Generative Design through Agent-Based Systems:

A new Methodology Integrating Alternative Materials, Fabrication and Construction Techniques in the Design Process

The research proposes a methodology that integrates Material technology, fabrication techniques and construction strategies within the design process in order to bridge the gap between design and build processes.

Background

Construction contributes to 40% of GHG emissions[1]. By 2050, the earth population will exceed 9 billion people[2]. This means that if construction works continue to perform at the current rate, this will contribute to the use of 60 million tons materials/year, i.e. constructing 10 Beirut(s) every Month[3].

In current design methodologies, architects are challenged to predict all present and future design requirements and possible alterations for buildings prior to construction. Accordingly, they attempt to resolve all matters in a single passive solution. This passive solution may not always be capable of responding to continuing drastic population growth and environmental considerations.

However, attempts to address this issue in architecture began in the late 1960s when a major extension to classic natural sciences has changed many views on natural phenomena in general, summarized in the discipline called complexity theory. While these changes have affected mathematics, physics and biology for decades, the slow impact in architecture was addressed by Venturi, who proposed a first theory about complexity and contradiction in architecture in 1966.

It was not until the early 1990s that some theorists wrote about complexity theory in architecture (influenced by the innovations in the digitizing of the fabrication tools), among which were Eisenman, Jencks and Lynn (The Nature of Order, 2003, Christopher Alexander). This resulted in several approaches in form-finding strategies such as parametric design, computational design and generative design, etc.… in search for *flexibility* and *adaptability*.

These innovations widened the scope of solutions to architectural problems; however, **current design strategies are not capable of utilizing efficiently these rapidly expanding technological possibilities when constructing.**

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[1] Global Status Report 2017, UN Environment

[2] World Population Prospects 2019, UN Department of Economic and Social Affairs

[3] https://www.constructiondive.com/news/report-global-construction-waste-will-almost-double-by-2025/518874/

Keywords

Self-Organizing Systems

Complex systems have several principles such as *flexibility*, *autonomy* and *robustness*, that traditional mechanistic systems lack. These qualities can all be seen as aspects of the process of self-organization: whereby systems spontaneously organize themselves so as to better cope with various internal and external perturbations and conflicts. This allows them to evolve and adapt to a constantly changing environment.

Self-organization is a characteristic that can be found in systems of many natural organisms: flocking of birds, collective building behaviors by various social animals and insects, pigmentations of cells in animal skin patterns, formation of dunes by sand particles, and so on. These behaviors are often called emergent behaviors, and emergence refers to "the way complex systems and patterns arise out of a multiplicity of relatively simple interactions," according to Camazine et al. (2002).

