The Red Queen Hypothesis

Chemotaxic stigmergic systems and Embodied Embedded Cognition-based strategies in architectural design

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The Red Queen Hypothesis is a research project on parasitic architecture, developed as a case study application of knowledge inherited from the fields of stigmergy-based systems, swarm intelligence and Embodied Embedded Cognition. The project aims to provide a possible answer to the increasing demand for the redevelopment of abandoned post-WW2 buildings in northern Italy, proposing an alternative to preservation logics in through strategies based on intrusion, adaptation and growth focusing on the relationships between different systems (host/parasite) and innovative fabrication techniques. Implementing such approach in a non-trivial way entails enabling access to increasing degrees of complexity and self-organization in the computational design approach while keeping the whole process coherent throughout its unfolding.The case study is an abandoned factory in Bergamo (which has become an urban landmark for a socially intricate community) a multi-agent system based parasitism strategy was implemented as design process for its transformation and reuse as spaces for community and cultural expression.

Keywords: *Stigmergy, Multi-agent systems, Architecture, Computation, Parasitism*

"Well, in our country," said Alice, still panting a little, "you'd generally get to somewhere else-if you run very fast for a long time, as we've been doing."

"A slow sort of country!" said the Queen. "Now, here, you see, it takes all the running you can do, to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that!"

Carroll, L. - Through the Looking-Glass and What Alice Found There, chapter 2

INTRODUCTION AND PREMISES

The Red Queen hypothesis is an hypothesis in evolutionary biology that derives from the dialogue reported in the introductory quote which 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. 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 "hacks" into the host system creating a communication interface that mimics the host's internal organization. Such interface has a very important role in establishing the communicative capacity and systems interactivity, and it can reach great sophistication. *Hymenoepimecis argyraphaga* is a parasitic wasp that lays its eggs inside the *Plesiometa argyra* spider (Figure 1) and hacks its web-spinning behavior by injecting it with a toxine that hacks its nervous system in order to build a specific web structure to protect the larvae when they'll hatch (Eberhard, 2001). The success of this strategy of hacking and control implies a comprehension of the host's system by the parasite. It is important to notice that the parasite changes the way the spider builds webs; in other words, construction is a rule-based process involving constructor agents and material systems and outcomes can be changed by literally re-programming the agents. 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 remains separate and perceivable and the original system isn't destroyed and becomes an extension of the parasitic system.

In our case however there's no inherent active construction behavior in the hacked object (the factory), the simulated parasitic system will alter the spatial and structural system of the factory 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.

