Towards a Living Architecture

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Interaction is the latest currency in architecture, as responsive components are now reacting to the inhabitant of the space. These components are designed and installed by the architect with a view to the phenomenology of space, where the experience of the environment is previewed and pre-constructed before it is translated into the conception of the space. However, this traditional approach to new technology leaves no scope for the architecture to be alive in and of itself, and thus the installed piece quickly becomes just that–an installation: isolated and uncontained by its environment. In this paper, we argue that a way to approach a responsive architecture is to design for a piece that is truly living, and in order to propose a living architecture first we need to understand what the architecture of a living system is. This paper suggests a conceptual framework based on the theory of *Autopoiesis* in order to create a "self-producing" system through an experiment entitled, "The Life of a Wall" (Maturana and Varela 1980). The wall has a responsive membrane controlled by a genetic algorithm that reconfigures its behaviour and learns to adapt itself continually to the evolutionary properties of the environment, thus becoming a situated, living piece.

1. INTRODUCTION: DEFINING LIFE

In order to consider the possibility of realizing an artificial model of a "living machine," we should consider how life systems could be formalized within the conventional formal theories. But first we should start by asking what life is? It seems that it is difficult to agree on a universal definition of life. Life is too complex, the answers are not simple, and certainly not the subject of clear consensus. It is nevertheless established that certain features are naturally mentioned: self-organization, emergence, autonomy, growth, development, reproduction, adaptation, responsiveness, evolution, and metabolism (Boden 2000). That all of these features are essential to life is dubious. There is general agreement, however, that the core concept of life is "self-organization:" the emergence (and maintenance) of order, out of an origin that is ordered to a lesser degree, by means of fundamental and autonomous structural development. "Self-organization" is the core concept because it necessarily involves some of the other items on the list, and because the remainder are all special cases of it. Thus, emergence, autonomy, and development are related concepts, included in the definition of "self-organization," whereas, growth, reproduction, adaptation, responsiveness, evolution, and metabolism are sub-products of it (Boden 2000).

Autopoiesis, introduced as a technical term in 1971 by Maturana and Varela, means literally self-production or self-creation, and it offers one of the most important theories for this discussion. Maturana and Varela endeavoured to to disclose the nature of living organization, to answer questions like: "What is the organization of living systems? What kind of machines are they, and how is their phenomenology, including reproduction and evolution determined by their unitary organization? Autopoietic systems in general are defined in terms of their organization, not of their components or even the properties of their components. What is crucial is "the processes and relations between processes realized through components" (Maturana and Varela 1980). The "circular" organization (organizationally closed but structurally, i.e., materially and energetically, open) of a living system (such as a cell) consists of a network of component pieces that produce the very network and its own components plus the boundary of this network.

Inspired by the theory of *Autopoiesis*, this paper seeks to describe a model for a "self-producing" machine in architecture as opposed to a "produced" or allopoietic machine. Allopoietic machines have as a product of their functioning something different from them-

