Stigmergic Architecture

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Abstract

SciArchitecture is the architecture of the post biological era, in which generative systems and decentralized thinking stimulate the growth of autonomous living architectural forms that are able to communicate with their context through interactions with the environment. This speculative future for architectural theory suggests architectural forms with unpredictable outcomes following a set of emergent rules of communication with a bottom-up hierarchy.

This work studies the processes behind the growth and development of architectural forms that are able to survive in their context. It focuses on processes for generating life forms as temporal sequences of frozen behaviours in an emergent system. Such forms will undergo endless transformation in response to their relentlessly changing environment, and so it is argued here that the outcome of the process will always be a temporary form as it leaves an enduring record of the behaviour which resulted in its creation in a certain time and space. Thus, this study is concerned with the processes within a system rather than the resulting form.

The development of modernist, post-modernist, and de-constructivist imagery in architectural theory has led to an approach which identifies and seeks to promote a superficial similarity between buildings and living structures, but such a model cannot capture the fundamental essence of living structures that are dynamic and self-organized. This has left the gap between the imagery of architecture and advances in technology and biology unaddressed. This work is concerned with bridging this gap.

The paper proposes the development of theoretical forms of architectural behaviour that are able to communicate with each other through interactions with their environment; the form is abstracted away from its material instantiation and encoded as a system of rules and principles working fluidly together. This work investigates the stigmergic behaviour of ant colonies in natural systems, and the forces and attractors that influence the creation of any spatial form, which can be demonstrated as any behaviour, structural configuration, pattern of organization, or system of relations that can occupy a space.

Decentralized Thinking in Architecture

For generations, architecture has been the subject of a multiplicity of design theories and movements. An authoritative classification of all existing theories of design is impossible due to the complex relationships and interactions between them. Almost all claim that design is a living process in one way or another but none have embodied the principles of living processes necessary to create an architecture which manifests itself as a living entity rather than as static nonliving matter. In order to address this

gap in current theories, the work described here focuses mainly on the process of creating living, adaptive architectural forms as opposed to the material outcome.
Survival is a key concept for this theory. The process of survival can only take place within some medium, and so we are compelled to focus on the context, the environment and their constraints as a reflection of the behavior of architecture and its users. This context will be in a continuous state of flux in which all parameters inevitably change over time. Ecological, cultural, economical, and political variables have a direct impact on the environment and the shape of the context in which architecture survives. These variables can themselves be considered as systems with their own attractors and forces of compression and tension that define a space within the larger set of possible contexts and create the environment in which the form grows.
Survival and evolution are two conflicting challenges that draw architecture in opposing directions. They both depend on the structure as represented by its architecture as a tempform or frozen behaviour[1]. A form survives in two cases: one, when it fulfils a need or function for which it was constructed and built, and two, when it changes its initial function into one that is now more suitable. However, in the real world, there are too many constraints and requirements continue to change, therefore, survivability, though necessary, is not efficient. At the same time, a form evolves as long as it can adapt to its changing context. However, the form cannot afford to lose its ability to survive in an attempt to evolve. The capacity to satisfy these two conflicting challenges is a vital and essential quality of any living form.

One of the most interesting ideas due to D'Arcy Thompson is that physical forces shape organisms directly; surface and volume ratios must influence the organism as it grows in size and as it inhabits different realms of forces. As a consequence of this, small creatures are influenced primarily by surface forces, while large creatures received stronger influences from volumetric or gravitational forces. Ranulph Glanville (1995) echoes much the same idea in design in architecture. Instead of concentrating on the material outcome of design, Glanville emphasizes the circularity of the system, and observation of the interaction of processes. He says: "What matters is the principles of the mechanism rather than its embodiment" (Glanville 1995).
Glanville presents a compelling idea about "the self and the other". This idea represents a radical alternative to conventional thinking about form design in architecture. Here what matters are the forces and the attractors of the system that help the observer to analyze, synthesize and design the form without thinking of its materials; designing a form with the power of control over the whole system. He argues that: "For circle and line are complements. They derive from the difference between the view within the system and that from without: the wheel and the track, the self and the other" (Glanville 1995).
The term "theoretical form" is the main focus of this paper. In the approach adopted here, the form is abstracted away from its material instantiation and encoded as a system of rules and principles working fluidly together. This idea of "form as process" (Price 1960; Price, Isozaki, Keiller, and Obrist 2003) was one of the most important aspects of Cedric Price's (2003) thinking about architecture. Though he did

