Potentials of Bio-inspired Generative Design Approaches: How are they related to sustainable design?

Ken Chen 4223217

Abstract

Generative computational design approach is highly linked to the neo materialism concept of “morphogenesis”, thus possessing biological inspiring characteristics. Generative design’s relevance to perfomative digital design reveals the potential of integrating itself with sustainable design objectives. Rather than simply being a form finding tool, generative design could be a bottom-up process for achieving top-down sustainable goals. This relation combines stakeholders of form, building behavior and integration of multiple behaviors, as well as design methodology of using environmental factors as system inputs and a multiple objective optimization process using genetic algorithms (GA). Example of personal experiments as a whole workflow of generating environmental-affected forms and then optimizing the genome with sustainable fitness criteria is introduced.

I. Introduction

Manuel Delanda, the French architect and philosopher refers to terms such as “self-organizing” and “morphogenesis” when introducing Gilles Deleuze’s philosophical concept of “abstract machine”. He argues the “abstract machine” to “indeed points towards a new form of materialist philosophy in which raw matter-energy through a variety of self-organizing processes and an intense power of morphogenesis generates all the structures that surround us.”[1] One could without much effort to recognize the materialism ideology behind those terms. This neo materialism definition points at a “generative matter”, which captures mattering as simultaneously material and representational, rather than opposing one of them to another.[2]

Broadly defined as an algorithmic or rule-base process through which various potential design solutions could be generated[3], generative design could be read as a wider implication of “morphogenesis” in the field of architectural design, after the fast development of computational technologies which could be adopted by designers. Holland argues that the proper generative computational work includes a “mechanism” of generative system and constrains limiting possibilities.[4] In this case, forms, or simply called “phenomena” could be emergent from the base of a complex individual and systemized rules. So it is reasonable to state that generative design’s connection with Deleuze and Delanda’s neo materialism ideology could reflect it fundamental character of biology inspired, imitating the Darwinist natural evolution process and its diversity.

Meanwhile, the intention of sustainable design is defined as to “eliminate negative environmental impact completely through skillful, sensitive design”, which requires designs to comply with the principles of social, economic, and ecological sustainability.[5] While perfromative design, which deals with building’s behavior and its influence in multiple levels of society and ecology, possesses largely similar attributes as sustainable design, its dependence on computational design due to the possibility of digital simulation and generation would reveal the potential relevance between sustainable design and generative design approaches. This article will provide some basic investigation into this topic.

II. Verification of the relationship

In Luca Finocchiaro and Anne Grete Hestnes' article named "Symbiosis and Mimesis in the Built Environment", they argue in favor for the validity of sustainable design in terms of its external-internal symbiosis in regard to nature, the way built form is "affected" by environmental conditions.[6] Nevertheless, although being quite in fond of the concept of "biomimetic", the authors regard the computational generative design approach, or defined by them as "digitally grown architecture", as "superficial appearance of natural phenomena", not being able to satisfy the "architectural requirements related to function" and material necessity. Not even to mention its reflection on the point of sustainable design.[7]

Just as many critics of our time, Finocchiaro and Hestnes draw the conclusion that the "emergent' approach of generative design is nothing except similarities with biological systems in form. This point of view could be the main counter argument for the relationship between generative and sustainable design. Admittedly, the capability of generative systems in form finding has been verified a lot. One could even argue that Durand's formal typological shape instructions are a kind of "generative" tool. The various computational generated formal languages, such as L-system, branching system, agent-based form finding and cellular automata, becomes representative label of generative approach. Moreover, most established examples of our time would simply use generative system as a form generating tool. In many cases, the application of generative approach is just like Michael Hansmeyer states with his L-system project: "Can L-Systems be applied to the production of architectural form? Could they serve additional functions such as the creation of an organizational logic or the segmentation of space?"[8]