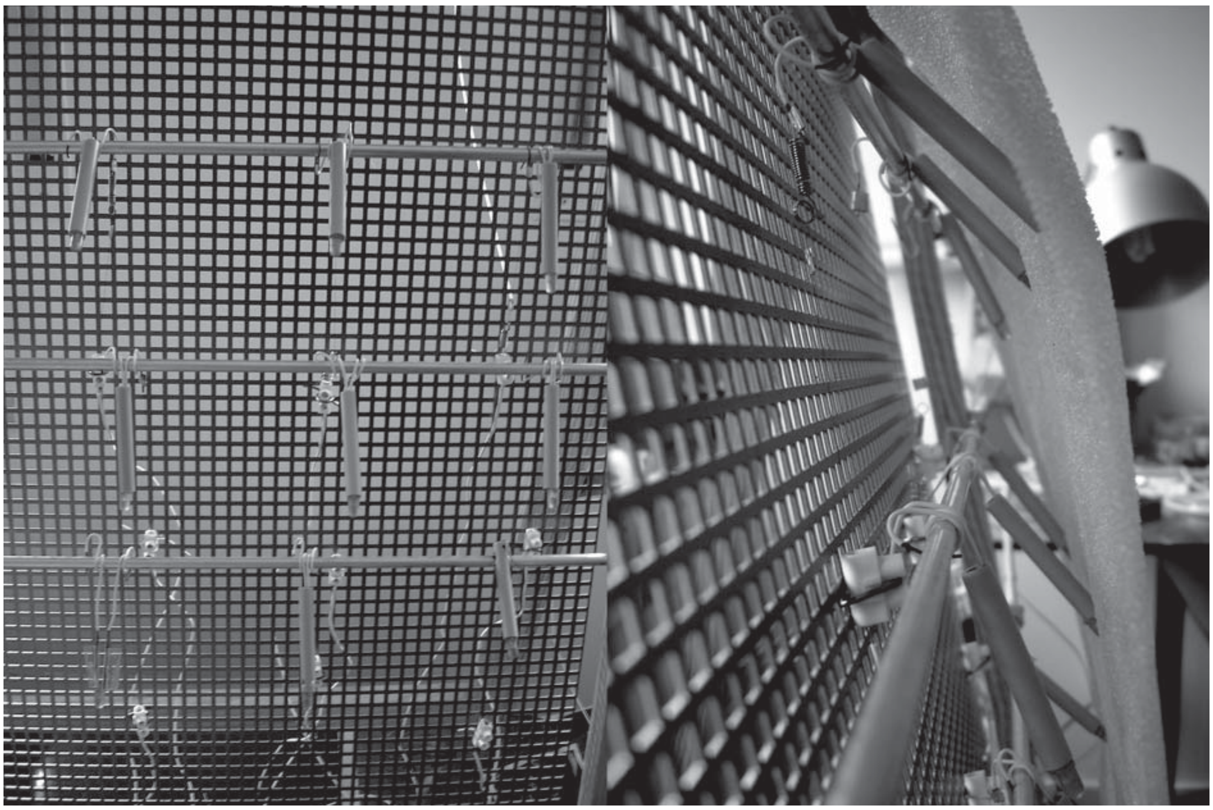

FIGURE 1 "The Life of a Wall": views of SMA's actuators.