[1] The word "tempform" is a combination of transformation, phenomenology and form. The phrase "temporary form" or "tempform" carries the meaning of circularity and change that takes place in a certain time (Murrani 2005). Frozen behaviour is a term used by biologists to refer to artefacts. "Artefacts leave an enduring record of the behaviour which resulted in their creation" (Hansell 1984).

not realize many buildings, his way of thinking has influenced generations of architects. In his architecture, Price aims to negotiate and adapt to the constantly shifting cultural climate. Stanley Mathews describes it as an “improvisational architecture” (Mathews 2005), in which Price introduced a novel synthesis of contemporary discourses and theories, such as cybernetics, information technology, game theory, and theatre. Price (1960) imagined his buildings would never look the same twice, but instead would blend with the context and adapt to survive in it. One of the most famous and radical buildings of his – sadly never built - was the Fun Palace [2] (mid 1960s).

Many aspects of natural systems can be seen in the work of John Frazer (1995), who introduced the concept of evolutionary architecture. His work emphasizes the natural sciences of cybernetics, complexity and chaos. In the well-known book “An Evolutionary Architecture” Frazer describes a set of rules for form generation in a genetic language and encodes these as a computer program. These computer models simulate the development of prototypical forms which are evaluated on the basis of their performance in a simulated environment through natural selection. He emphasizes the idea of a hierarchical process-driven program but in contrast to the work in this paper, Frazer’s hierarchy demonstrates a well-defined direction of influence in which one process drives the next. This work posits that richer and more complex results may be expected if processes are allowed to interact and overlap, making both bottom-up and top-down drives possible within the same system.

Kas Oosterhius mentions the use of the phrase “Swarm Architecture” (SA) as a metaphor and to indicate the running process of complex systems such as urban environments where there is an information flow between the buildings, users, cars, and all objects around in a context.

“When we look at an urban environment from the point of view of SA we no longer see isolated objects. Instead we see objects which have a relation with each other” (Oosterhius 2006).

Stigmergy and Communication:
Hierarchy, Circularity and Feedback

Nature has inspired researchers and architects with its endless fascination of phenomena to create new approaches in design and solve difficult construction and/or design problems. Buckminster Fuller’s geodesic dome is one of the most influential examples in design for autonomous forms. In an era of booming complexity, where not only nature but even governments, economies and societies have become impossible to understand, the study of social insects and the construction of uncommunicative, simple creatures that are responsible for epic feats of organization and creativity such as termite mounds, anthills and the individuals’ collective behaviour can do more than just pave the way to new approaches of design.

“It turns out that not only might we, as multi-cellular organisms, be composed of swarms[3], but so could our societies, economics and perhaps even our minds” (Gordon 2003).

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[2] One of the most famous inbuilt buildings of his was the Fun Palace (mid 1960s). Price thought of the Fun Palace as an instrument of social improvement: The emancipation and empowerment of the individual (Mathews 2005).

3 A swarm is simply a set of self-organizing agents capable of performing distributed problem solving, the body of a multicellular organism can be seen to constitute such an entity (Hoffmeyer 1994).

Or it could be our cities, our architecture also composed of swarms with local rules for construction.

Communication is a vital process for generating collective behaviour in decentralized and self-organized system. Although, generative systems are composed by simple individuals, that follow patterns of indirect interactions developed through experience rather than a pre-designed pattern, the frozen behaviour or the tempform is vastly more complex than the individuals themselves which behave randomly sometimes on an individual level. This field is known in computer science and robotics as swarm intelligence, an artificial intelligence technique, the behaviour that result from these swarms is referred to as stigmergy[4]. In swarm intelligence the indirect interactions of a population of simple agents which communicate locally with each other and their environment is referred to as "stigmergic behaviour".

The richest natural example of stigmergic behaviour can be seen in ant colonies. The discrepancy between the complexity of the anthill and the complexity of the individuals that construct it is, to say the least, striking.

"A single ant has no global knowledge about the task it is performing. Ants' actions are based on local decisions and are usually unpredictable" (Benzatti 2002).

These performances in time will represent indirect communication between the ants in their environment which leads to an organized emergent behaviour that shows some kind of ordered pattern of interactions. Therefore, and on an individual level, the behaviour of the ant is simple while at the level of the colony the behaviour is cooperative and self-organized without any preconceived designed plan.

Ants communicate indirectly by laying down pheromones[5] along their tails while foraging.

