ISSN 1828 5961

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Oltre la simulazione
Beyond Simulation

In natura "fare" o "crescere" implicano una relazione intrinseca tra forma, materiale, pattern, spazio, in cui funzione e performance sono i risultati emergenti dell'interrelazione organismo-ambiente.

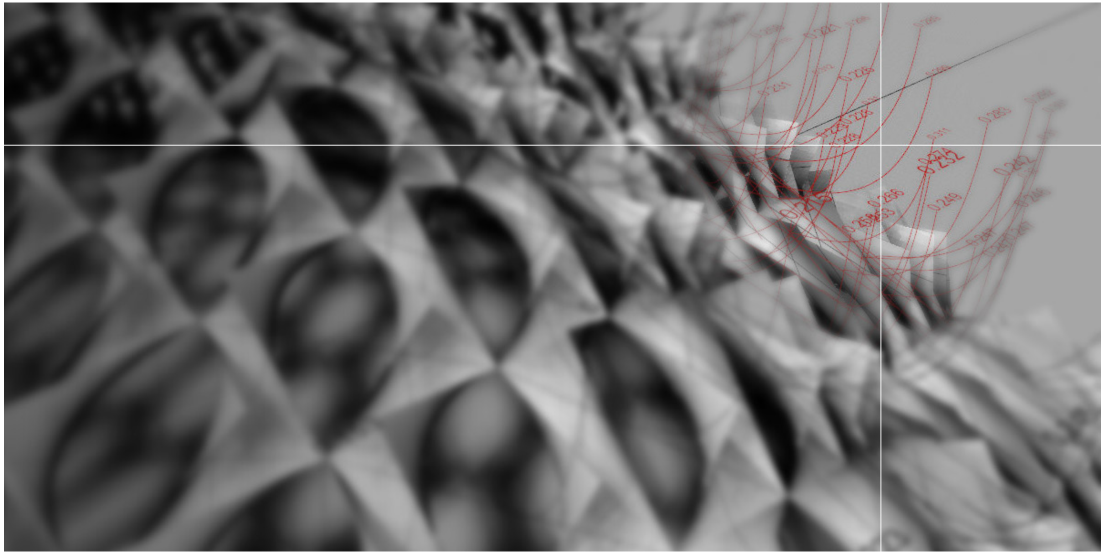
L'energia è strettamente coinvolta nella variazione complessa del principio di minimo sforzo, sia nel mondo inorganico (cristalli, gocce d'acqua) che in quello organico; negli organismi, il metabolismo è l'espressione di questa relazione tra forma, energia e materia.

Al contrario, i nostri sistemi di produzione tendono a separare e ottimizzare le fasi di progettazione, fabbricazione e costruzione. Gli strumenti digitali stanno riavvicinando e fondendo queste fasi tra loro, promuovendo una ecologia di progetto più sensibile nel loro facilitare una migliore comprensione delle sinergie tra sistemi e ambiente, o interazione tra sottosistemi.

In nature "making" or "growing" implies an intricate and embedded relation between form, material system, pattern, space, where function and performance are the emergent result of the organism-environment interrelation.

Energy is tightly involved in the complex variation of the principle of minimal effort, both in the inorganic world (i.e. water drop or crystals) and in the organic; when dealing with organisms, metabolism is the expression of this relation between form, energy and matter. Conversely, our systems of production tend to separate and optimize the various phases of design, fabrication and construction.

Digital tools are tightening and fusing those phases together, fostering a more sensible design ecology as they may facilitate a better understanding of synergies between systems and environments, or subsystem interaction.



Architecture is doubtless experiencing a paradigm shift. The progressive intensification in the use of computational power into design and fabrication and the simultaneous (and mutually inflected) arousal of new sensibilities that bridge together computing, biology, philosophy, genetics and creative disciplines has favored an increasing engagement of complexity into several levels of application within architectural and design practice as they thrive on the expanded influence that other disciplines bring to them. On the other hand an impellent demand for an amplified and more aware environmental sensibility is increasingly focusing attention on nature through the expanding field of sustainability. What is generally intended as such however is often an oversimplified and superficial shrinkage of a wider and more comprehensive definition of ecology, which is the set of relations between an organism and its environment, towards a single environmental strategy: energy saving. Digital tools are the key to come to an understanding of these two apparently disconnected tendencies as part of a more complex system, mutually influencing each other without however search for an unification or reduction, as well as the trigger to a range of diverse and efficient environmental strategies.