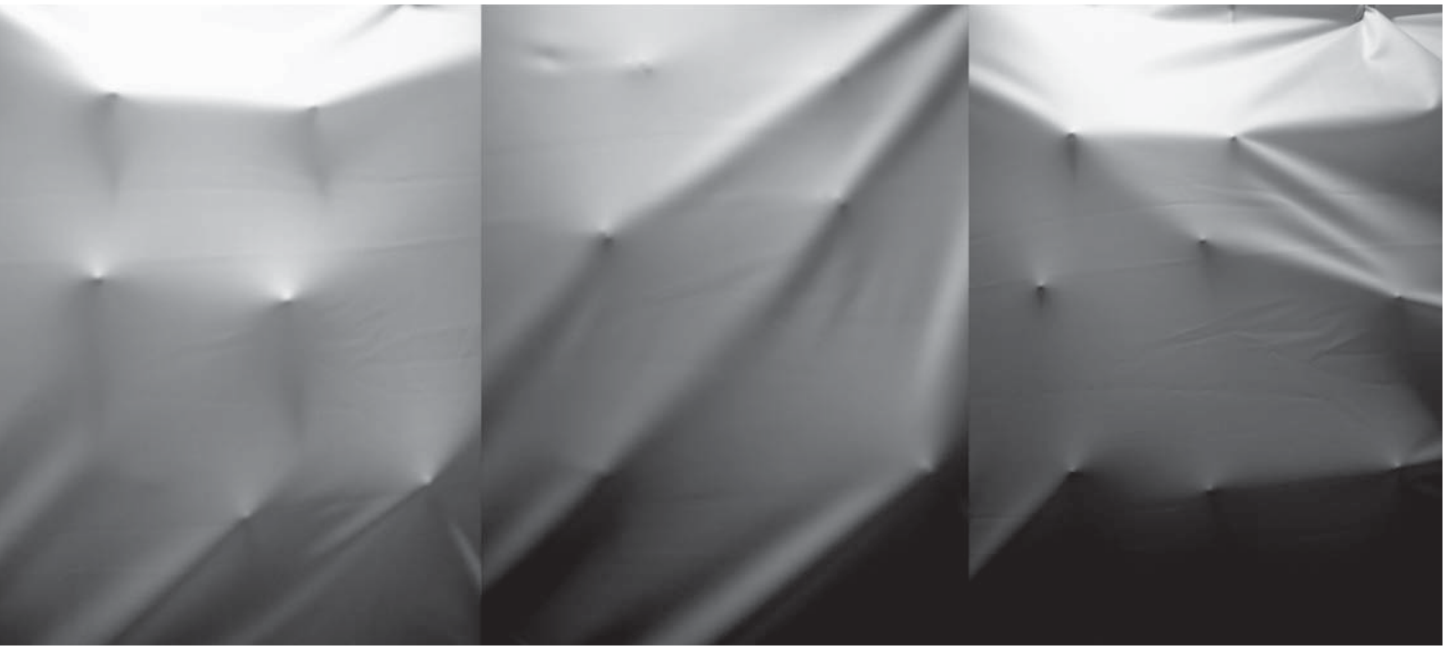

FIGURE 2 "The Life of a Wall" membrane and its actuated system changing its shape. This prototype was produced by the authors in January 2007.

selves. A robot gives us a best example of a "produced" machine, since it is biologically non-self-productive, and does not sustain itself. Its actions are deliberately programmed by a designer so as to make it behave like a human being. The robot is simply an assemblage of parts which cannot reproduce itself. When it breaks down, the broken parts must be replaced from an outside system. Therefore, the system is not running "by itself," and consequently must be to a "produced" machine. We feel this is a good description of the experiences we observe today with interactive design. Interactive surfaces, adaptive devices, art installations and so forth are taking place everywhere. They quickly become isolated pieces, technologically dated and uncontained by their environment, merely representations responding to flows, light, and sound—in reality little more than kinetic pieces of art.

The paper is structured as follows: In the second section we describe the origins of *Autopoiesis* theory. In the third section we will clarify what *Autopoiesis* is and why we have chosen it as the theoretical framework for our experiment. In the fourth section we will identify the main guidelines for creating a "self-producing" machine motivated by *Autopoiesis* theory through our experiment entitled "The Life of a Wall" and finally, in the last section, a short conclusion reflects on the outcome of the results.

2. ORIGINS–*AUTOPOIESIS* AND ARTIFICIAL LIFE

From the beginning, cybernetics has been interested in the similarities between autonomous, living systems and machines. As a specific field it grew out of a series of interdisciplinary meetings, the Macy Conferences, held between 1946 and 1953 that brought together a number of famous intellectuals, including Norbert Wiener, John Von Neumann, Warren McCulloch, and Heinz von Foerster. From its original focus on machines and animals, cybernetics quickly broadened to include minds (Bateson 1972 and Ashby 1956) and social systems. Through the 1950's, cyberneticians joined with the school of General Systems Theory (Bertalanffy 1968) founded at about the same time by Ludwig von Bertalanffy, as an attempt to build a unified science that would lay out the common principles that govern open, evolving systems. Cybernetics had a crucial influence on the birth of various modern sciences: computer science, control theory, Artificial Intelligence, cognitive science, and Artificial Life. Many of the central concepts in these fields such as complexity, self-organization, and adaptation were first explored by cyberneticians. However, after some of the sciences became independent, the remaining cyberneticists felt the need to clearly distinguish themselves from the more mechanistic approaches. They did this by emphasizing autonomy, self-organization, cognition, and the role of the observer in modelling a system.

