Towards the design and fabrication of unsupervised learning construction systems

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Abstract. In this paper we explore the concept and design guidelines for an Autonomous Learning Oriented Proto System (ALOPS), a construction system designed to enhance its own performance through time. Our research has been focused on the fabrication of a prototype for a porous wall system which reacts to light intensities by closing or opening its apertures. Taking that aim, we used a combination of robotics, programing, and material behaviour to endow the system with the capacity to record reactions towards encountered sets of conditions during its active energy periods, allowing the system to use this knowledge database to evolve autonomously by feeding this information back into the computation process. This approach in construction systems opens up the architectural design processes to address the creation of digital memory structures rather than complex algorithms in order to operate specific functions. With this development, the architect could think of architectures constantly evolving by learning from their environments as well as of users forming symbiotic and behavioural bonds with the emergent spatial personalities, thus affecting the underpinning relationships between architecture, user and context.

Keywords. Performance architecture; unsupervised learning; machine learning.

1. Introduction

For the last year (2012) we were working to generate an art piece related to architecture. Our first approach looked at the fabrication of a responsive surface that reacts to light intensities to open or close its apertures; we referred to this prototype as a ‘proto-membrane’ due its main function of controlling the light exchange from one side of the surface to the other. As the project moved forward we faced decisions that shaped and changed the direction of our research, from selecting a
solar power source to feed the prototype and no batteries appealing to an unplugged performance, and the use of softer and flexible materials for actuation to the recording of the information encountered by the system.

Questions like “What kind of information can we save?” or “What for?” Started conversations about how spatial performance could be affected if we included this recorded information in the computation process. Upon further research we came across the field of machine learning and to be more specific the unsupervised learning methods. These concepts seemed to fit somehow with some of the latest descriptions of how performance in architecture works.

The current paper is divided in three main sections in the first part will address the performative paradigm and unsupervised learning techniques defining a theoretical and practical ground upon which the concept of ALOPS is based. In the second part we talk about our experience working with these types of systems through the description of their components and the design challenges that were presented. The third part will revise the design process and capture the different creative activities in which we incurred throughout the development of the first prototype.

2. Contextualization

The incursion of robotics and cybernetics in the field of architecture has been around for several decades, attempting to portray the notion of a moving, responsive and adaptable space. These attempts have generated a conversation in the theoretical discourse of the architectural field finding a niche in the performative paradigm; moreover the attempts themselves remain as samples of the different approaches to this intersection as well as their flaws and achievements.

2.1. CONCEPTS OF PERFORMANCE IN ARCHITECTURE

In the theoretical discourse of “Performance in Architecture” we have witnessed the two main approaches in which this term has been used. From Performativity as a form of representation leading buildings and spaces to attempt the representation and interpretation of different characters falling into symbolic designs used in the first incursions of the performative turn in the 1940s and 1950s, to the use of performance merely as a synonym for function. These definitions suffered from crucial disadvantages coping with a fast changing society and technologies hence we will not use them for the purpose of this paper.

In recent years the concept of architectural performance has been expanded by Michael Hensel (2010), defining it as a multi-agent network of relationships that result in a broader range of possibilities for spatial performances considering four main agents as components of this network: the subject, the environment, spatial
organization and material organization. We will adopt this notion of multiple forces shaping the performance of architecture which introduces a new state in the relationship of form and function, where form becomes a result of the interaction and communication between the agents, and specific functions are demanded by the nature of their relationships. Although the concept of performative architecture proposed by Hensel relies on a biological paradigm making many interpretations fall into bio-representation and performance choreography, we will use the new concepts of multiple interaction as a definition of performance to work as a theoretical base on which our research stands.

2.2. PERFORMATIVE DESIGN PRECEDENTS

When it comes to the actual spatial performances accomplished via construction we take as a first reference Jean Nouvel’s Museum of the Arabic world 1981; in this famous (or to some infamous) design, the building’s façade was inspired by the traditional Arabic apertures that filter the intense light of the environment, this exterior treatment was embedded with a mechanism to open or close the apertures controlling dynamically the amount of light entering the space. The relevance of this building, whether or not it was a successful endeavour, resides in its attempt to include a certain performance where the building’s aesthetics express different effects while responding to information obtained from the environment, achieving a first attempt of communication between the agents: environmental and material organisations.

Outside the field of architecture Theo Jansen’s Strandbeest dynamic structures 1990, the wind powered skeletons that work between the realms of sculpture and robotics were used to represent artificial life. They also use information and energy from the environment to act as animals, combined with its materiality. Although his structures did not form a spatial enclosure they added dynamism to the ambiance of the context of the beach. The former examples play with environmental forces and start producing performances that convey effectual results on the subject.