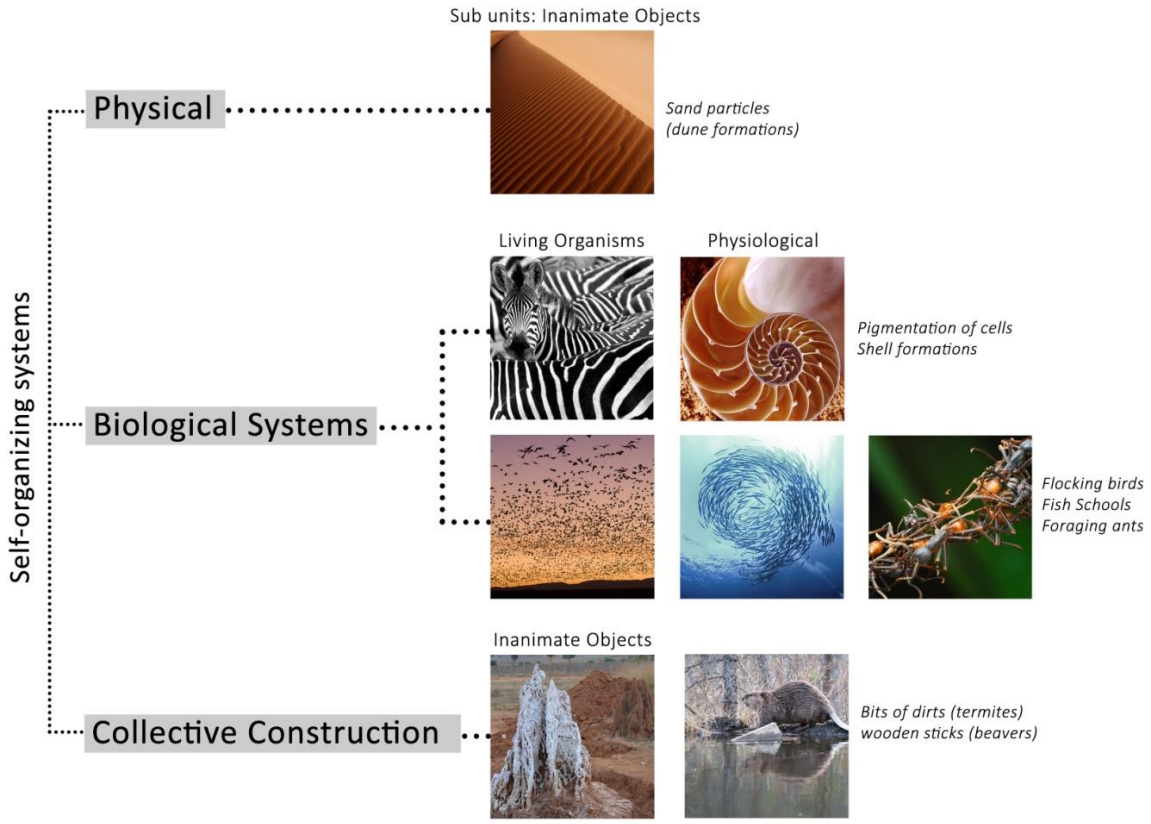

Figure 1 Categories of Self Organization. (2002). Self-organization in Biological Systems by Camazine et al.

Agent-based systems
A complex system is typically modeled as a collection of interacting agents, representing components as diverse as people, cells or molecules.

Agents are individual components that act upon their environment in response to the events they experience. The number of agents in the system is in general not fixed as agents can multiply or become obsolete.

Cause-and-effect or condition-action logic: an agent will react to a specific condition perceived in the environment by producing an appropriate action. The rule connecting condition and action, while initially fixed for a given type of agent, can in some cases change, by learning or evolutionary variation.

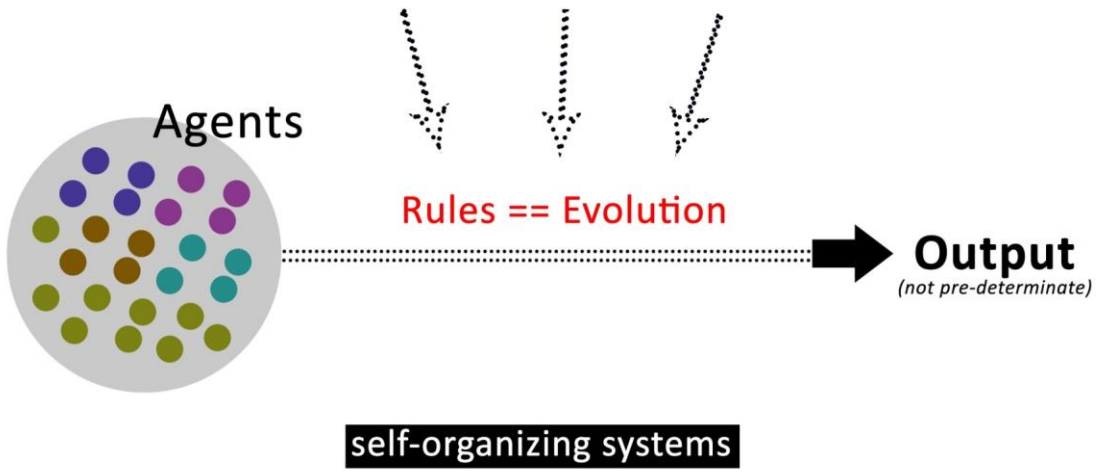

Figure 2 Self Organization Systems

Generative Design
The introduction of mutation is a key issue in generative design. As opposed to computational modeling, it confers design with the concept of 'emergence', in this case adding unpredictability to the process' outcome. Generative design is an iterative design process that involves a program that will generate a certain number of outputs that meet certain constraints. Instead of using computer tools to design a form, form is generated from a specific set of instructions which will tell the computer the series of steps it needs to take to make it.

Purpose
Adaptation of self-organization to architectural creations is an uncultivated area of study worthy of investigation.