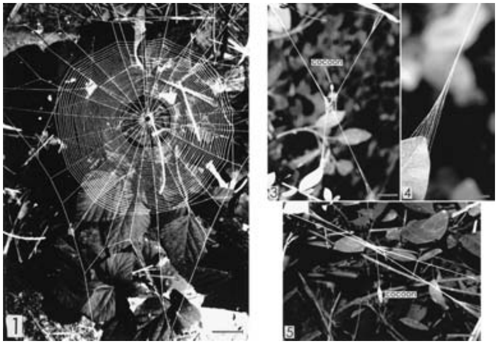


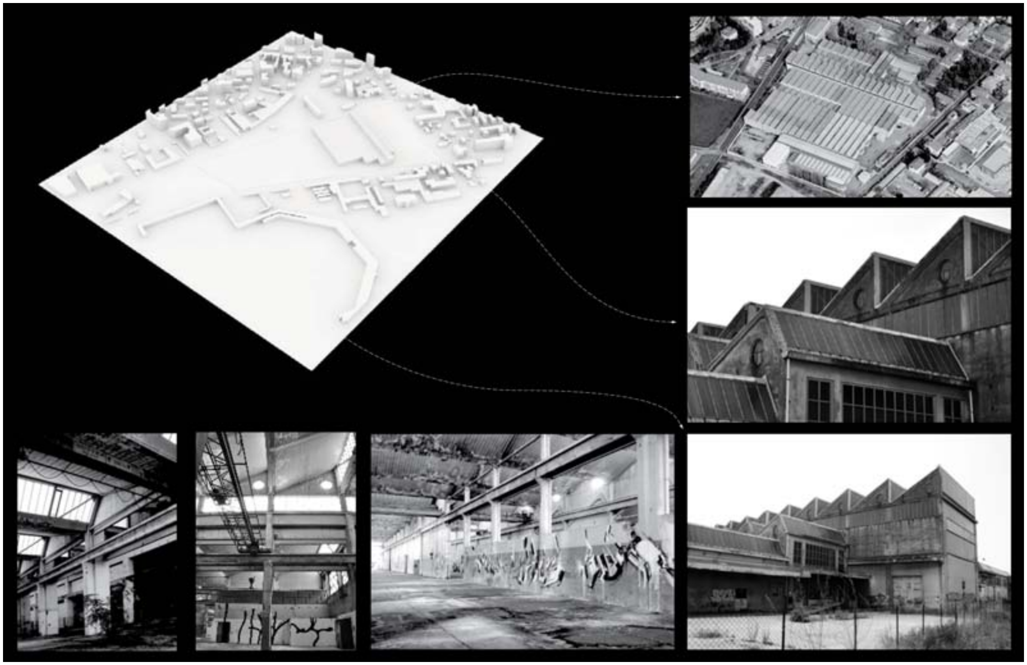
Figure 1
Plesiometa argyra webs in normal state (left) and under the influence of the Hymenoepimecis argyraphaga parasitic wasp (right)

CONTEXT

The chosen case study is a former factory in the city of Bergamo, the ex-OTE (Figure 2). 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. The current widespread cultural trend in Italy 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 (such as a 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.

The social and cultural environment is quite problematic, with continuous struggle to establish a community-based cultural and recreational life, as the basic spaces and structures to house and empower these kind of activities is sorely lacking. The factory is an ideal candidate for its sheer size and location, but its spatial structure (comprised of a cen-

Figure 2
Context: the ex-OTE factory in Bergamo



tral square open space hall and a transversing 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 while still grant information and physical exchange among each other. These are the kind of evaluation and filtering criteria that will be adopted in the process of driving the spatial explorations towards a possible convergence.

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.

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 3).

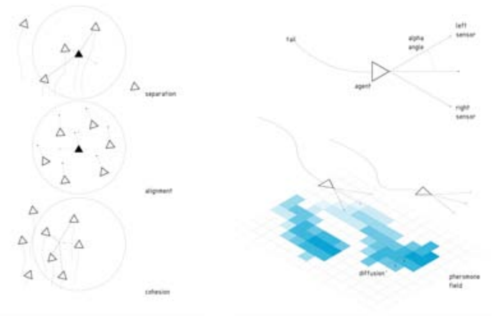


Figure 3
agent rules: classic swarm behavior model from Reynolds (left) vs stigmergic model from Jones (right)

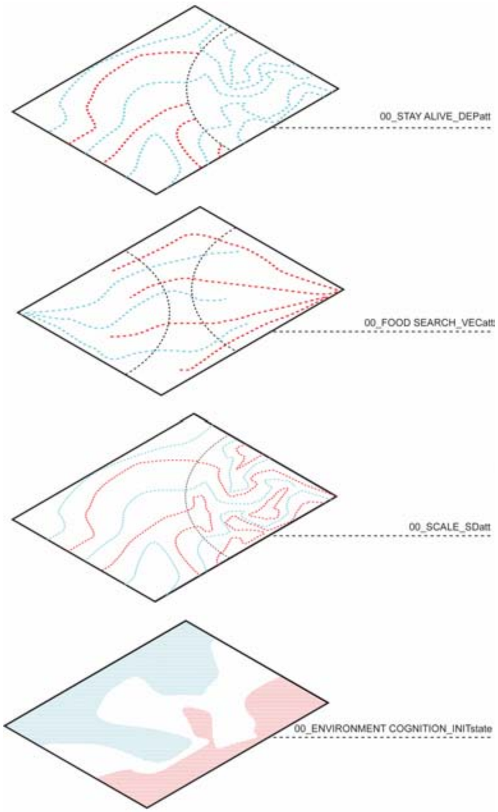


Figure 4
Stigmergic grammars

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 communication 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. 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.

