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Stigmergy-based parasitic strategies in architectural design for the transformation of existing heritage

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Abstract: The refurbishment of an abandoned post-WWII factory becomes a case study to propose an alternative approach to Italy's mainstream preservation logics through parasitic architecture. Drawing from the fields of stigmergy-based systems, swarm intelligence and Embodied Embedded Cognition, their characterizing features and processes have been coded into a digital ecosystem where multi-agent systems operate. The project exploits the ecosystem and develops through strategies based on intrusion, adaptation and growth focusing on the relationships between different systems (host/parasite); the goal is to turn the present building (which has become an urban landmark for a socially intricate community) into a polarizing element for the community that facilitates its cultural expression by working on the material and spatial substrate as its prerequisites.

Keywords: Parasitism, Stigmergy, Architecture, Multi-agent systems, Ecosystem, Computation, Refurbishment.

1 Introduction and premises

The Red Queen hypothesis is an hypothesis in evolutionary biology that derives from the dialogue between Alice and the Red Queen in Lewis Carroll's *Through the Looking-Glass and What Alice Found There*. It proposes that the struggle organisms face in order to adapt, evolve and spread is not just aimed to gain reproductive advantage, but it's also a basic prerequisite for survival while facing similarly evolving opposing organisms in an ever-changing environment (as the Red Queen says "*it takes all the running you can do, to keep in the same place"*). These kind of interspecies dynamics emerge in ecosystems at the scale of the community (or *biocoenosis* - as coined by Möbius, 1877), where several species compete for the resources of a common habitat.

Parasitism is one of the strategies by which such struggle is successfully carried on; it's a non-mutual symbiotic relationship where a system (parasite) exploits resources from another system (host) in order to thrive and proliferate; the original system is not destroyed and becomes an extension of the parasite system. Since the two involved systems are very different from each other in structure and organization, the parasite needs to "hack" into the host system creating a communication interface that mimics the host's internal organization. Such interface has a central role in establishing the communicative capacity and systems interactivity, and it can reach great sophistication.

The success of this strategy of hacking and control implies for the parasite a capacity to read and navigate the host's system. There are two other important factors to parasitism that are relevant for architectural application on our case study:

- the identities of the parasite and the host remain separate and perceivable
- the original system is altered but not destroyed and becomes an extension of the parasitic system.

The aim of the paper is to explain in deep the design process based on the relation among behavioral rules of competing multi-agent populations, stigmergy-based parasitic strategies and spatial and tectonics integration, through its application to a specific case study. Although it is important for such process to be as seamless as possible in terms of consistency, for methodological purposes (i.e. some assessments relying on the designer's sensibility, phases that have to be applied sequentially as one's outcomes are the input data of the next one) and limitations of technological nature (i.e. computational power required vs available) the implementation had to be fractioned into steps. In other words, steps are a choice made out of both necessity and opportunity; our position among the variety of computation-based approaches to design holds that a designer's sensibility should be trained in the framework of complexity, and emergence and that it can be exerted and traced through the pattern of choices he makes throughout the process.

In our case the simulated parasitic system will map and alter the spatial and structural existing system (host) by means of two populations of agents competing for its resources in a two-phases process. Competition-driven spatial organization patterns of intrusion and alteration will be explored and filtered in the first phase, while the second phase will introduce an expansion strategy by means of soft bodies adaptation on the altered factory space.

2 Case study

Figure 1: The Ex-OTE Factory (3D and photos by the authors, 2013)

As the design process requires a host to deal with, the choice of a case study tended towards something that could be altered (but not destroyed) and yet needed to maintain its own identity. The chosen case study is a former factory in the city of Bergamo, the ex-OTE. Built in 1950 and abandoned in the 90es, it belongs to a series of factories that were built along the Seriana Valley (along the Serio River - Bergamo, Italy) following the railway expansion in the area at the beginning of the 20th century and that are now abandoned. Italy has an history of its own that tends toward preservation when dealing with pre-existing buildings: the current widespread cultural trend for this kind of building and spaces is to give them the status of heritage and thus calls for a low-impact refurbishment. The flip side of the coin is that the permanence of a substantially unchanged rigid system (the former factory structure, spaces and distribution) constitutes in itself an obstacle in spatial organizations for strategies and architectures that can address much better contemporary issues that call for spatial heterogeneity. We don’t claim to have found a new strategy for building renovation, rather try to propose a different process that requires an in-deep investigation on the tectonic and spatial level since we consider spatial and material organization the pre-requisites for implementing new functions and open up potential for positive social impact. The factory is an ideal candidate for its status, its size and location, but its spatial structure (comprised of a central square open space hall and a traversing volume which cuts parallel to one side close to its edge) isn’t quite fit for the task.