The target is to achieve a system that is Robust (able to function as a whole, beyond the imperfections in performance of particular agents) and flexible (able to respond to constant changes).

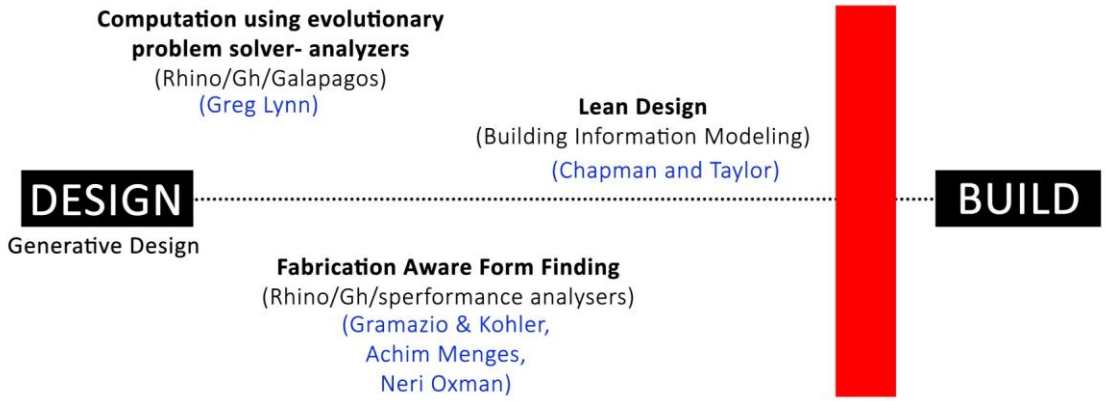

Figure 3 Contemporary Architecture process: Design+Build

One remarkable finding from the observations of collective construction by insects is that their processes do not seem to have a discrete design phase before the construction. **Design, construction, and operation are seamless concurrent activities in their processes, and these characteristics help them to gain significant flexibility in their habitat designs:**
De-centralized Process.

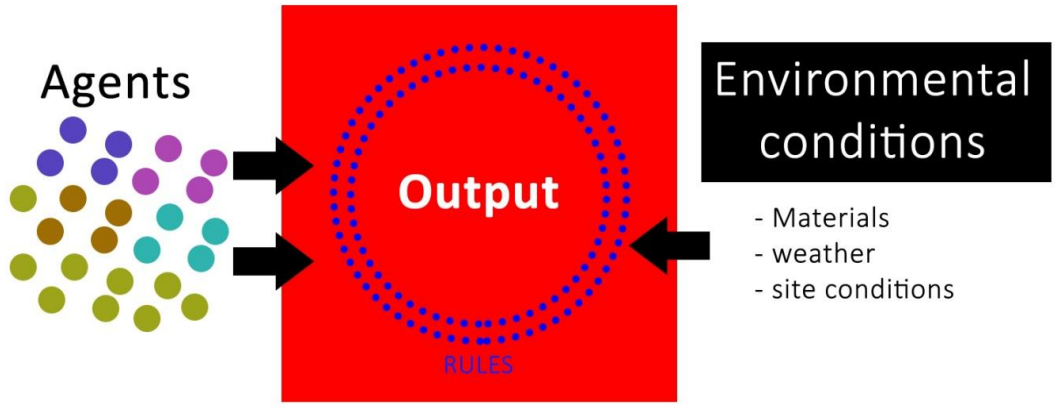

Figure 4 Architecture Process based on Self-Organization logics

Objectives

- To analyze the current logics of generative design and categorize attempts of applying self-organizing systems.
- To investigate the possible integration of material, fabrication and construction constraints in a generative agent-based model for an energy-efficient architectural outcome.
- To critically appraise the generative design model based on a holistic methodology considering both the form-finding strategies and construction techniques.
- To test the proposed model based on case studies; generating a comparative analysis between the discussed models based on their energy efficiencies.

