condition and generating rough configurations for the pavilion, its structure as well as its circulation system in relation to specific clusters of program.

The geometric logic of the recursive generative system utilizes branching in order to allocate and search for the optimum floor plan arrangements considering wind and sunlight qualities of the site. Since CFD simulations are dynamic, a strategy was established to transfer relevant data, from Autodesk Project Vasari, to Rhino through Grasshopper. The strategy consisted of implementing multiple simulations as for instance simulations for dominant seasonal conditions and employ color-coded mapping to inform the point-cloud. At the same time, evaluation of solar-radiation was conducted and the results were associated with

15 A. B. Downey, Think Complexity, Needham, Massachusetts: Green Tea Press.

the grid of points populating the site, giving each point within the point-cloud, a multi-dimensional data-structure comprising different environmental values.

The first implementation of the branching system on the informed point-cloud produced the circulation scheme of the pavilion and secondary branches were then developed as well as required floor area and enclosures creating clusters of spaces.

In parallel to the initial parameterization and generative procedures, optimization routines are integrated in the process in order to improve structural and environmental efficiency at micro level. This implies that in addition to environmental conditions internal geometrical constraints are embedded in the recursive system. These internal conditions were defined based on spatial and programmatic requirements. Eventually, the cyclic nature of the designed computational flow allowed the team to explore and test the performances of alternative designs for different seasons. This resulted in the development of meaningful design interventions into the optimization process.



Figure 5: Renders illustrating spatial and morphological quality of the eco-locator project (2013)

This experimentation has proven that integrating complex generative systems into a holistic design information model enabling data exchange between different stages of computational design, not only makes the complex systems more applicable and informed, but also establishes a balance between top-down decisions and bottom-up emergence processes.

3 Conclusion

In generative, data-driven design processes natural and artificial agents operate as actors involved in creating meaning at both material and semiotic level and humans represent only one of many possible agential embodiments. This understanding relies on De Landa's neo-materialist theory that rejects the dualism between nature and culture, matter and mind, natural and artificial, wherein reality is revealed in material, self-organized processes. In this context and in opposition to Alberti's (1452) formalization of (notational and authorial) architectural representation¹⁶ consisting of plans, elevations and sections from which materialization is implemented, multiple and various architectural materializations emerge today from interactions between (natural and artificial) agents while authorship becomes hybrid, collective, and diffuse.

Thus notions such as original, copy, production and reproduction are subject of re-definition: If the apparatus used to create (pen) was in the age of mechanical reproduction different from the apparatus used to make copies (printing machine), today, these apparatuses conflate (into one data-driven system) blurring not only the distinction between original and reproduction but also between representation and generation¹⁷ due to the processes through which physically built space is produced and utilized. Multiplicity and variation imply, therefore, not only that design emerges from local interactions between non-human and human agents but also physically built space incorporating artificial agents (e.g. sensor-actuators embedded in building components) adapts and reconfigures (with respect to indoor climate, 24/7 use, etc.) in response to human needs.

In this context, data-driven architecture is not only produced (created or designed and fabricated) by digital means but is, actually, incorporating sensing-actuating mechanisms¹⁸ that enable them real-time operation and interaction with environments and users. For instance, data collected from e.g. outdoor environment informs on the one hand the design and it informs the real-time operation of the interactive indoor climate control. Furthermore, the data incorporated in design with respect to form, structure, and materialization informs computer-numerically controlled production. Data-driven architectural design to production and operation implies, therefore, that data informs parametric models on which simulations are implemented. These, in turn, interface the real-time operation of physically built architectural systems¹⁹ implying that data-driven design establishes an unprecedented design to production and operation feedback loop.

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¹⁶ M. Carpo, *ibid*.

¹⁷ W. J. T. Mitchell, *Picture Theory - Essays on Verbal and Visual Representation*, University of Chicago Press.

¹⁸ H. Bier and T. Knight, *ibid*.

¹⁹ H. Bier and T. Knight, *Data-driven Design to Production and Operation* in H. Bier and T. Knight (eds.) *15th Footprint*, Delft.



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After graduating in architecture (1998) from the University of Karlsruhe in Germany, Henriette Bier has worked with Morphosis (1999-2001) and ONL (2004) on internationally relevant projects in the US and EU. She has taught data-driven design (2002-2003) at universities in Austria, Germany, Belgium and the Netherlands and since 2004 she teaches and researches at Technical University Delft (TUD) with focus on data-driven architecture. She initiated and coordinated (2005-06) the workshop and lecture series on Digital Design and Fabrication with invited guests from MIT and ETHZ and finalized (2008) her PhD on System-embedded Intelligence in Architecture. She coordinated EU projects (2008-10) and since 2003 she regularly lectured and led workshops in EU and US. Results of her research have been internationally published in books, journals, and conference proceedings.

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Sina Mostafavi is a practicing architect, PhD-candidate, and expert in computational design. He researches and teaches at the Delft University of Technology with focus on computational design methodologies and technologies that facilitate integrated, performance driven design processes from conception to production. He practiced architecture since 2007 and is founding partner, co-owner, and lead designer of TAO (Transformative Architecture Office), a firm that offers consultancy services for innovative design solutions and state-of-the-art construction processes. He holds a master degree in architecture from University of Tehran and a bachelor degree from Tehran University of Art. He is currently project researcher in Robotic Building project at Hyperbody group at TU Delft.