In the early 1970's this movement became know as

Second-Order Cybernetics. Second-Order Cybernetic epistemology is, in essence, constructivist: it is defined by the belief that knowledge is not passively received either through the senses or by way of communication, but is actively built up by the cognising subject. Another principle is that the function of cognition is adaptive and serves the subject's organization of the experiential world, not the discovery of an objective ontological reality (von Glasersfeld 1995). The importance of constructivism is best understood by comparing it with the opposite, more traditional, approach in epistemology or cognitive science, which sees knowledge as a passive reflection of the external, objective reality. This implies a process of "instruction:" in order to get such an image of reality, the subject must somehow receive the information from the environment, i.e. it must be "instructed." *Autopoietic* theory provides a specific basis for explaining and addressing "contextualization," because it is an example of Second Order Cybernetics' systems-theoretic analyses which incorporate the role of an observer in defining systems—hence constructivist.

What Maturana and Varela did was to articulate a complete formulation of all the thoughts and ideas from the Macy conferences. So it was from that abstract and, to some extent, top-down theoretical perspective at the beginning of the 1970's that they started to construct the idea of *Autopoiesis*, grounding it in the notion of organizational closure, and foreseeing it as the definitional principle of a minimal living system. From their conception of *Autopoiesis* as the nuclear principle underlying the phenomenon of life, they created a new, clear, and far-reaching interdisciplinary and philosophical view.

3. WHY ADOPT *AUTOPOIESIS* THEORY TO DEFINE LIVING SYSTEMS?

3.1 THE NOTION OF *AUTOPOIESIS*

The definition of life as an autopoietic system is formulated in a mechanistic framework, i.e. all natural phenomena can be explained by physical causes. It can be contrasted with Vitalism, the philosophical theory that maintains that vital forces are active in living organisms, so that life cannot be explained solely by mechanism. An autopoietic system is formally defined by Maturana and Varela as follows:

> An autopoietic machine is a living cell, which is *a machine* that is organized (defined as a unity) as a network of processes of production, transformation, and destruction of components that produces the components which: (i) through their interactions and transformations, regenerate and realize the network of processes (relations) that produced them; and (ii) constitute it (the machine) as a concrete unity in the space in which they (the components) exist by specifying the topological domain of its realization as such a network. (Matura and Varela 1980)

To re-state: a system is autopoietic if the "bits and pieces" out of which it is composed interact with each other in such a way as to continually produce and maintain that set of "bits and pieces" and the relationships between them. According to the theory, such central biological phenomena as evolution, self-reproduction, replication, are phenomenological secondary to the constitution of autopoietic units in the physical space.

The main reason for adopting the autopoietic definition of life is our belief that a definition of life should have a certain level of abstraction in order to be applied to living systems not only as we know them, but as they could be (Langton 1986); that is to say, ultimately the definition should be universal. Critics of *Autopoiesis* say a more specific characterization of minimal autonomous systems is required, one well grounded in the universal laws of physics and chemistry (Ruiz-Mirazo and Moreno 2004). It is quite common, especially in a field like Artificial Life, to argue that a definition of life that makes any explicit reference to particular types of molecular components would be too restrictive and elitist. In this