There are embryos of art and writing culture and DIY culture, but they need to be nurtured in appropriate spaces: heterogeneous yet continuous spaces, that can offer a variety of differentiated qualities and opportunities while still grant information exchange and physical connection among each other. Spatial heterogeneity and continuity of flow are the kind of evaluation and filtering criteria that will be adopted in the process of driving the spatial explorations towards a possible convergence.

3 Simulation framework

Multi-agent based simulations emulate the behavioral qualities of swarm systems by interaction rules among individuals and/or between an individual and its environment; such rules can be aimed towards (or lead to an emergence of) cooperation or competition. Our intention was to go beyond the sheer collaborative bearing of single swarms and tap into the spatial formation qualities (which are essential in defining the resource distribution network topology) of processes triggered only by the competition of two or more populations sharing a common habitat, which in this case is the parasitized host. Thus, our simulation involves two populations of parasites (simulated as stigmergy-based multi-agent systems) competing for the host's resources.

The parasites-host interface that tightly connects the involved systems throughout the several phases of the design process by allowing continuous data flow integration and communication is implemented via an environmental information substrate through which all the involved systems are able to communicate. This form of indirect communication through an environment or medium is well known in biology as stigmergic behavior: it is typical in communal species (such as ants and termites) and it works through the release in the environment and eventual detection of a chemical agent called pheromone, which in our case will be translated as a number representing a concentration in specific locations. Starting from the theoretical premises in Jones (2010), the classical multi-agent system model theorized by Reynolds and comprised of the basic local rules of cohesion, separation and alignment was extended with chemotaxic stigmergy, the capacity of perceiving and react to chemical gradients of concentration.

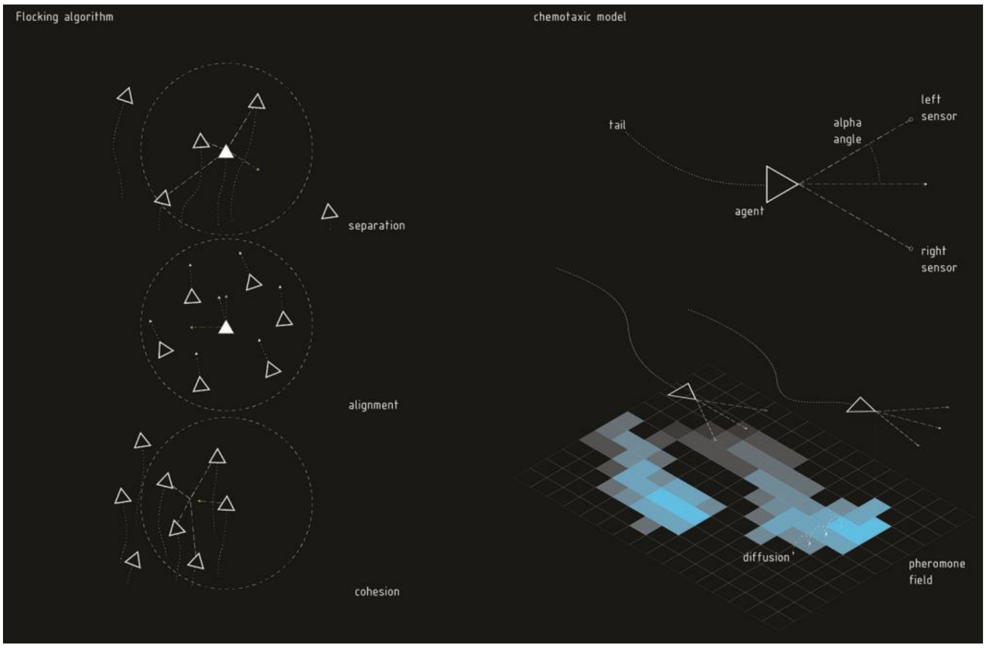

Figure 2: The Reynolds (left) and Jones (right) models for agent behaviors

Since our environment was modeled as a discreet 3-dimensional non-isotropic voxel field with chemical gradients encoded as tensor data in each voxel, not just chemical concentrations but multiple layers of information such as solar radiation, stress and any other pervasive information the designer might consider relevant can be stored in any point of its discreet grid.