Nature is the substratum on which architecture, ecology, life and cognition take place, the stage where they play and interact together, therefore knowing that stage is paramount. Way far from the image of a picturesque arcadia, nature is not inherently good: diseases, death and destruction are part of it, anything that happens in our universe happens in nature, whether naturally growing or man-made. Nature is a complex adaptive system [1]: these kind of non-linear systems continuously redefine their boundaries, incorporating external aggressions (generally defined as “noise”) by generating order out of chaos (as opposed to the linear logic that sees order only coming out of pre-existing order) thanks to processes of self-organization among a high number of interacting agents that lead to the appearance of emergent properties [2]. Not only there is no direct relation between cause and effect (as the system is non-linear), but since every product of a process in the system is again part of the system itself clear and closed concepts of cause and effect do not apply.

Within this framework operational variables must be redefined too, making a shift: from the individual to the population, from being to becoming, from scale to level, from linear to network, from global determinism to local determinism. Finally, from an *hylomorphic* model (which posits the superimposition of form on amorphous matter) to the divergent actualization of "body plans" (or abstract machines[3]) of a common *machinic phylum* [4]. In short, life is structured becoming, which means that in a universe where change is a continuous and perpetual condition (in a wide variety of scales and expressions), structured assemblies of matter-energy create systems of growing articulated complexity by exploiting immanent properties and capacities. Systems are defined by the set of relations occurring among their constituent parts: the concept of nature[5] itself is not in the substance of things but in the relata established among the various elements; this web of relations is the topological structure (form) that shapes things in nature, in other words is the abstract machine that encompasses the potential and all possible states of a given system, and the materialization (the actualization of the virtual that the abstract machine is) is only one of all the possible states. Matter is morphogenetically pregnant, and tends to gravitate around the closest stable state in the space of all possible configurations [6]. The different stages of growth (i.e. a seed and the mature plant) are then all possible stable states which are not imposed as transcendent entities but are immanent properties of the systems themselves which unfold in space and time.

This unfolding happens dynamically through sequences in which information is organized (patterns) and involves an intricate and embedded relation between form, material system in a perpetual exchange of matter-energy information. Information processing is thus a crucial aspect: we are used to think about information mainly associating its notion to its coded aspect (language, symbols) but before that information is embedded into the spatial and material aspect of things. The chemical reactions that happen in the cell are regulated by the recognition of spatial patterns of molecules: the structure and composition of molecules is the information needed by the chemical process, in a sort of key-lock mechanism. The linkage between morphology and life functions is provided by the set of chemical relations that happen into an organism in order to maintain life: metabolism. Morphology is then linked to life processes through metabolism, and this involves material system, patterns, space occupation and environmental relation and response. For example phyllotaxis is regulated by the chemical flow of a particular hormone controlled by the quantity of light that is monitored in the growing part. It is also commonly said that phyllotaxis is controlled by the Fibonacci Sequence, or the Golden Rule: this is a misunderstanding and a potentially dangerous confusion between a natural process and its model (the describing algorithm in this case), between representation and behavior. Nature is not mathematically controlled or strictly based on mathematical laws, but algorithms and mathematics provide so far a very efficient description and a great operational tool to get as close as possible to those processes and behaviors (the Fibonacci Sequence provides a very good description and simulation of phyllotaxis, but the process is not based on numbers), but we should never forget they are approximations [7].