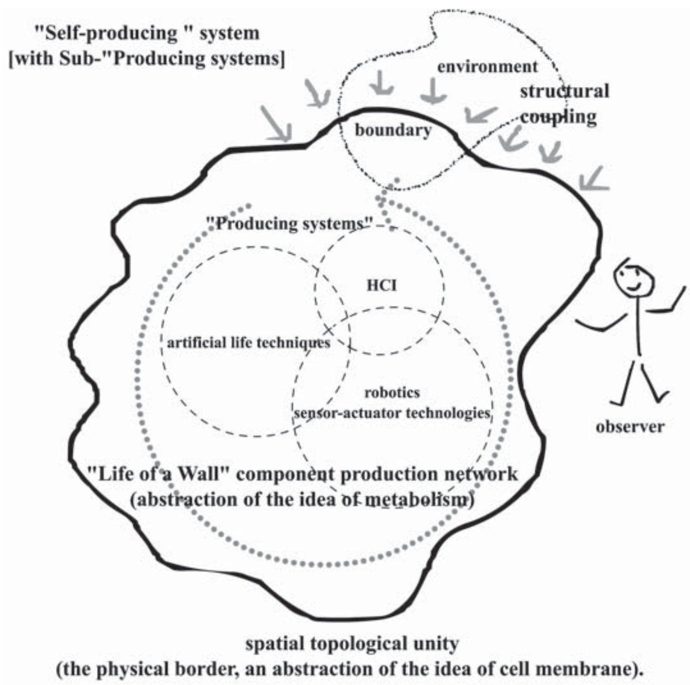

FIGURE 3 Diagram of the proposal for a "Self-Producing" machine based in "Autopoiesis" incorporating the "sub-producing" systems of our experiment.

respect, the autopoietic definition of life for Artificial Life is perfectly adequate and that is why we think it is so powerful and versatile. Furthermore, the theory of *Autopoiesis* was never (in contrast to biochemistry and molecular biology) a theory of the properties of components of living systems (Maturana and Varela 1980). *Autopoiesis* has been deliberately suggested as part of a general, abstract theory of life, a theory that attempts not only to catch the biological phenomenon of life in its most general sense as a contribution to a theoretical biology, but also to give a biologically founded epistemology, as the distinctions the observer makes (among living systems and any other units) are reflected in the theory from its very beginning.

We are aware that Autopoiesis is a highly controversial theory and it has been neglected by biologists as well as philosophers of biology as not providing the sufficient criterion for establishing the difference between living and non-living systems. It rejects the notion of genetic or biologic information as something intrinsic to the autopoietic system; rather, information is seen as being ascribed to the system from an observer's point of view. Any form of intrinsic teleology, (in technology teleological is frequently used as equivalent to goal-oriented), or, by implication, semiotics, (a form of activity, conduct, or process that involves signs, including the production of meaning) is also rejected. According to the theory such central biological phenomena as evolution, self-reproduction, replication, are phenomenologically secondary to the constitution of autopoietic units in physical space. But these aspects transcend the scope of this paper and it is not our aim to make a defence of this theory in light of biochemistry or molecular biology. Despite having a too scrupulous style, in our opinion, the theory offers a particular and logically consistent way of seeing life and thus, has a remarkable cognitive organizing capacity. Though one can question (Fleischaker 1988) whether other instances of autopoietic systems other than biological ones exist, the autopoietic definition of life is clearly not just about a particular example of DNA-based life. Rather, it has been widely demonstrated that it is possible to think of Autopoiesis in virtual, non-physical spaces (Zeleny 1977). Yet, the definition of Autopoiesis seems to be specific enough to capture a very fundamental feature of biological life—its autonomy and closed organization.

3.2. *AUTOPOIESIS* IN THE PHYSICAL SPACE

The central claim of autopoietic theory is that autopoietic organization is necessary for the emergence of living phenomenology. If that claim is taken seriously, it naturally defines a particular program within artificial life: the attempt to realize autopoietic organization in artificial, especially computational, media. Indeed, the attempt to do just this has been an integral part of work on *Autopoiesis* from its very foundation. The idea of *Autopoiesis*, and especially its computational realization, has proven very fruitful in its development and elaboration over the last thirty years (McMullin 2004). It represents a core thread in the history of what we now call artificial life; linking back directly to Von Neumann's founding work on evolutionary automata. Still, in order to for life to exist, as *Autopoiesis* defines it, embodiment is required: "*Autopoiesis* in the physical space is a necessary and sufficient condition for a system to be a living one" (Maturana and Varela 1980). And embodiment, in turn, involves more than mere physical existence. It requires the self-creation of a unitary physical system by the spontaneous formation of a physical boundary (Figure. 1).