The global environment is thus coded as an antiobject, a computational object that reverses the foreground/background relations by becoming an active subject in the computation (Repenning, 2006), that carries and computes multiple discreet information in each of its voxel cells, doing most of the heavy-lifting in the computational process. It acts as common substrate for data exchange through which the multi-agent systems and the host are communicating by just reading/writing on it. The information in the environment is then simulated as a chemical element that diffuses and evaporates with a changeable rate: by changing its concentration, diffusion and evaporation rates, along with the agents capacities to detect and react to it as well as the intensity of such reaction (whom correspond to the three basic actions involved in behavioral ecology: sensibility, reactivity, irritability) it is possible to affect the outcomes and explore the global system expression range. The environment is also readable as a map of the driving factors for adaptation, which emerges through indirect coordination. Agents can selectively read and write data from it and change their behavior accordingly: such continuous feedback loop allows for indirect coordination among agents system and intercommunication among different agent systems within the same environment. Building the design process upon a common information substrate makes it also possible to coherently embed and correlate relational properties of agents, morphological generation, spatial negotiation and organization protocols, providing also sound information for the fabrication phase (which is possible but not yet developed at this stage of the research).

The potential of the chemotaxic approach for spatial negotiation, emergent pattern formation and integrated tectonics has then been probed through a series of digital simulations on a multiplicity of scales ranging from massing and volume morphogenesis to surface tectonics and discretization.

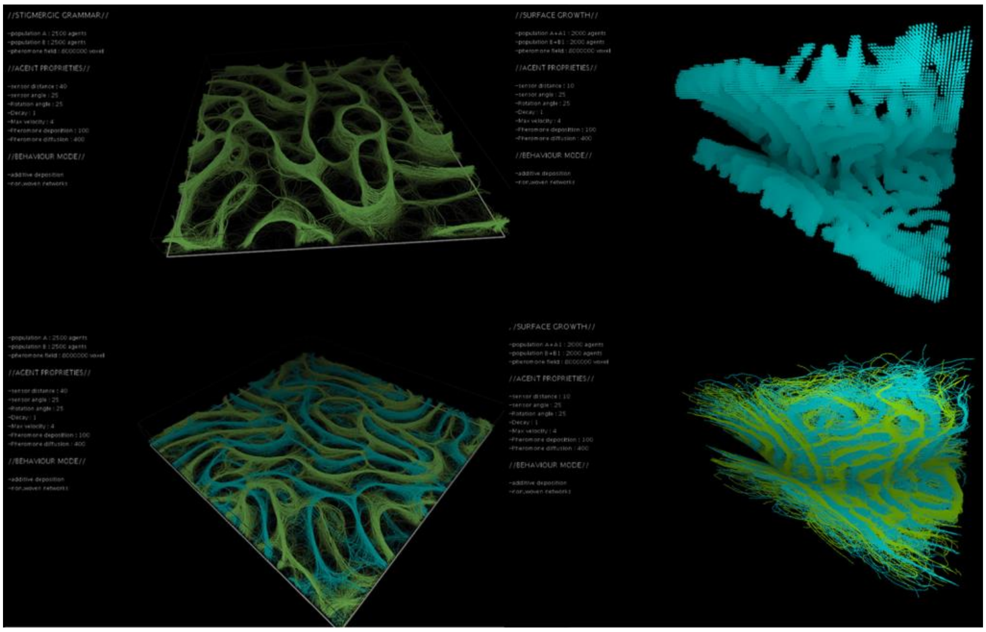

Figure 3: Schematics and simulation of the stigmergic grammars for competing populations

The simulations are built upon a common framework, called stigmergic grammar: each agent perceives pheromone deposition from its population mates, but consumes pheromone from the other one; this is the way the pheromone field acts as communicative substrate for inter- and intra-agents population relationships and helps calculation avoiding heavy neighbor search and proximity calculations. The saved computational power is not used for the purpose of speed but in order to increase the size of the populations involved or the resolution of the architectural outcome. The multi-populated system grows along the Z axis, casting material and mutually avoiding each other's trails networks on each loop. The 2.5D simulation was chosen as a simplified initial setup that allowed two important features: simulate growth by deposition over time and extract isosurfaces of volumetric and spatial organization from the voxel space. The choice of two populations is motivated by the fact that each population tends to grow until it fills the whole space or encounters a constraint (like a competitor) or inhibition (resources depletion): the two populations will tend to fill the whole space assigned by mutually and continuously negotiating the reciprocal boundaries, resulting in patterns of spatial subdivision that emerge over time. It is then possible to consider one of the two populations' resulting occupied volume as a void, forming an inner space that creates continuous networked connections within the existent factory space.