All of these information-processing interactions happen perpetually during the lifespan of living organisms: in order to maintain a stable condition (homeostasis) such as internal body temperature a huge number of processes are dynamically regulating body functions in order to account to every change in the environment and in the endogenous conditions. Many of these processes (such as skin respiration) do not need a central processor, they are locally triggered and controlled (self-organized) by chemical loops. Energy is thus tightly involved in dynamic systems as the complex variation of the principle of minimal effort: material systems self-organize in spatial patterns or configurations that are not an optimized version of a low energy-wasting system but they converge toward stable states (which are also called attractors) in the space of all possible configurations. In order for a system to operate such convergence, or in general to be dynamic (which could mean growth, movement, maintain homeostasis or even a change of phase), energy should be produced or injected on the system from outside and the system should be structured in a way so that energy is able to influence it and cause a variation on its status. This means that morphology and its related metabolism are not strictly optimized but they are an efficient compromise (or one among all the possibilities)to ease the flow of matter-energy under the complex and interacting force fields of the environment: in corals, the same growth process (the same abstract machine) gives birth to two kinds of very different morphologies (spherical or dendritic) depending on the different flow of currents which transport the coral nutrients [8]. None of these solutions can be universally optimized, but they are two versions of specifically efficient solutions in which form organizes matter in the most efficient way to get the best performance with the minimum effort. In other words, form is cheap, material is expensive; not in a strict and universal way, but within the constraints of complex system [9]. Energy is also involved (and linked with redundancy) since all structures in nature are made out of weak materials, which means they require less energy in their chemical bonds and thus less energy to be constructed and synthesized, as opposed to our use of high resistance materials, whose high energy required for production is very demanding in environmental terms.

Efficient compromises coupled with a high variety of solutions is what makes a system resilient, adaptable to the sudden changes in the environment. Optimized solutions in this case do not work, since their high specificity is obtained at the cost of poor adaptability. Analyzing natural systems it is quite evident that their design relies not on single function optimization but rather on the opposite principles: redundancy and multiperformance.

To summarize briefly this introductory part, in nature there is a complex, intricate and embedded relation between form, material system, pattern, space, where function and performance are the emergent result of the organism-environment interrelation. Since this interrelation is dynamic and under a perpetual condition of change redundancy and multi-performance are ways to rationalize the use of matter-energy flow in order to produce a wide variety of efficient and adaptable solutions. Random generation and self-organization generate continuously novel possible solutions, while environmental pressures act as a filter to sort out the efficient ones.

Conversely, our systems of production tend to separate and optimize the various phases of design, fabrication and construction in search of a unique

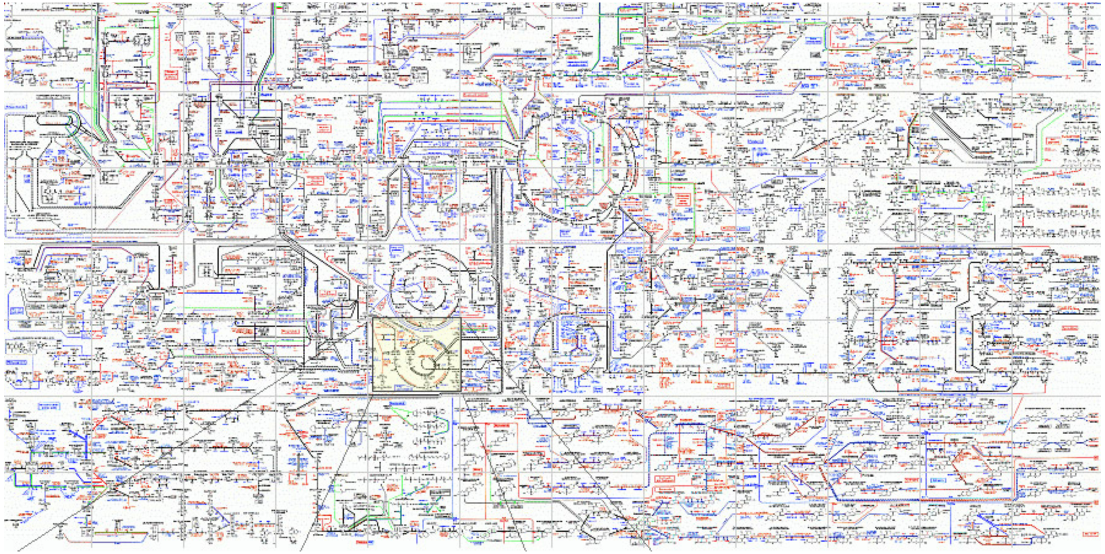


Fig. 1. Complex metabolic chemical pattern of ongoing relations every time we breathe.

solution. When has this distance started to form? Its evident appearance can be seen in the application of the linear model and military strategies into the world of production during the second industrial revolution, but it has to do with the way we interact and live in our environment.