The simulations are built upon a common framework, called stigmergic grammar (Figure 4, 5): 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 isovalue surfaces (or isosurfaces - surfaces that describe the boundary of space with the same data value) 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

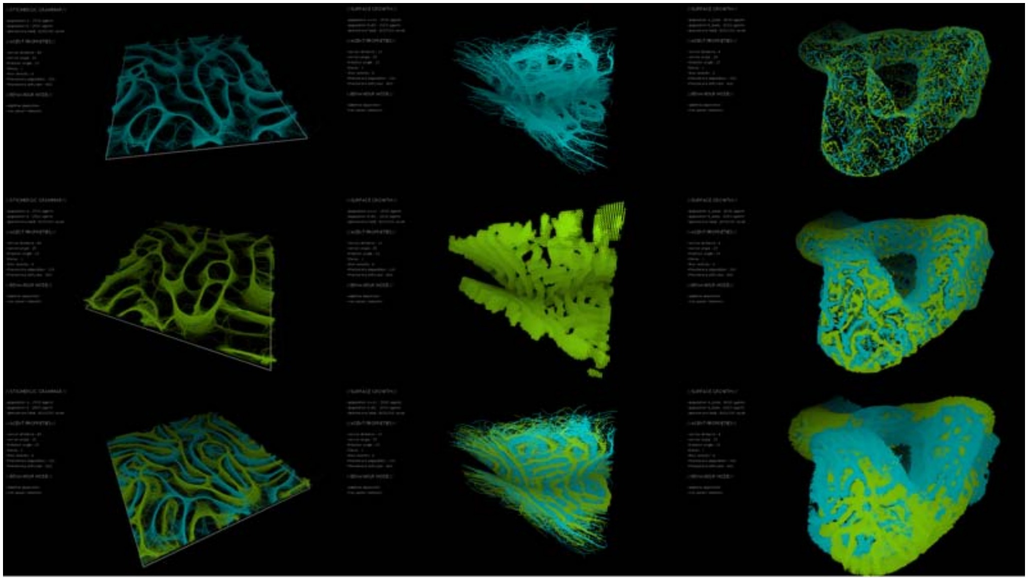


Figure 5
Simulation samples: stigmergic grammar on spatial negotiation and volumetric growth on surfaces

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 new continuous networked connections within the existent factory space.

DESIGN IMPLEMENTATION

The stigmergic grammar has first been applied 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 emergent 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 an 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.

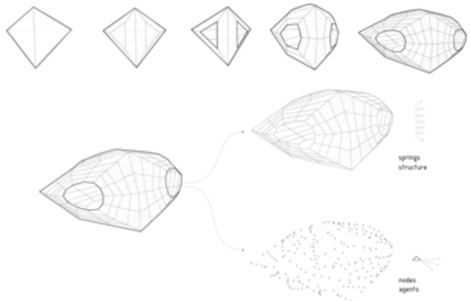


Figure 6
Softbody module generation and structure

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 6, 7). Softbodies are adaptive morphologies 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 develop-