"An isolated ant moves at random, but when it finds a pheromone trail there is a high probability that this ant will decide to follow the trail" (Benzatti 2002).

Hierarchy is certainly in evidence in ant colonies, and is achieved in a very efficient way. It follows a bottom-up rather than a top-down system which depends heavily on communication. The adaptation seen in such structures is very much functional, as the main drive of the inhabitants – an emergent drive rather than a designed one - is to exploit food sources through communicating with each other, but the end product is vastly more complex than just a giant storage room for food. Each ant colony maintains a multifunctional complex system providing an environmentally controlled mass, with solar and defence systems, rooms for storing food, housing, and even places for cultivating fungi which are fed and maintained on stored food and water.

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4 Stigmergy meaning "incite to work" is a tool of communication in emergent systems, where the individual parts of such a system communicate with one another by modifying their local environment. The term was introduced by French biologist Pierre-Paul Grassé in 1959 to refer to termite behaviour. He defined it as: "Stimulation of workers by the performance they have achieved" (Grasse' 1959).

5 Pheromones are hormones produced by ants that influence the behaviour of others from the same species.

Circularity is a very important aspect of such complex systems through which the system is defined as a coherent, organized, and functional entity. This appears within the context of the anthill through the ways that ants interact with the structure and each other, and also in the way the combined system of structure and ants interacts with the environment. Circularity within a system pushes the parts to learn through repetition (experience), reminiscent of activity in the neural networks of the human brain, where each flash of brain activity triggers an array of neural circuits, but a large number of possible neural circuits go unrealized over a very long period of time though certain circuits repeat themselves again and again. These circuits are feedback loops and all decentralized systems rely on these loops for both growth and self-regulation. In such systems, negative feedback is crucial as a way of indirectly driving a fluid changeable system towards a goal and a way of transforming a complex system into a complex adaptive one as Steven Johnson (2002) echoes further:

"Negative feedback is a way of reaching an equilibrium point despite unpredictable – and changing – external conditions. The "negativity" keeps the system in check, just as "positive feedback" propels other systems onward" P138 (Johnson 2002).

The patter of interactions that develops over time contributes to the dynamics of the system and behaviour, where such behaviour results in task allocation.

"Colonies perform various tasks, such as foraging, care of the young and nest construction. As environmental conditions and colony needs change, so do the numbers of workers engaged in each task" (Gordon, D M 2003).

Interactions between ants provide both negative and positive feedback according to specific environmental circumstances which has an important role in creating the pattern of interactions. Deborah M Gordon (2003) echoes this fact saying:

"It appears that what matters to an ant is the pattern of interactions it experiences, rather than a particular message or signal transferred at each interaction. Ants do not tell each other what to do when they meet, but the pattern of interaction each ant experiences influences the probability it will perform a task" (Gordon, D M 2003).

Survival:

Rules of Construction

Scientists describe the collective behaviour of the ants as a complex system that provides intelligent solutions to problems, but in fact, these problems only exist as a consequence of the drive to survive in their environment.

There are simple rules of construction that these simple creatures follow that represent their collective behaviour. These rules were first documented by the father of stigmergy the French biologist Pierre-Paul Grasse' in his 1959 study of termites:

- First, they simply move randomly, dropping pellets of chewed earth on any elevated patch on the ground. And soon small heaps of moist earth form.
- These heaps of moist earth encourage the individuals to concentrate their pellet-dropping activity and soon biggest heaps develop into columns which will continue to grow while other ones with less height get to be ignored.
- Finally, if a column has been built close enough to another, one other behaviour develops; the individuals will climb each column and start to build diagonally towards the neighbouring columns.

These are the basic rules for construction which cannot be separated from other rules of communication mentioned above, as part of the survival of the coherent whole. All these rules are based on patterns of interaction and changes in the environment as well as the needs of the colony. The individuals are not coordinated from the start of the process until the finish. Every single time in a certain space gives a different frozen behaviour which is revealed, depending on the state of its immediate environment, as stigmergic behaviour.

Swarms:
Architecture of Stigmergic Behaviour
The architectural forms of stigmergic behaviour that are most relevant to this paper are the ones that grow greater intelligence and learn, through patterns of interactions with their environment, how to respond to their context in a certain space and time.