We do not just see our reality, we *model it* [10]. We continuously create models of reality in order to understand it, and not just static models, but highly dynamic and interactive ones. Modeling, design and cognition are tightly linked in our brain activity, and they all are connected with the spatial structure of our neuronal cortex, resulting in patterns that are spatial themselves and that organize information spatially. It is not a one way process: we are also influenced in the way we think our reality by the models we build for ourselves; for example the renaissance models of human figure relied on integer numbers for proportions (like the head being 1/8 of the body) mainly because real numbers were not yet introduced [11].

Architecture is a process that begins exactly in the moment we build those models in our minds, it is part of our cognition and life process, and it is analytic and operational at the same time. No matter how sophisticated our models of reality are (and we must keep in mind that higher sophistication is paid at the cost of sacrificing operability), our brains just cannot handle its inherent complexity. Therefore a simplification is needed: we should create a viable model of our world, one that give us enough means to live in it, providing both description and operational ability (analysis and synthesis). Simplicity is not an inherent property of things (nothing is inherently simple) but a convenient way to read complexity, which is a crucial part of our key to survive in the predator-prey race arms [13] in the days our specie was inhabiting caves and that we now have as a blueprint to operate in the world at large. In order to raise our chances of success, we developed ways of sharing efficient models and saving those information for the next generations: our DNA, our social structures (including building and cities) and our language are all part of this evolutionary process of information storing, processing and sharing. Back in the cave days, our specie was also beginning something extraordinary: technology, in the form of tools.

Fig. 2. (a) Coded information. (b). Embedded information - the skin colour gives account on the maturation stage of the fruit.

We call tools the mediation interfaces we build to interrelate with our world at large, influencing and reconfiguring our brains accordingly [14]. Those tools are often put on a different plane with respect to models, but given the above statement on modeling it becomes evident that the two terms are the recursive application of the same underlying concept. We evolved a larger skull to incorporate a larger brain (at the expense of a weaker jaw). More of that brain was devoted to the cerebral (prefrontal) cortex, so we gained the ability to do recursive thinking. We became capable of assigning a symbol to a complicated set of ideas and then using that symbol in yet more elaborate structures of ideas. This enabled us to devise complicated procedures for creating tools, and to handle the recursive structures in language [15]. This ability, combined with the ability to manipulate and change our environment [16] building physical correspondents of our mind models and testing them, made us able to trigger a new evolutionary process: technology.

Technology is the evolutionary process undergone by pieces of information that can be easily replicated (ideas, or better, memes, in the definition of Richard Dawkins) and recursively combined to form complex structures even without the support of biological material: the development of a language and devices to store and transmit information helped in speeding up the diffusion of memes, which were then not linked anymore to biological cycles of reproduction. Like any other evolutionary process (in biology and language for example) it is not a linear progression of raising improvement, rather a process driven by drift and randomness which undergoes self-organizations around stable states, catastrophes (sudden changes and re-configurations) and parallel evolution-devolution; all of them are complex outcomes of emergent processes driven by information. The technology we have is not the peak of all possible technology, it was not necessarily evolved this way, rather is the result of processes of drift and bifurcations in history that were driven by a complex set of endogenous and exogenous factors. If we were to re-run the wheel of history, our technology (and ourselves) would be very different.

When dealing with living organisms, they are wired with the world in terms of information processing and metabolism is the expression of the relation between