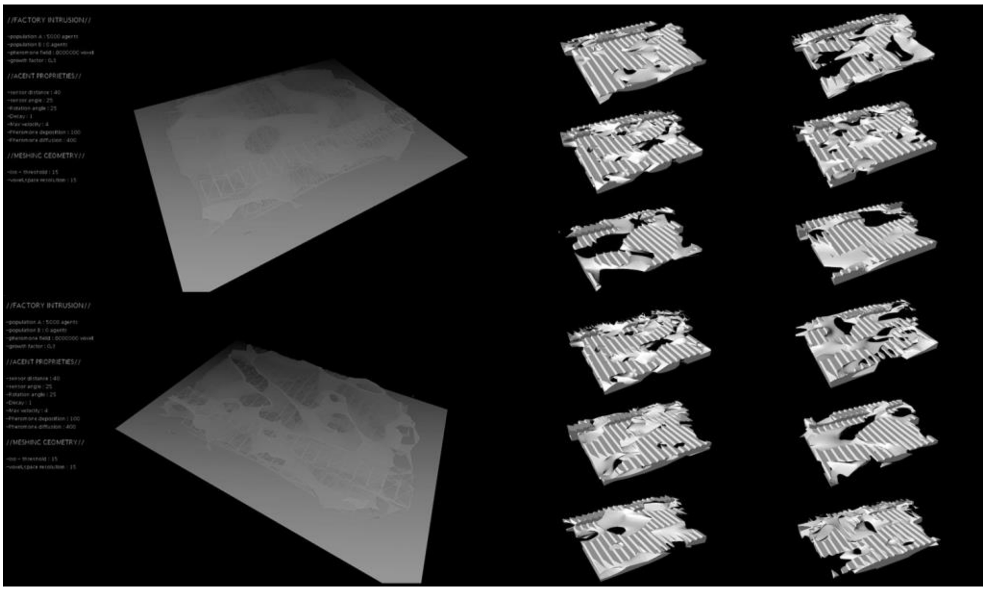

Figure 4: Isosurface simulation and array of solutions (selected by spatial heterogeneity criteria) corresponding to simulations with varying behavioral parameters

4 Design implementation

The stigmergic grammar has been applied first to the scale of the existing building. Initial information extracted from the site analysis such as main access points and possible flows through the area were passed to the agent system in the form of spatial information data as inputs parameters and system constraints. A series of simulations was performed (extracting isosurfaces from the density values field), producing a taxonomy of outputs, a catalogue of possible spatial configurations among which choose by means of criteria based on spatial continuity, permeability and connectedness in order to feed the next generation of simulations.

The designer exerts different levels of control over the bottom-up process: although he/she does not impose the final outcome, once a relation and understanding of the affects produced by changes in input parameters is established, he/she has the possibility to affect the self-organization capacity of the multi-agent system by exalting/inhibiting system expressions and qualities that emerge from the simulation, or channel it towards pre-traced design trajectories (i.e. making it work on a designed morphology).

Embodied Embedded Cognition (EEC) is a philosophical theoretical position that states the emergence of conscious and intelligent behavior as interplay between brain, body and world. Contrary to the cognitivistic approach (according to which cognitive systems are purely brain based to whom bodies act only as input-output devices) it considers embodiment (topology and organization of the body and its internal milieu as influential on higher cognitive processes) and embeddedness (physical interactions between body and world constrain the possible behavior of the organisms) are an integral part of cognitive processes: body, world and brain form a system and together they are responsible for the emergence of intelligent behavior as a system property.

In the attempt to encode the same kind of 3-factor system for the exploration of adaptive morphological capacities, a further simulation step was implemented by introducing softbody modules.