When we turn into the subject as an active agent, the BMW Gina concept Car 2008 proposes a new relationship between the functions of the car and the user, where the car reacts to user interaction. Although the concept of interactive controls for a car has been around for several years, Gina’s interaction is exponential due the material selected to actuate in front of the user; shifting from hard metallic panels towards the use of flexible textiles the car delivers soft shape transformations that communicate beyond the functional states of the machine.

Perhaps one of the most relevant works that closely relates to what the elements postulated in this paper try to achieve is the Hylozoic soil installation by Philip Beesley for the Venice Biennale in 2009. This artificial forest implements a
distributed sensor network driven by dozens of microprocessors, generating waves of reflexive responses to those drawn into its vast array of acrylic fern stalagmites. This referential piece, described as pursuing the physical and functional representation of a biological organism uses global behaviours to choreograph aesthetical performances and it accomplishes several goals desirable by the performative paradigm in architecture; like the luring and continuous stimulation of the subject via the dynamic shifts in shape, material organization as well as it creates a communication network between these elements that results in a spatial defining system whose performance is not specified entirely by the designer.

Taking these works as precedence of a contemporary branch of architectural theory and practice oriented towards the exploration of the performative paradigm including all the concepts that it might entail, our work positions itself recognizing these achievements, adding memory, its structures and information flows as crucial elements in the performative process.

2.3. A GLIMPSE INTO UNSUPERVISED LEARNING

Inside the field of machine learning emerges the Unsupervised Learning approach as an alternative methodology for machines to achieve different objectives. In general terms, the machine is able to recognize certain patterns or structures inside the bulk of input data; since it does not get any error or reward signal when evaluating a potential solution it’s said that its learning process becomes unsupervised. There has been a number of different approaches to address the UL processes using purely statistical computation, data mining methods, KDD (Knowledge discovery in data), Clustering, Fuzzy logics, Blind Signal Separation and Neural Networking.

Although the field of UL applied to machine learning has been around for the last half of the XX century there are fundamental questions to be solved. Some issues have been highlighted with their potential approaches for a solution (Hinton et al., 1999). The first issue could be explained with a question: What do we want the system to learn without giving external instruction? Some possibilities are to find clusters in the input data, extract features that characterize the input data more compactly or uncover non-accidental coincidences within the input data.

Another issue was the fact that most unsupervised learning algorithms are based on statistical estimation of the input data. Such algorithms generally suffer with large patterns as the ones produced by the real-world behaviour. In this case computational complexity is an important consideration. Therefore, future investigation on unsupervised learning would need to incorporate appropriate prior structure.

Despite these obstacles, as Andrew Ng pointed out at his conference at Stanford University titled *The future of Robotics and Artificial Intelligence* (2011), machine learning methodologies can help us achieve the bigger Artificial
Intelligence dream of creating machines that can see the world, think, understand and be intelligent the way that people are via neural computation and Unsupervised Learning techniques.

2.4. UNSUPERVISED PERFORMANCE

We will address two problems presented by Unsupervised Learning approach inside the performative paradigm of architecture (using the term of unsupervised performance for these effects). The first problem states an ambiguity of direction where the reason for the system to learn is not clear. In his reading of Umberto Eco’s work, Michael Hensel brings out that:

Umberto Eco’s work invests part of the action in the spectator (Eco, 1989). Such ‘open work’ is characterised by a deliberate ambiguity of meaning. According to Eco, ‘open works’ must leave the arrangement of some of their constituents to the public or to chance, thus giving these works a field of possible orders rather than a single definite one (Hensel, 2010).

Bringing the question of performance control down to a matter of balance between control and ambiguity where the designer’s directive is needed but does not control the complete performance of the system, letting the other agents to participate in shaping the performative results through time. We will use this approach to include the designer as an influential agent of the system through the establishment of such directives and the system’s creative integration.

The second issue addresses a problem of computation overload when systems deal with the real world and its immense amount of information in order to learn from scratch. As a possible solution it states (as the analogy of the new-born baby’s brain illustrates) the necessity to take into account previous knowledge gained through its experiences and more important, the communication of this information through different generations to be used as a source of knowledge. Our approach investigates the possibility to endow constructive systems with the ability to digitally record and communicate information relevant to the directive stipulated by the designer through generations marked by active or inactive periods of energy in the system. Heading towards a performance that includes both the different agents before mentioned in the performative results and the information stored from previous experiences and previous generations.

3. Elements of ALOPS (Autonomous Learning Oriented Proto-System)

ALOPS (Figure 1) are constituted by two main characteristics: the autonomy or independence from human control and the ability to learn from their own
experiences. Independence is needed from the start to unplug the system from different types of infrastructure, de-contextualizing it, making it a free constructive entity with the possibility to be a learning body which also becomes crucial in the adaptation of the system to different environments, users and other constructive systems.

3.1. SYSTEM HARDWARE COMPONENTS

The physical composition of the system forms a multi-layered arrange of elements that communicate geometrically and digitally between each other. We will start our description from the structural component which in this case serves not only as a chassis for the system but also as the generator of geometrical communication possibilities between the components that are arranged throughout and within it. The next two layers going inwards consist of the Digital Memory and Processing Units, in charge of performing all the digital control of the system, such important tasks take advantage of the structural component arrangement to get protected.