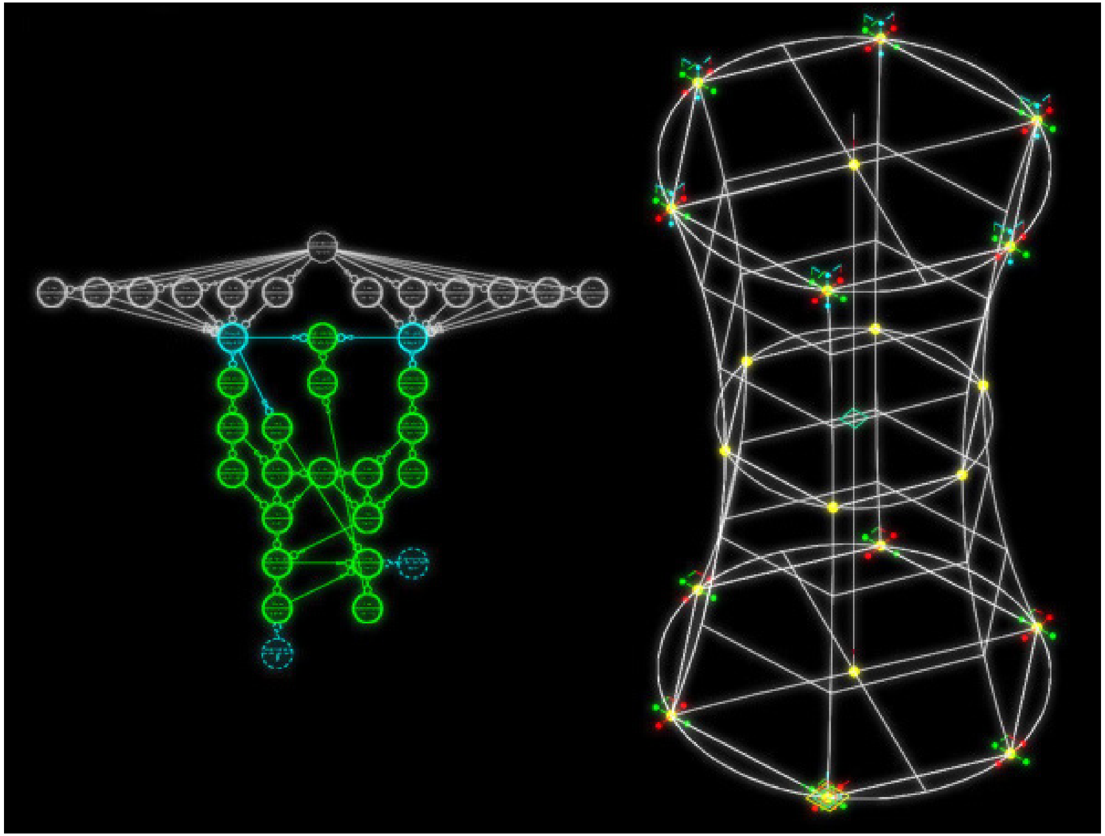


Fig. 3. Screenshot from Generative Components (c) Woojaesung.

form, energy and matter undergoing through it. But we should not forget that information processing is present also in the non-organic part of nature: rivers, with their flow of currents, sort and smooth particles depending on their material characteristics (weight, density, stiffness); this process is a form of computation. And since information processing is the basis of computing, every system capable of information processing is a computer. Our idea of computers is highly tied to their present aspect as metal boxes filled with circuits that operate symbolic operations on data, transforming sequences of 0 and 1 into numbers, words, graphics, 3D models and so on. The conceptual blueprint of modern computers as symbolic processors is the Universal Turing Machine, theorized by Alan Turing in 1936. The actual computer architecture (CPU, ROM, RAM, BUS and peripherals) was first introduced by John Von Neumann in 1945, exploiting the binary system invented by Claude Shannon and Warren Weaver. Computation, however, is an idea based on the same process of information exchange that is the base of cognition and life: the computers we know (such as our laptops) can thus be considered a very primitive form of organic specie. Kevin Kelly in an insightful article [17] promotes the idea that technology has its own agenda (just as we have one - based on survival) even if it is not yet an