Another important notion of *Autopoiesis* is "structural coupling," an autonomous and strictly bounded system that has nevertheless been shaped extensively by its interactions with its environment over time, just as the environment has been shaped by its interactions with the system. Note that this is not the "fitting" of a system to its environment, but rather correspondence between systems and environment, arising from the changes that each prompts in the other. Structural coupling in biological systems arises as a result of the plasticity of their structures, and the plasticity of the structure of the environment.

The physical embodiment of *Autopoiesis* is our core concern and it is exactly what we want to achieve with our experiment, with the help of Alife techniques. We propose to take *Autopoiesis* to a physical medium taking a deliberate and difficult step into embodiment. In *Autopoiesis* theory, cognition is a consequence of circularity and complexity in the form of any system whose behaviour includes maintenance of that exact form. As a biological phenomenon, cognition is viewed with respect to the organism whose conduct realizes that phenomenon. This shifts the focus from discernment of active agencies and replicable actions through which a given process ("cognition") is conducted (the viewpoint of cognitive science) to the discernment of those features of an organism's form which determine its engagement with its surroundings. This orientation led to a systematic description of organisms as self-producing units in the physical space. The principles and definitions making up this systematic schema will be called the formal aspects of autopoietic. Deriving from this formal foundation a set of operational characteristics (e.g., self-regulation; self-reference), Maturana and Varela developed a systemic explanation of cognition and a descriptive phenomenology. The principles and definitions making up this systemic description will be called the phenomenological aspects of autopoietic theory.

4. "THE LIFE OF A WALL" EXPERIMENT

What we can construct we are also able to explain (Emmeche 1997), this complements Maturana's opinion that: "Explanations are constructive: In explanations, we reproduce a system by producing another one" (Maturana and Varela 1980). Beginning with the same premise, that we cannot identify a living system unless we know what a living system is like, and to know what a living system is like means to explain it, we justify our experimental method for the fabrication of a physical prototype, our purpose is to formulate a set of guidelines for a "self-making" piece of architecture challenging *Autopoiesis* theory on its diverse formal aspects.

4.1. DESIGN DESCRIPTION

We introduce *"The Life of a Wall"* (Figures 2-3) as a prototype based on previous work from the authors (Diniz 2006, 2007). It is specifically, a reconfigurable and visual prototype, inspired by the manner in which an organism, or any of its parts, evolve and change form in a short time span, triggered by some combination of external stimuli in its ever-changing environment. It physically responds to movement, light and sound thus, it interacts spatially and temporally with the environment and its inhabitants thus communicating and constantly reshaping their perception. The dynamic of the material (our bits and pieces) is made of dozens of actuators made by Shape Memory Alloys (SMAs) and LEDs which react in real time to change the behaviour of the membrane. *"The Life of a Wall"* is controlled by a genetic algorithm in an attempt to develop a technological approach to performance skins that possess adaptive and evolutionary personality relative to changing phenomena of the environment of buildings. The behaviour of "The Life of a Wall" is the result of a complex system composed of sensors, actuators and a Genetic Algorithm (GA) component. From Alife literature (Langton 1989), we know that GA is a computational technique that roughly simulates biologic genetics. A GA involves a "genotype" which is a string of code specifying a "phenotype." Here, our "phenotype" is the shape of the membrane and the behaviour of the levers and LEDs. The environment feeds are inputs for genetic variations. When there is a feed for a low temperature, the LED's brightness increases, for example or, with high pollution levels, the actuators create "disturbed" patterns. These occurrences change the behaviour of the membrane in shape, trigger motion and light and can create random patterns on the surface, making the wall a situated living piece. The wall should respond to "empathy" and "repulsion" from the people around it. A wide range of possible phenotypes can be generated, and are evaluated for their "fitness" based on some formally specified criteria. The wall begins its learning phase by running a random set of behaviours (raising and lowering levers to form patterns), and will try to adapt its effect sequences to get the maximum "empathy" responses. The membrane will have a memory of its own "life," a record of different "events" and data setups and it will able to catalogue them into categories. Finally, conclusions should be drawn: "fitness" moments according to different crossover and mutations will be analyzed. This ephemeral experience, will tell the life story of this membrane, narrate this experiment, the "birth, life and death" of this wall, through times of "happiness" and "grief."