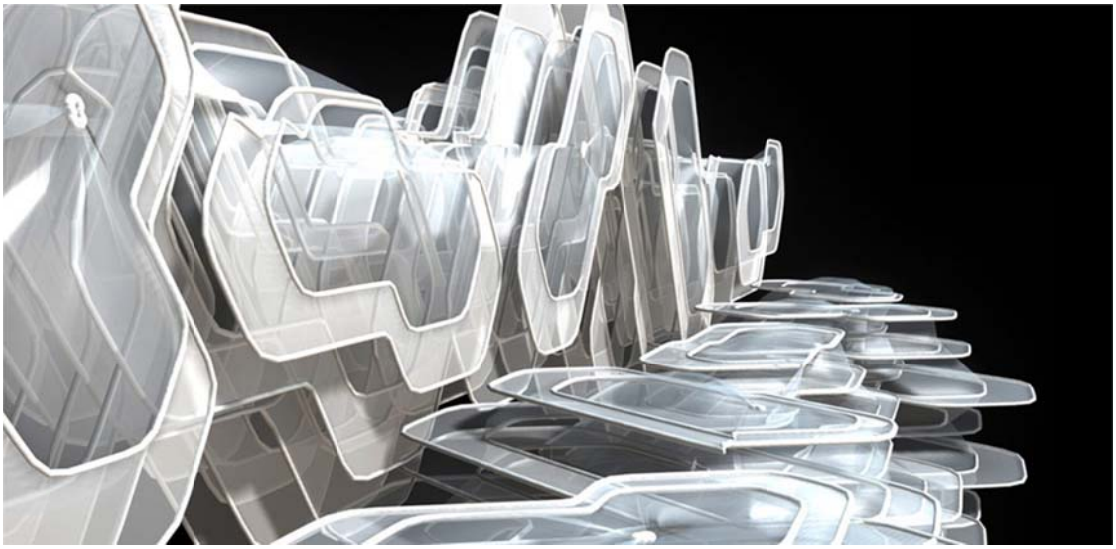

Fig 1 Hanmeyer's L-system project

However, this wide application if form finding process does not imply a total engagement with formal design of generative systems. The critics may neglect the fundamental truth that Delanda would argue that forms generated here are only the fold of "representational", while the other layer of materialism should be included. Just as all living organisms in nature would adjust its appearance by adjusting to environmental variations with a complex "mechanism" which could be influenced by inputs, the core of generative design is its inner mechanism for generating not only form, but also environmental adaptability and self-organizing systems, thus, performance. Performantive design, as mentioned above, is in requisite for a shift from aesthetic approach to a more multi-level approach, which could be integrated to the generative computational framework aiming at

problem solving process.[9] In this way the generative design become no longer pure form-finding, but a more convinced integrity of form and content which could be “affected” by environmental inputs with a convinced, informed and intelligent materiality.

So it is reasonable to state that the relationship between generative and sustainable design gains its validity only when these two design approaches are integrated into one continuous process. If described more accurately, it is sustainable design to act as the top-down objective for designers, and generative design to serve as the bottom-up design methodology. Being different from traditional design thinking in which the methodology usually tend to possess a top-down attribute, in generative sustainable design it is the defined goals to become top-down decision. With computational algorithms becoming bottom-up “generator”, the whole design will pass through deductive verification and be finished with artificial-intelligent efficiency.

III. Integrated methodology

To name one thing “integrated” is to reveal its complexity. In generative design aiming at being sustainable, this integration is composed of two layers of meaning: top-down set up stakeholders and bottom-up design methodology. The former again consists of two principal components: one is the integration of generated forms and building performance, the other one is integration among multiple building systems such as structure, solar accessibility, inner climate, etc.[10] As with the bottom-up design strategy, there are also two major approaches to integrate generative system with sustainable objectives. One is to use various environmental factors as inputs of the generative system to affect the initial form finding process at the earlier phase of design. The other is to run a multiple objectives optimization algorithm after the earlier building components are generated, by which the building “representation” could go through a significant update in order to perform better sustainable behaviors.

One crucial phase of this integration is the process of multi-objective optimization. If defined broadly, optimization is a searching progress with a problem-solving methodology in purpose to satisfy a prescribed need within several constrains using available means.[11] Nevertheless, when applied as multi-objective process in the field of generative design, it could be restricted into certain methodology as genetic algorithm (GA). We all know the term “genome” is used in describing biological transcription. It is the identification, in order, of the sequence of nucleotides which are the “ladder rungs” of its DNA strands. Human beings, with just four nucleotides types, are able to possess individual characteristics. The key factor here is the sequence of the three billion long DNA chain. When this “genome” is made into analogy in architecture, a genetic algorithm relies on a combination of randomness methods and goal-driven methods to search out the fittest members of a given population based on the theory of natural selection is identified.[12] GA transforms a set of individual objects into new generation using the Darwin principle of reproduction and survival of the fittest. The algorithm assumes that if a particular genome achieves a strong fitness score, then other genomes which are similar to it or are derived from it may perform even better.[13] In this way all design variables with genomes throughout the entire solution space are tested. This multi-optimization with GA once again could reflect generative design’s connection with biological field.