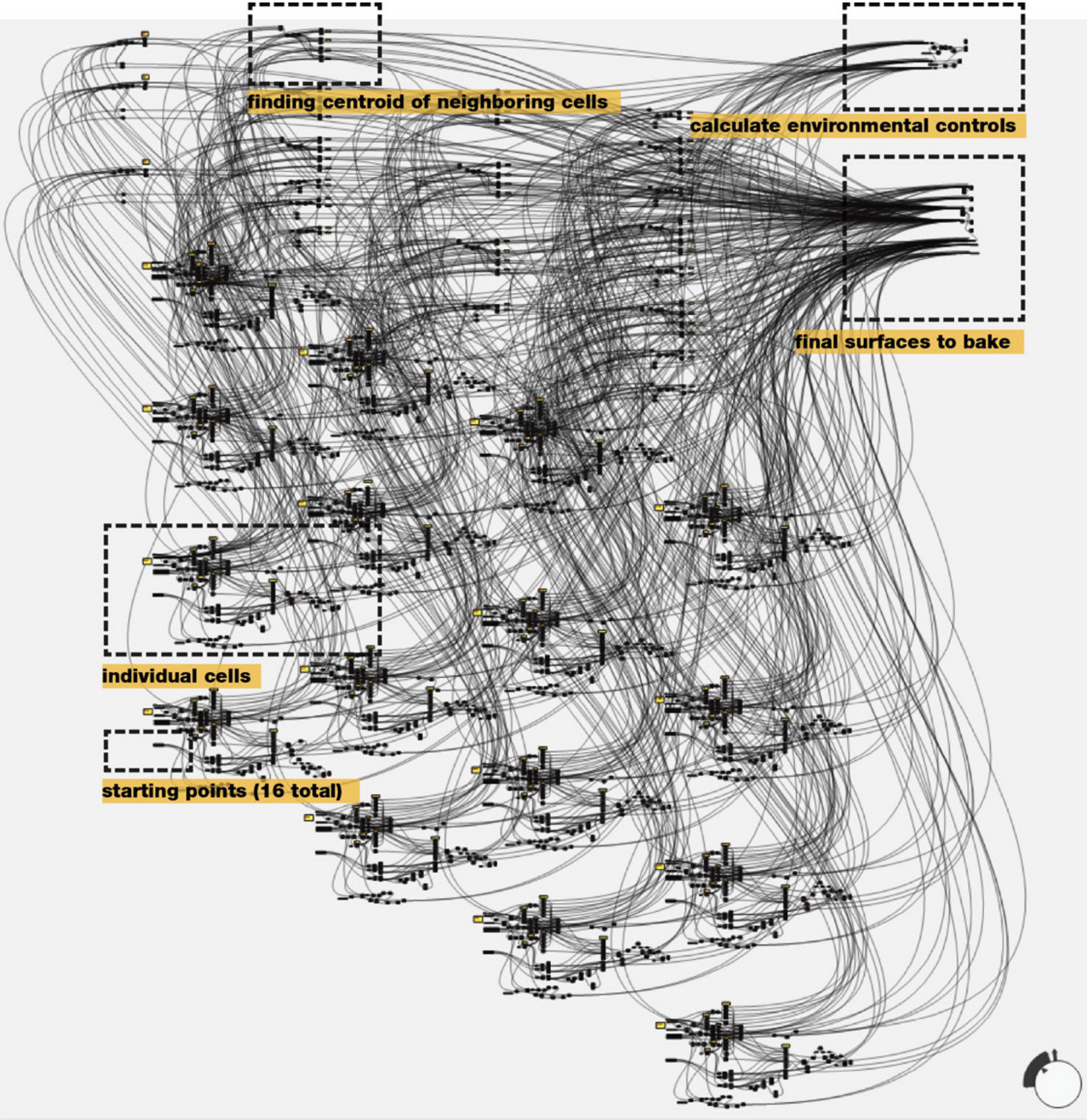


Fig. 4. Screenshot from Grasshopper.

autonomous specie, and that at the present moment we are the necessary means for its reproduction. Just like a baby trains his parents to give him attention, feed and take care of him, technology is training us on producing more sophisticated technology and constantly take care of it. When John Holland first released his genetic algorithm the result was totally unexpected and far from man's logic so far: software is engineered more for man than for the machine it has to run on. It is engineered for humans in order for them to reproduce technology.

Even without fully subscribing Kelly's standpoint (which is however powerful and enriching in the way he looks at technology) there are interesting considerations that can be made with regard to computers as primitive form of organic specie: computers (as universal symbolic processors) store and process information the same way nature does, through pattern recognition. As they grow in computational power, they grow even in complexity and in intricacy and number of connections, blurring the barrier between organic and mechanic. Bodies and organic species are wet computer, our organism continuously computes through sensing the environment, regulating our metabolic functions, keeping us in homeostasis. Seeing computers just as boxed calculators does not account for their very nature or potential. Premiszlav Prusinkiewicz and Aristid Lindenmayer are the authors of The Algorithmic beauty of plants, as well as the inventors of L-systems, a class of recursive algorithms which are the digital abstract machine of nearly all the vegetal world. They were among the pioneers of the use of computers for dynamic system behavior simulation in order to understand nature's processes: *According to Professor Prusinkiewicz, the use of computational models has several benefits. Firstly,*