4.2. "LIFE OF A WALL" AS A "SELF-PRODUCING" SYSTEM

With the demise of Vitalism, it was recognized that living systems are made of the same kinds of things as the non-living. It follows that the distinctiveness of living systems must arise from the particular manner or modes of organization that they embody. Moreover, Autopoiesis allows that some of their components can be allopoietic or in our definition: "Produced systems", as so an autopoietic system can be made of produced parts.

> We can describe physical autopoietic machines, and also manipulate them, as part of a larger system that defines the independent events which perturb them... To do this however amounts to treating an autopoietic machine as an allopoietic one, and to recognize that if the independent perturbing events are regular in their nature and occurrence, an autopoietic machine, can in fact, be integrated into a larger system as a component allopoietic machine, without any alteration in its autopoietic organization. (Matura and Varela 1980)

It is difficult to articulate what this mode (or these modes) of living organization consists of. This project tries to answer such questions by first detailing where exactly our experiment is an autopoietic or "self-producing" system and where it is "producing" or allopoietic, also we are going to clarify each characteristics in terms of positive and negative tendencies (Table 1). We demonstrate that while at some levels, *"The Life of a Wall"* shares a common organization to a "self-producing" autopoietic machine; at other levels they differ substantially. Consequently, we propose a model for a "self-producing" machine that incorporates "producing" machines from our project "Life of a Wall" (Figures 1

Table 1: Comparison Between "Self-producing" and "Producing" Machines

Autopoiesis Formal Aspects		Autopoietic machines– "self-producing machines"		"The Life of a Wall"– "producing machines"
Autonomy	Yes	Autonomous, they subordinate all changes to the maintenance of their organization.	Yes	Autonomous as an organization to respond to the "world."
Individuality	Yes	Individuality, keep their organization invariant	No	Identity is dependent on the interactions with observer.
Unity /Boundaries	Yes	Self produced boundary	No	Collectively produced (boundaries defined by the observers)
Inputs/Outputs	No	Do not have inputs/outputs	Yes	Inputs/outputs
Purposes/Goals	No	Purposeless Systems	Yes	Goal oriented system
Reproduction	Yes	Reproduction by copy	No	Reconfiguration, amorphous
Evolution	Yes	Evolution between systems	Yes	Evolutionary orientation
Positive/Negative Tendencies				
		Predictable		Unpredictable
		Homeostatic—all feedback is internal to them		Dynamic balance
		Efficient		Adaptable
		Rigid		Flexible
		Growth		Evolutionary
		Central control		Central control
		Require constancy		Open to change
		External Structural Coupling		Internal/External Structural coupling
		Linear Narrative		Non-linear narratives

and 2) as an example of a special case of organization in *Autopoiesis* theory.

The experiment proves the two intimately entwined closure properties of a "self- producing" system in:

1. *Closure in production:* The system demonstrated that has its own organization—the system is composed of "bits and pieces" (levers, LEDs, SMAs, latex, steel, etc) that give rise to processes of production that, in turn, collectively produce more of those same components. The prototype organises itself to respond to the world by creating a metabolism. There is a global unity—a memory of what the system wants to be—that reaches down to organise the parts even while those parts may be adding up to produce the functioning whole.
2. *Closure in space:* This is the self-construction of a boundary, between the living self and the ambiance in which it is embedded, yet from which it distinguishes itself. The notion of individuality, or spatial topological unity (the physical border, here, the membrane possibly as an abstraction of the idea of cell membrane) is maintained by the boundary.