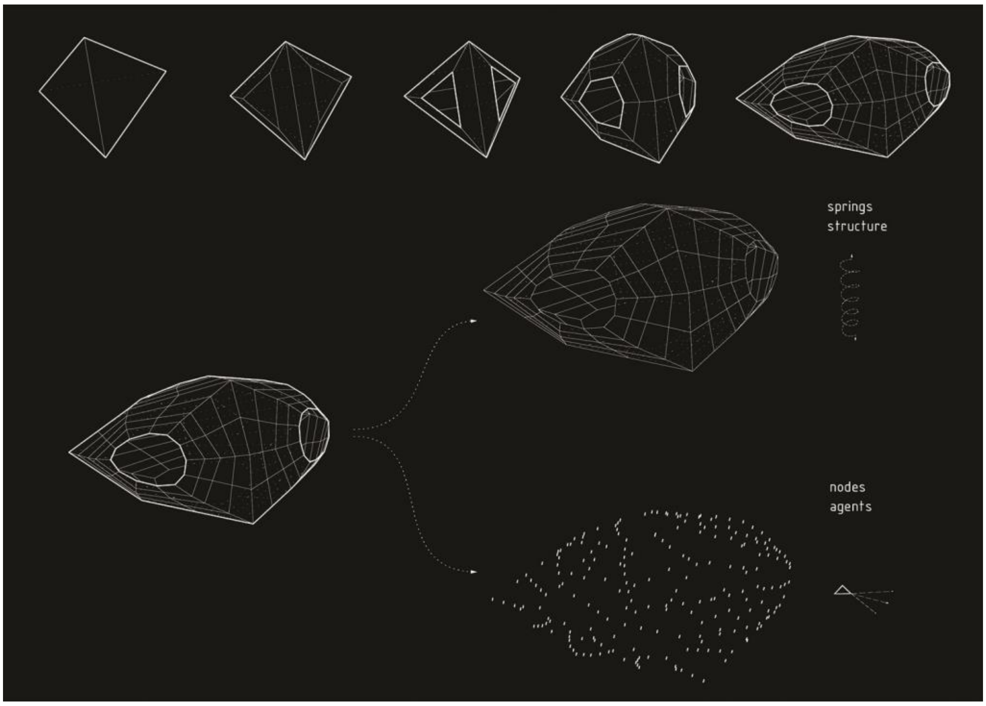

Figure 5: Softbody modules implementation, from topology to agent and springs structure

Softbodies are adaptive morphologies that preserve their topology built by instantiating agents on the vertices of discrete spring-based mesh lattices (coded via Verlet integration). The agents are influenced through gradients of spring stiffness and particle forces by continuous pheromone interaction. Agents instanced on vertices are also obliged to relate to agents/mesh vertices neighbor, avoiding mesh collapse (which was often happening with non-manifold meshes). Here data flows directly from the agents' sensor-based perceptual system to the body configuration; informed topologies produce shapes layouts that in turn affect the information pattern, its distribution on the softbody itself and the environment, feeding back into the agent system until eventually a stable configuration is reached. The final configuration was chosen after series of simulations on a wide range of mesh samples; those simulations evidenced that closed manifold meshes (deriving from genus 2 meshes), led to an interesting compromise between designer's control and systemic variation in terms of outcomes. At a smaller scale, thanks to the development of a custom strategy for mapping 2D simulation to 3D topological space through undistorted projections, the surfaces intricate tectonics are the result of multiple populations of agents acting influenced by several parameters, including inherited-endogenous (such as performative ones) and intentional (designer decisions) ones.