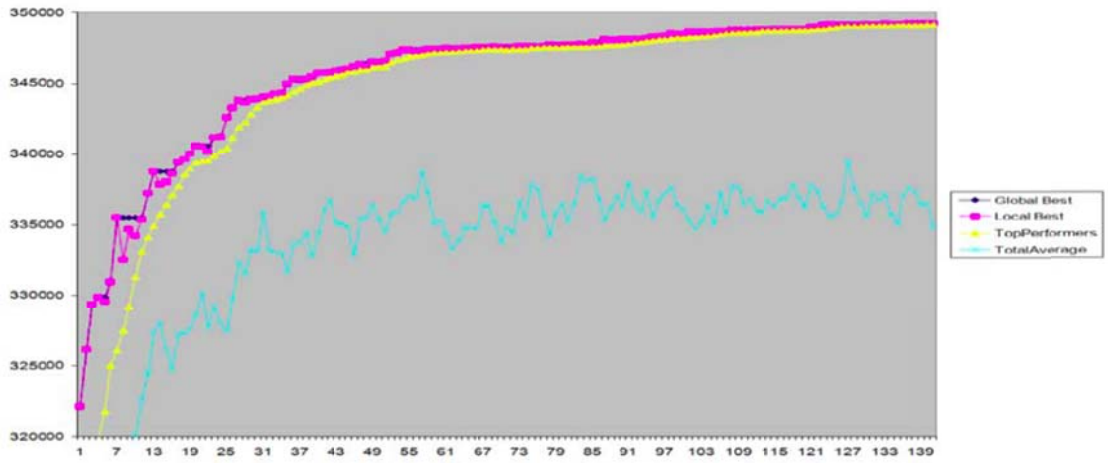

Fig 2 Sample results curve showing number of generations along horizontal axis and fitness function score along vertical axis. SOM Hypothecal project.

This optimization process based on genetic algorithms has already been applied in practicall projects. SOM uses this approach when making the design of Hypothecal tower, setting up the X and Y size of five individual tower floors and their gradient as design variables to produce genome populations, and using solar access of outer building surface panels as fitness criteria, to create an optimized geometry.[14] However, this practical example does not reflect the possibility of an integration with generative computational system since the geometry of the tower is only digitally lofted.

IV. Personal experiment

Under the framework of Hyperbody graduation studio, lots of experiments on generative computational strategies have been carried out. In previous experimental projects, the initial integration of sustainable affecting factors as generative system inputs has been one central theme of the design methodology. For example, in some projects in past studios, one common approach is to map the site with a weighted performantive factor point grid, which is composed of points with various environmental scores to serve as a searching space for programme agents. The agent-based generative system would use different clusters of agents with different behaviors to generate the building form, with much respect to the preferred environmental values needed of each individual agent. In this way that the whole set of agent-based form finding process is informed and balanced by environmental inputs.[15]

In this year's studio, this layer of methodology is still at central position. For example, in the author's workshop project, the starting points and breaking points of an initial branching system are digitally selected in a point grid with weighted environmental and accessibility value. This branching system serves as the initial topology map for generating the footprint of the programme spaces. Moreover, multi-optimization by genetic algorithm has been introduced along with the generative system. Taking the workshop projects again, setting a certain amount of solar radiation access as fitness a criterion, which is simulated by computational simulation tool, some design parametres are chosen to produce genomes. Of them are the proportion of fractal iteration to generate floor areas, height of 3D volumes as macro-scale genomes and rotation angle of each roof panels as micro-scale genomes. The outcome calculated by Grasshopper plugin Galapagos shows both sustainable performative characters as solar radiation could be restricted within certain level in individual programme

spaces, and aesthetic achievements as the panels' rotation angles become gradual with the roof geometry, being a definite result of its sustainable objective.