As part of this work, a pre-programmed model has been designed to illustrate the ideas behind the stigmergic behaviour of architecture. The theoretical model incorporates principles and processes that have been discussed earlier beginning with sequential growth from seeds and the forces that shape a form depending on the level of sophistication and involvement in the process. The first stages of the model concentrate on the idea of frozen behaviour and especially on the individuals that construct these sections in time as well as their level of engagement with their environment (image 1 and movie 1). The second stage of the model involves stigmergy as a tool of communication between several colonies of individuals. In this stage the model exhibits another dimension as patterns of interaction between two or more swarms develop. This represents the emergence of stigmergic behaviour between more than one colony and the environment (image 2 and movie 2).

Colonies of theoretical architectural forms of frozen behaviour interact with each other and their environment to survive in their continuously changing context, like swarms of simple individuals communicating through patterns of interaction (image 3 and movie 3).

The study of the behaviour of such colonies may then be used as the basis for a taxonomy for a theory of design for the creation and growth of architectural forms that can survive within a dynamic and volatile context. SciArchitecture is a fertile field and the future of the Stigmergic behaviour of architectural colonies is a speculative one full of unpredictable outcomes and unrigged patterns that allow the environment to contribute to its behaviour.

Movie 1: Frozen behaviour: http://sanamurrani.me.uk/july06/movie1.mov
Movie 2: Stigmergy: http://sanamurrani.me.uk/july06/movie2.mov
Movie 3: Architectural colony: http://sanamurrani.me.uk/july06/movie3.mov