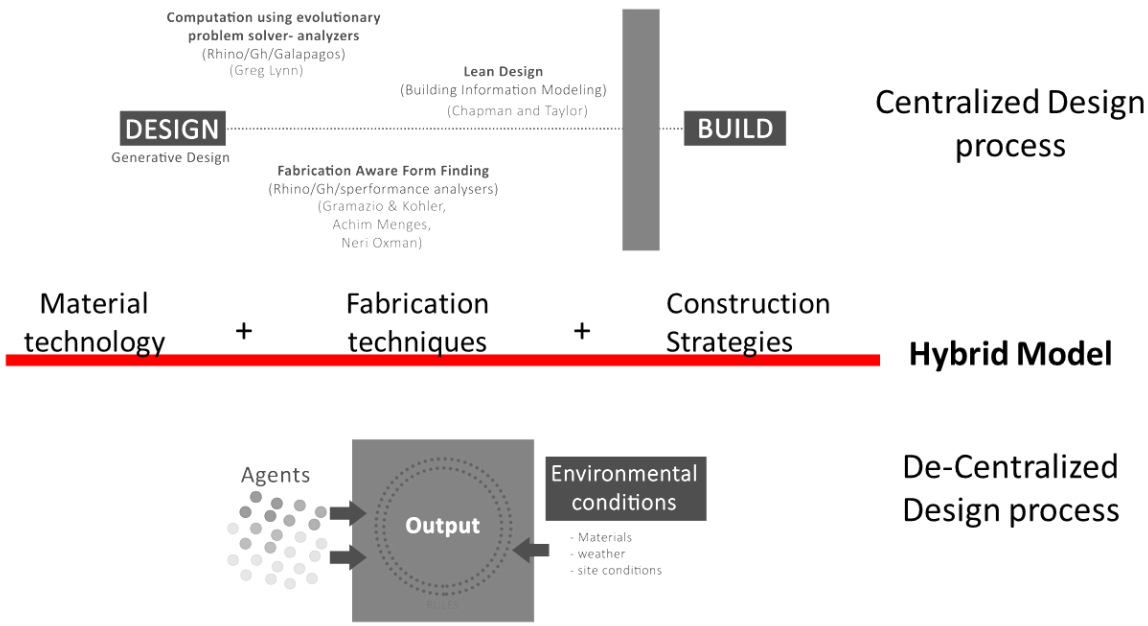

Figure 5 Proposed Layout of the Hybrid Model

Hypothesis

The hypothesis of this thesis is that eventually sufficient computational power, material and construction innovations will lead to conceiving extreme forms of adaptability. With that in mind, what we can optimally gain in order to take full advantage of decentralized notions within the reach of current technology is the agenda for the thesis.

Within the depleting resources in the urban settings, the desire to be able to accommodate new needs will increase demand for more adaptable buildings that can be efficiently executed. As one possible adaptation to likely future conditions, **the research proposes an active model that integrates material, fabrication systems and construction techniques into the architectural process for complex models.**

Outline Methodology

The Methodology is divided into three levels:

1- Reviewing current methods and literature review of generative design for complex architectural components.

2- Suggesting a hybrid model that provides an efficient strategy for designing and building generative architecture.

3- Assessing the proposed model through case studies: comparative analysis between the current architecture process and the proposed one: a checklist for optimizing the model, taking into consideration material, fabrication and construction techniques for energy efficiency evaluation.

Proposed Outline

1. **Introduction**
    - 1.1 Background
    - 1.2 Contextual framing
    - 1.3 Constructing the inquiry
        - 1.3.1 Research goals and questions
        - 1.3.2 Hypothesis
    - 1.4 Methodology
    - 1.5 Dissertation Structure

2. **Self-Organization and Generative Design**
    - 2.1 Natural Systems and their Computational Simulations
        - 2.2.1 Introduction
        - 2.2.2 Self-Organization
        - 2.2.3 Collective Construction
        - 2.2.4 Applications of Self-Organization
    - 2.2 Generative Design
        - 2.1.1 Framing Self-Organization in Generative Design
        - 2.1.2 Agent+Based Systems in Generative Design
    - 2.3 Hybrid Model

3. **Investigations on the hybrid model**
    - 3.1 Material Investigations
        - 3.1.1 Background and Motivation
        - 3.1.2 Method
        - 3.1.3 Result
    - 3.2 Fabrication Strategies
        - 3.2.1 Background and Motivation
        - 3.2.2 Method
        - 3.2.3 Result
    - 3.3 Construction Systems

3.3.1 Background and Motivation
3.3.2 Method
3.3.3 Result

4. System Evaluation and Discussion
4.1 Results analysis and evacuation
4.2 Comparative analysis

5. Summary and Conclusions
5.1 Summary of Results
5.2 Contributions
5.3 Overall conclusions and future work
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