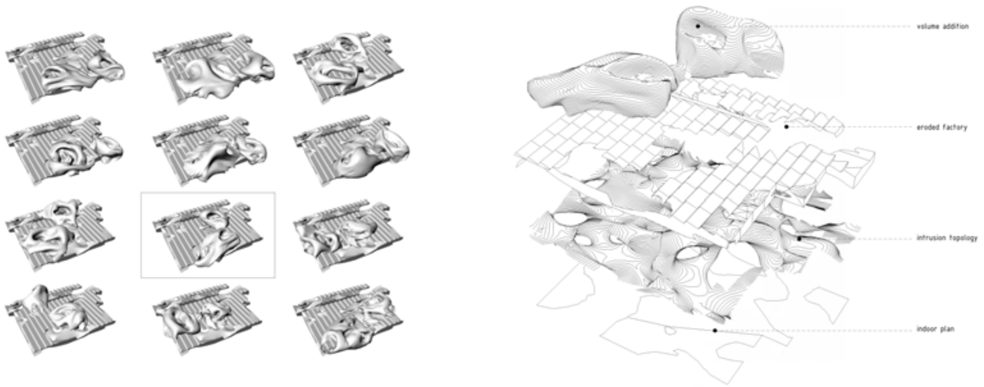


Figure 7
Taxonomy of softbody configurations and exploded view of the selected one

ment 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.

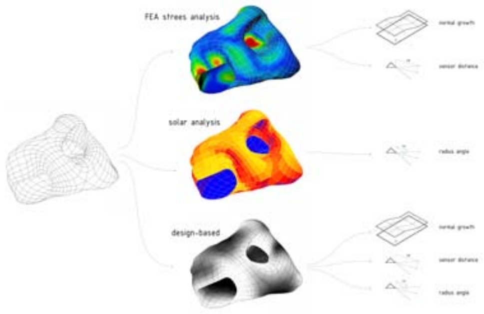


Figure 8
Softbody information layers stored as vertex colors

Mesh vertices acted as tensor space, embedding two different information layers derived form solar radiation analysis and FEA structural stress analysis (both mapped as RGB values map; Figure 8). A third layer (again, there is potentially no limit to the number of information layers embedded) 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). 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 networks methodologies.

The purpose of the Red Queen Hypothesis is to investigate alternative proposals in the topic of building redevelopment through parasitism; in order to explore such strategy it is necessary to introduce in the computational design process access to increas-

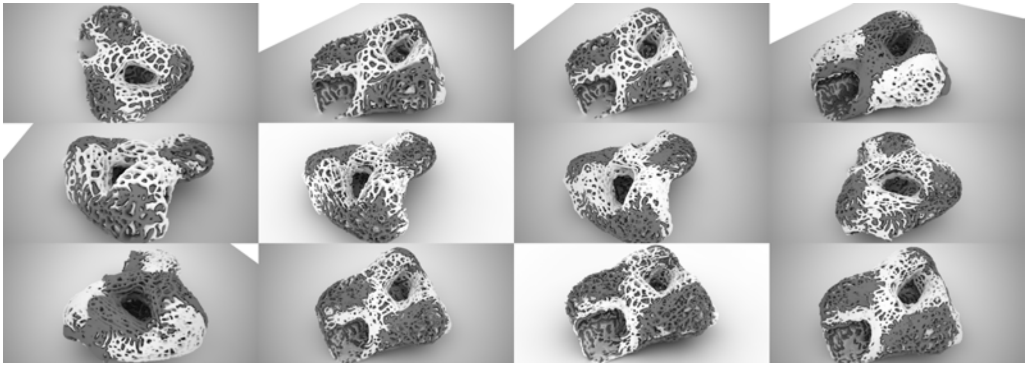


Figure 9
Tests on different values of diffusion, growth and other core parameters show the potential for variety and control over the interlocking system

Figure 10
Photos of 3D printed model showing inner space articulation and the structural surface's interlocking pattern

ing degrees of self-organization and potential emergent behavior. Continuous data flow processing empowered by cognitive capacities of multi-agent systems that are influenced by body consciousness (which is also a pivotal argument for AI cognitive protocols) can provide such access with very promising potential that, although it needs further investigation, already delivers interesting outcomes on the aesthetic, tectonic and spatial levels. (Figure 9, 10).

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