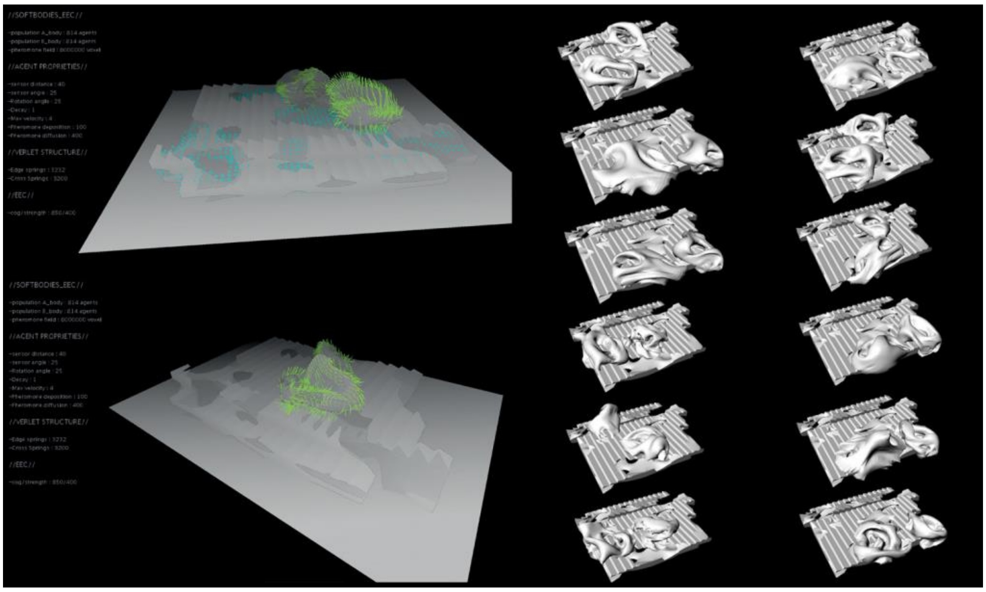

Figure 6: Softbody simulation on the isosurface (pheromone level in cyan, agents in green) with array of filtered configurations

Mesh vertices acted as tensor space, embedding two different information layers derived form solar radiation analysis and stress analysis on a finite elements model based on the same mesh (both mapped as RGB values map). A third layer (again, there is potentially no limit to the number of information layers embedded in the nodes of a mesh topology) was added up to let the designer influence and drive intentionally the growth process by painting mesh vertices "weight" (in mesh modeling, weight refers to the relative importance of a vertex during an operation; in our case the weight was represented in a scale form black to white).

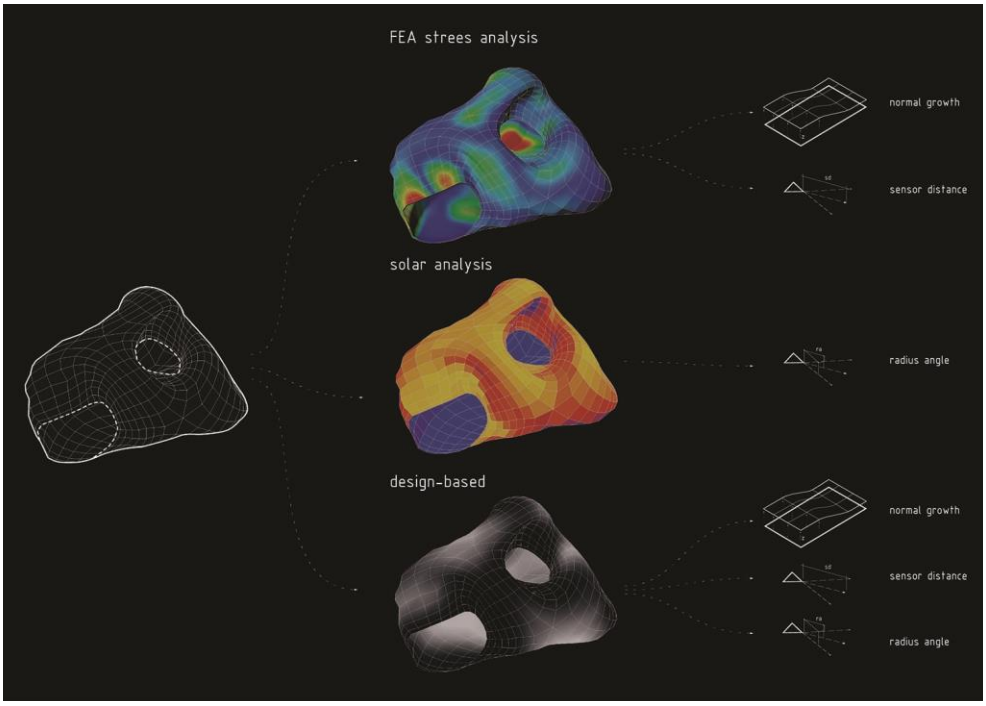

Figure 7: Embedded information in softbody modules via vertex color maps and the related influences on agents behavior and skin pattern formation

During each loop agents read the data directly from the mesh vertices, and translate it into behavioral outcome (including feeding back a change in the same data that was read). Proprieties and parameters of the agents cognitive system was assigned to each weight layer, with the precise intent to avoid direct control on agents movements, but only influence their environment perception and consequently the way they translate perceived and embedded data into structured configurations, like spatial layouts, matter organization and structure formation.