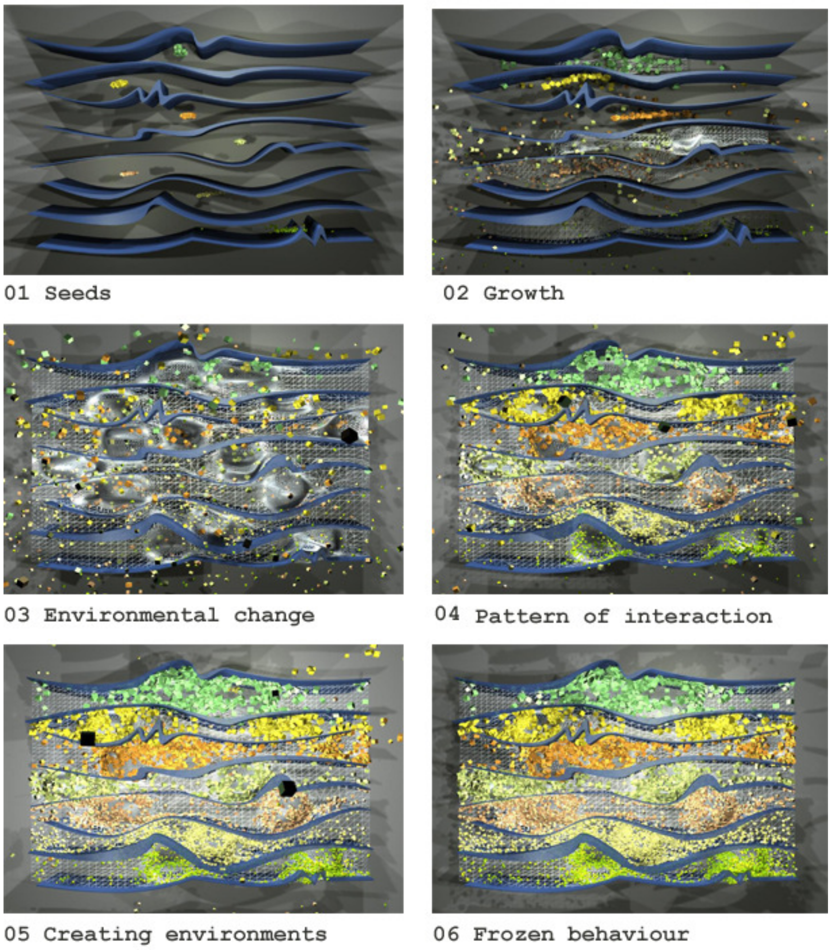

Image 1 – Sequence of frozen behaviour

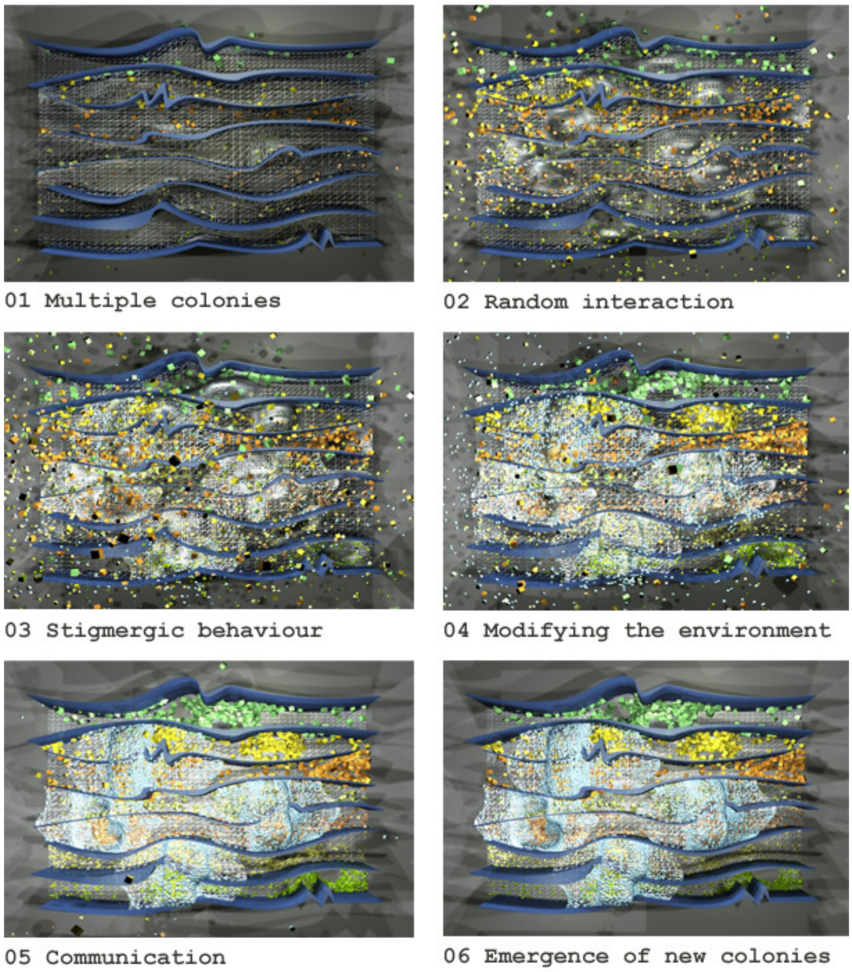

Image 2 – Stigmergic sequence

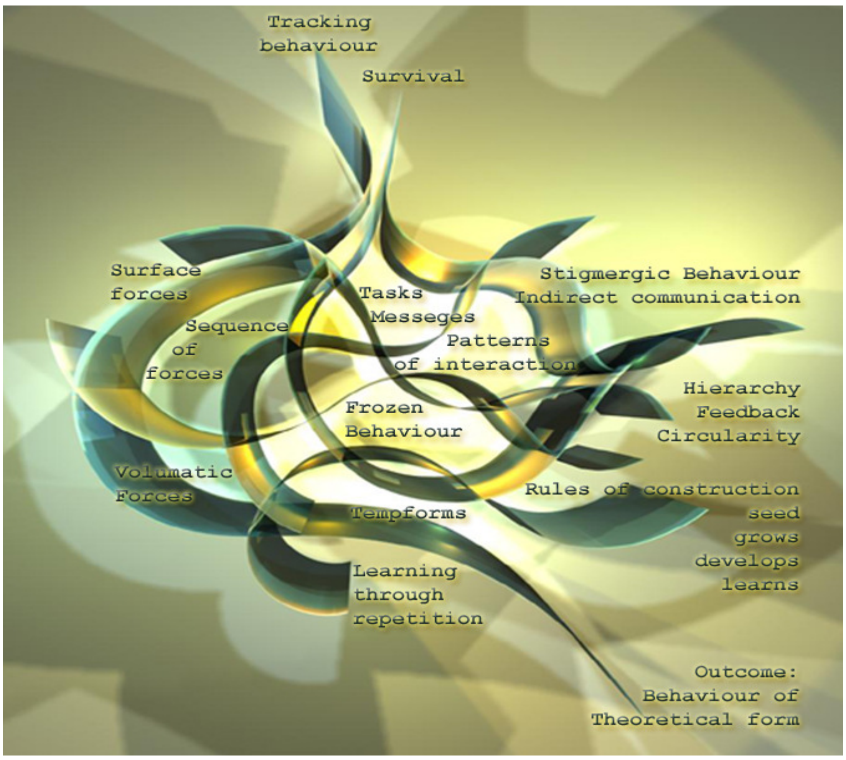

Image 3 - Sketch map

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