However, the experiment does not follow the "self-producing" rules with respect to the principle of boundary and the connection between purposes and input/outputs. The interaction with the environment might not fit the Autopoietic definition of inputs and outputs but it does execute some important features: it is a homeostatic system, its goal is to be a "machine organised to respond to the world," when it is stimulated, it reacts homeostatically, striving to reach a new accommodation that preserves its integrity. Also, our systems are guided by goals or purposes; we consider the idea of purpose to be crucial, no matter how futile it might be, in order to avoid creating autistic, isolated systems. On the other hand "The Life of a Wall" comes up with a series of features like flexibility, evolutionary aspects, and unpredictability that constitute important facets of what a living architecture should personify. We admit that defining a living system is too complex to be taken on the single autopoietic view. With our experiment, a plurality of results are welcome and therefore we suggest that "The Life of a Wall" contributes with features than the "self-producing" system based in the formal aspects of *Autopoiesis* does not preview.

5. CONCLUSIONS

Architectural design is witnessing a new and challenging age with interactive technologies. Designers are building a wide variety of physical and interactive systems drawing extensively on biological metaphors with the purpose of making people more engaged with space and "ultimately responsible for the production of architecture with the poetries of its inhabitants" (Haque 2006). Yet, no one has been able to come up with a conceptual framework that helps designers formulate systems that run by themselves, instead we watch a proliferation of nice installations everywhere. The focus should not be just in technology and smart materials. The problem with these responsive projects is that they are strictly representational, semiotic, and teleological methods of "life" systems, with notions of "genetic programme" that somehow "codes for" or "represents" information, or of the whole organism, of signs or signals that are being "interpreted" by the organism, or of "purposes," "functions," or "goals" of subsystems of a living being, are considered to be purely metaphorical, and not, according to the theory, how such systems actually operate in themselves. As a result, they are totally "*producing machines*." Artificial Life artists have demonstrated this with engaging projects on representational or metaphoric levels, pushing and giving architecture new language repertoires and new layers of interactivity. Nonetheless as much as we want to implant these experiences into the architectural fabric and not just as expensive and high maintenance performative pieces of art we have to re-invent them as real cyber-agents in the creation of meaningful space.

In this paper, by testing Maturana and Varela's notion of *Autopoiesis* as "necessary and sufficient to characterize the organization of living systems," we set up a conceptual framework based on the autopoietic phenomenology of a "self-producing" embodied system adding a sub-set of "producing" systems from our practical experiment. We demonstrated that *"*The Life of a Wall*"* could be considered a "self-producing" system as *Autopoiesis* allows particular cases of autopoietic machines in the physical space with sub-machines incorporated on it. We have argued that purpose, inputs, and outputs are important in order to create truly situated interactive pieces in space as contrary to what the "pure concept" of *Autopoiesis* looks to. Because our prototype "learns" from the environment, it concurs with the general constructivist approach of Autopoiesis with learning as a dynamic, internal, self-organizing process of coming to know, constrained by developmental interaction with an environment and fellow "knowers." We reasonably think that our system fulfils the possible lifelessness that an artificial system can realistically accomplish in the physical space. We emphasize with our prototype the "personal nature of reality" (Frazer 2001), and on the process of learning as stemming from the consensual agreement of interacting actors in a given environment. Life and intelligence might lie somewhere in the conflict between closed, unique, construction ("self-producing" systems) and open, shared, interaction ("producing" systems). The formula for that unattainable material with living characteristics might be between a specific material structure, and a general conceptual/functional organization. In future research we will analyse similar experiments in architectural contexts and do a formal comparative study with our results. *"*The Life of a Wall*"* offspring might have processes anchored in a method in which concepts such as information, meaning, and knowledge are studied in relation to the particular "observer" of the processes that implements them. We will continue our quest for a conceptual framework for living architectures; we wish the distinctions aroused by our experiment harmonize with a more flexible autopoietic theory or inspire different ways to design "living" systems.

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