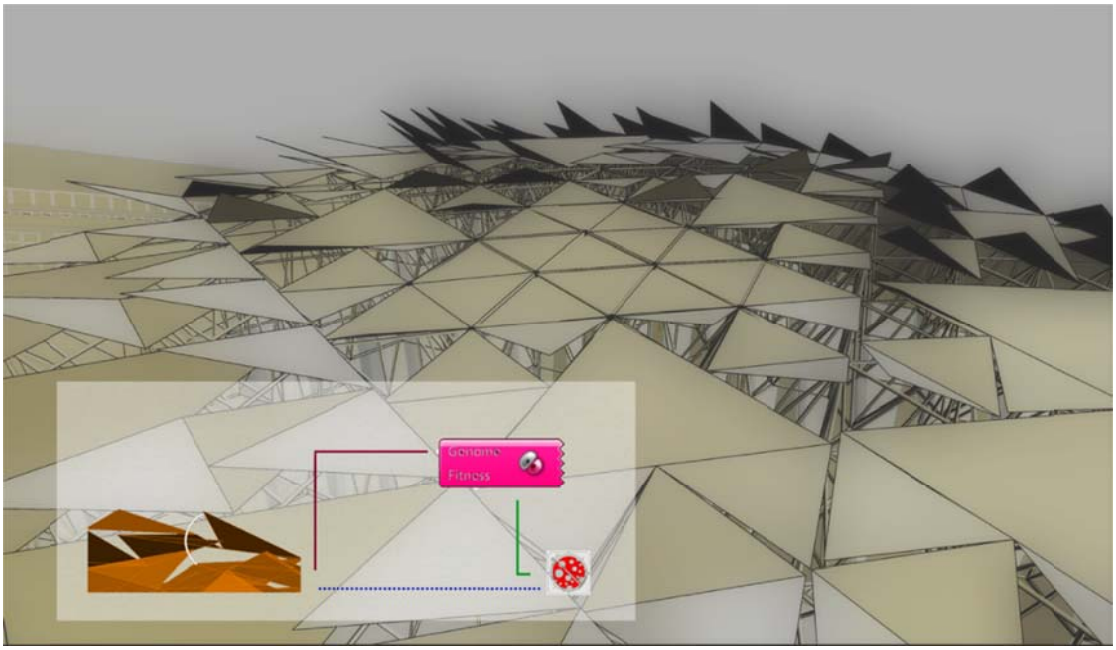

Fig 3 Panel rotation angles optimization for solar radiation fitness

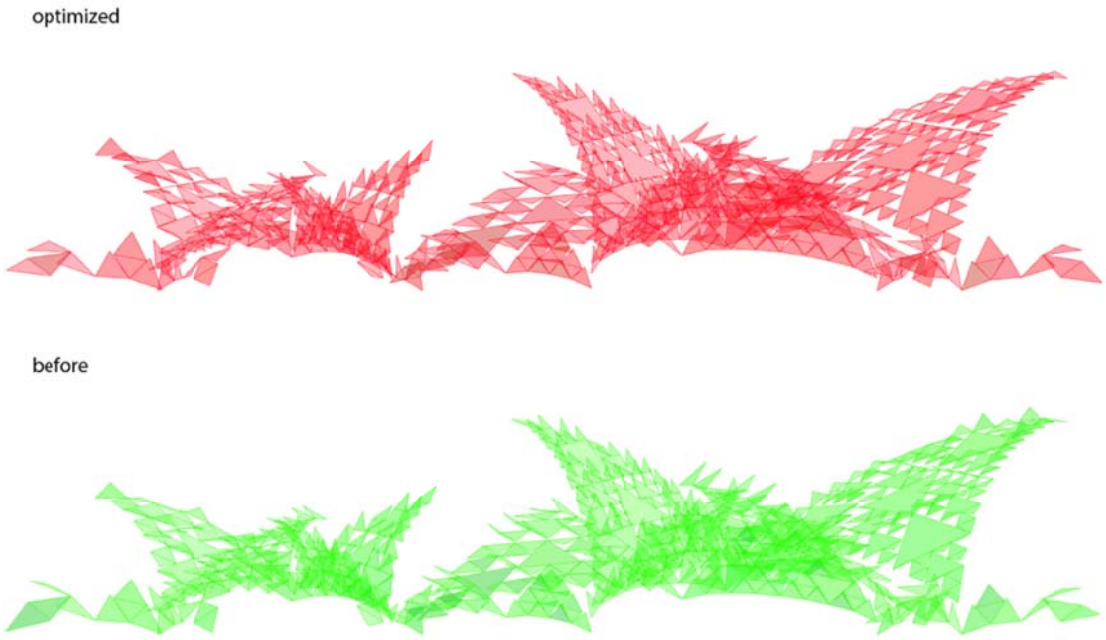

Fig 4 Panel optimized and not

Conclusion

Aforementioned are just fundamental observations of bio-inspired generative design's potential of being integrated with the top-down goal of sustainability. It is worthwhile to pay attention to this research field

because of its vast probability to be discovered yet, as well as computational design and sustainable design are almost two leading research field in our current era of information revolution and global environmental crisis. We need to be specifically aware that the coorporation of these two design thinking will be constantly in a state of updating in terms of being reflected by design outcome, just as our post-structural society is in “continuous differentiation”.

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