Competitive behavior once again allows for the definition of an intricate double system of interlocking elements, creating fibrous based material systems in two different ways: the first based on matter accumulation through additive deposition (compliant with contemporary additive manufacturing processes) and the second based on non-woven fibrous networks methodologies.

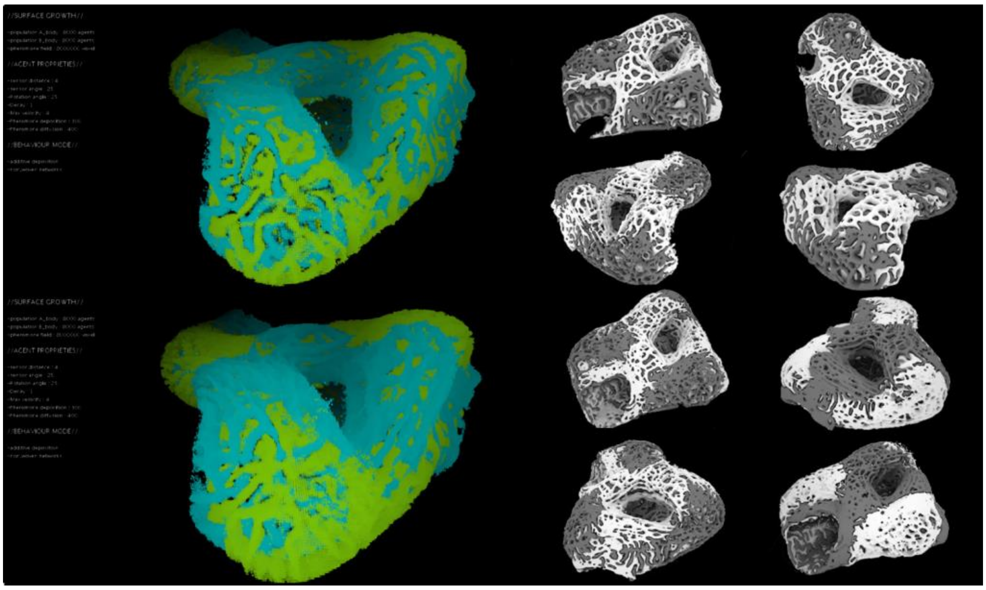

Figure 8: Interlocking skin pattern simulation and tests with varying behavioral parameters