The other three layers described in (Figure 2) as going on top of the structural component are the interfacing components of the system consisting of an Actuation System transforming instructions and energy into movement, Material Communication expressing these adaptations with the desired aesthetical coordination, and an Energy Supply/Sensibility component in charge of gathering information from the environment as well as the necessary energy to perform the required processes. Let us remember that the layering rendered in (Figure 2) does not imply a geometrical superposition of elements as they can be weaved, attached or arranged in different ways, in this case the diagram focuses on the geometrical and digital communication between these physical components.
3.2. SOFTWARE MODULES

The flow of information is arranged into an eight shaped feedback loop where the input from the context, designed patterns, and user interaction is collected by an
Environment Status Module where even the status of other ALOPS is added to have a richer image of the present. At the centre of both loops we find the Behaviour Computation Module in charge of aggregating information stored in the knowledge database to calculate a resulting behaviour according with the proposed directives. That resulting behaviour is then sent to different actuation and communication devices via an Output Module and is also sent to the Digital Memory Module for the recording of the current experience and its addition to the knowledge database; our first prototype used a simple milestone interpolation algorithm to statistically record system status over time.

4. Design

The conceptualization part of the process is crucial, is at this point when we state the primary objectives, the purpose of the system and the functions of the elements that compose it, as well as its overall aesthetic concept, entangled to the spatial qualities you want to achieve. The primary directive can be any function you can think of for a construction system, a motif to consider the design of an ALOPS system in the first place. In this case we used as our main directive the efficient control of solar incidence for an interior space. The secondary directive has to deal with stimuli and self-preservation. Thus the system’s objective is to survive or at least prolong its energy cycles to carry out the primary directive. The third directive will address the evolution of the system, making it transcend through generations via memory transmission.

After defining our aesthetic and functional intentions as well as considering our main directives, we proceed to carry a design method where all the fields are tackled in parallel keeping different systems informing each other and reacting to design changes and decisions. With this approach we also keep the integration of the systems very close not to leave it as a later process. We catalogued the main design activities into the following fields:

- **Creative Perception System**: With very little input you can figure out a lot of information. For example, measuring light intensities we can know about light cycles (time), knowing the number of light cycles we can know how many generations have passed and their average life span, then we can differentiate behaviours in light from cloudy day to a hot summer.
- **Creative Actuation System**: We need to be creative with our actuation systems, nowadays the actuation options have expanded but they are still not as diverse as we would want, besides the energy consumption becomes crucial in the design of this.
- **Creative Learning Mechanisms**: In the field of structuring memory transmission, the quality of the information and the way we store it is of great importance, we already mentioned the different approaches in machine learning to accomplish
unsupervised processes. For the first prototype’s memory structure we used a basic statistical process of saving information data inside a series of milestones obtaining interpolated values to be used in the computation. The algorithm attaches different weights to both direct input and the values obtained from the previous generations to calculate its behaviour, finally an energy threshold is placed so when the system is about to run out of energy, it then records the information stored in the milestones of that ending generation consolidating knowledge preservation.

- **Creative Materiality**: This part of the design process works very close to the actuation system for the sake of minimizing active motion, relying on material properties and behaviours to fulfil the effectual goals.

5. Conclusion and Future Development

The first ALOPS prototype (Figure 4) achieved the system’s reaction to changes in light intensities, and showed certain movements that were clearly not programmed but evidenced reflexes obtained from previous experiences. The materiality, its dynamics even the sound of the actuation mechanisms started communicating different expressions and behaviours to us and without knowing the exact status of the system we started to relate them to happy, playful, sad or anger moments. Currently displayed as part of a multidisciplinary art exhibition, the first ALOPS prototype hangs in a museum room as a sort of robotic taxidermy.

Possible lines of research were found both in the specific design techniques previously described and in the overall coordination of material, perception and actuation by the designer towards an effective characterization of the system. As a next step our research line will look into how the different design activities recognized can be introduced into academic programs. Another direction points towards the issue of evaluating efficiency for specific ALOPS functions when there are uncontrolled variables inside the computation process. Although overall
machine learning field of study is at early stages we visualize different ALOPS being used in buildings for climate control, structural adaptation, dynamic spatial reconfiguration and the production of aesthetical effects.

We can then imagine a space, a building even a city surrounded by ALOPS, where the behaviours of structures materials and other building systems continually evolve and communicate to each other adapting to changes in the environment, different users, and the shifts in the states of other ALOPS. Not only in the computer aided design process will the constructive elements communicate and react but in the physical realm as well. While effectively carrying their functions, they could then start to establish different languages to communicate with us, behavioural languages rich in complexity that directly engage our emotions.

References