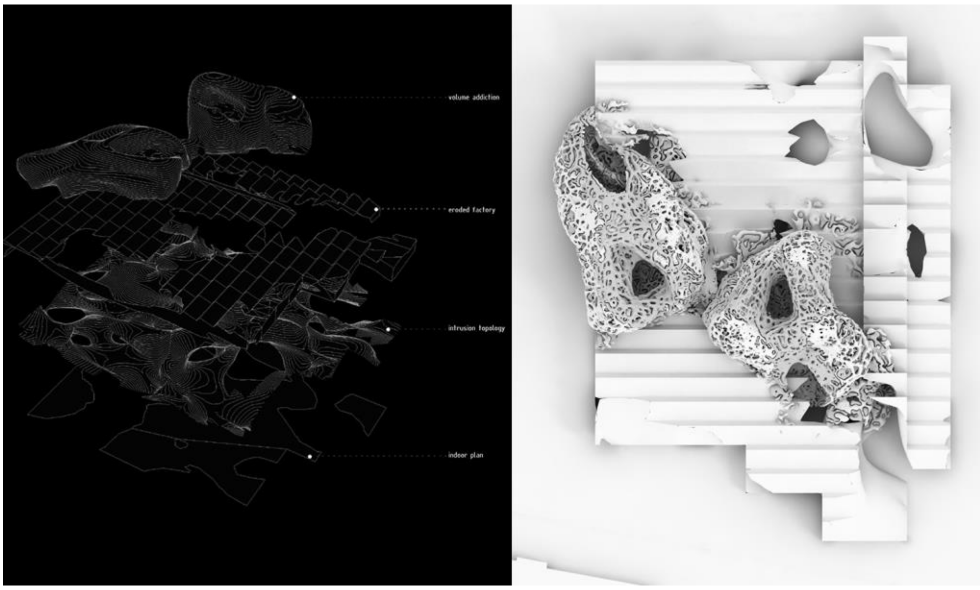

Figure 9: Final outcome, exploded axonometric and plan

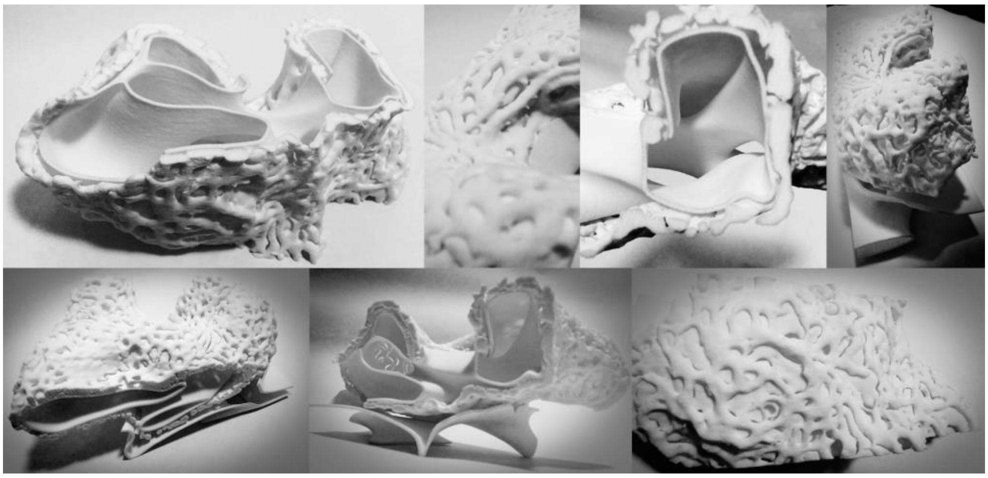

Figure 10: 3D printed model of softbody section with interlocking skin pattern

5 Conclusions

The purpose of this paper is to explore a design strategy for the generation of spatial organization and coherent tectonics rooted in multi-agent simulation (implementing collaborative/competitive behaviors) and stigmergy-based computational processes that allow access to increasing degrees of self-organization-based complexity by means of continuous information exchange through an external medium.

Although the process proved more than once to be time consuming and difficult to setup and control (also, as it frequently happens with non-linear strategies, sometimes unpredictable in terms of time spent before a satisfying solution is met), the biggest trade-off is that coherency and consistency of construction tectonics is maintained throughout scales even in the most complex shapes thanks to the embedded constraints in the behavioral rules and the continuous data flow through a common environment. The overall quality and resolution of the detail is however limited by the computational power at hand, which in turn both affects and characterizes the aesthetics.

It has to be noted also that, in lack of available ready-made specific tools, a lot of time was invested by building the necessary code from scratch. This however does not undermine the potential of the chosen strategies: as off-the-shelf tools are becoming more and more sophisticated it is likely to think there will soon be some easily implementing multi-agent simulation, thus emphasizing further the importance of creatively exploring their potential for complexity and avoid their trivial application.

On the process side, continuous data flow processing empowered by encoded body-environment awareness of multi-agent systems can provide such access to complexity with very promising potential that, although in need of further development and investigation, already delivers valuable outcomes on the aesthetic, tectonic and spatial levels. On the architectural side, the result shows clear recognizability of the pre-existing and the new design as separate yet connected entities, with a spatial arrangement that although complex does not disrupt orientation within the interior spaces.

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Paolo Alborghetti is an Architect and coder, graduated from Politecnico of Milano with a research thesis about swarm intelligence and cognitive protocols , His interests focus on simulations of non linear system in intensive environments, emergent and adaptive behaviors. Supporter of the open-source and open-knowledge community, he's deeply interested in creative coding as new communication medium. He collaborated with different studios in Italy and abroad, working as computational expert on large scale and complex shape projects, while he's been keeping on his personal research (http://radical-reaction-ad.blogspot.com). He's been teaching assistant at Politecnico of Milano and teaching tutor at different workshops about computational design and digital fabrication. He expresses his design sensibilities combining advanced mesh modeling (Maya, Blender, Softimage), parametric design (Rhinoceros/Grasshopper) and programming (Processing, C#, Python) .

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