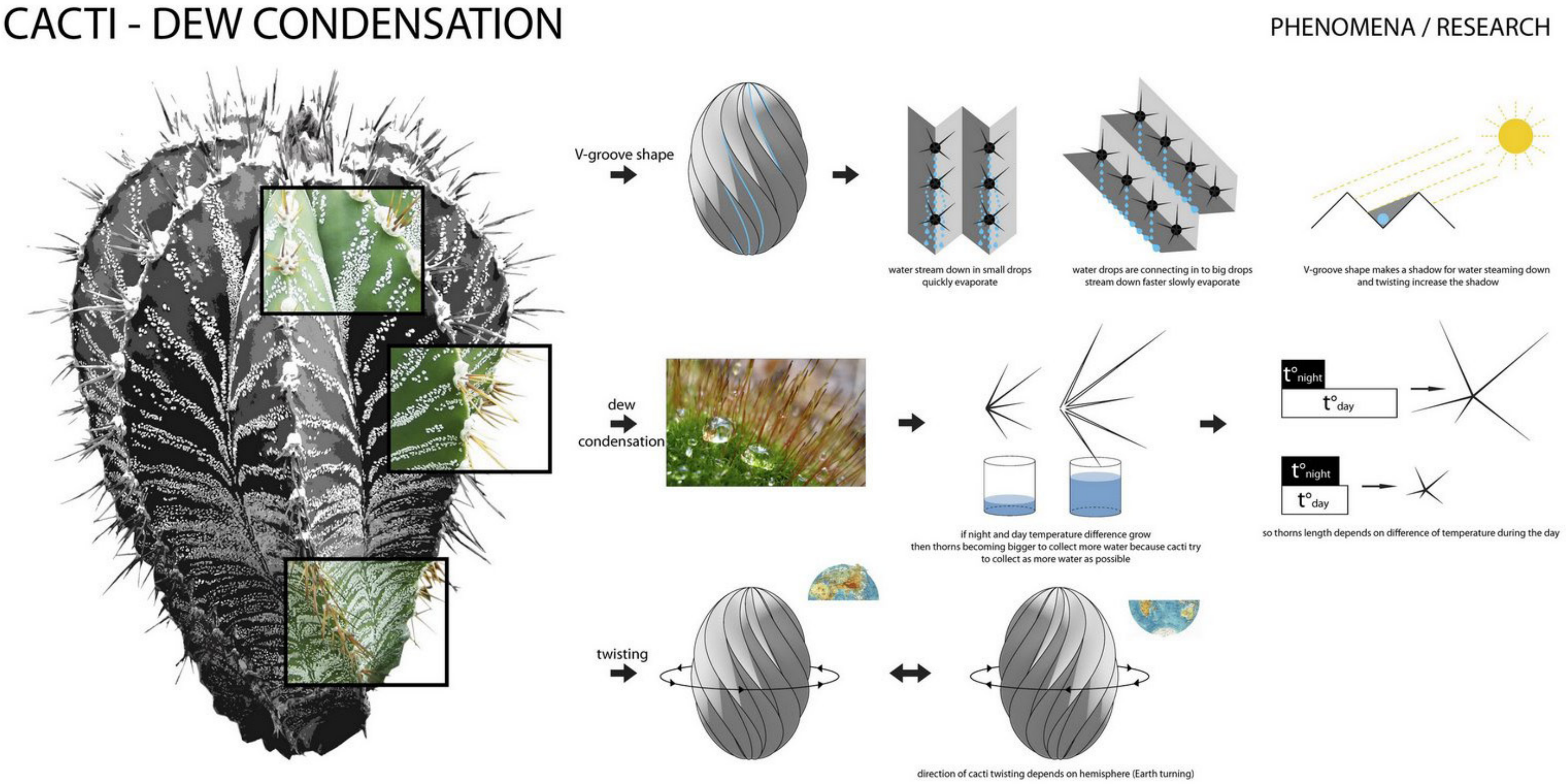


Fig. 5. A new understanding in material and economy of form.

they can 'provide quantitative understanding of developmental mechanisms; secondly, models might lead to a ***synthetic understanding of the interplay between various aspects of development*** *[18]. In doing so, such models might also provide a new analytical and generative sensibility to architectural design, as* ***they may facilitate a much better understanding of synergies between systems and environments****, or subsystem interaction, in terms of their behavioural characteristics and capacities with respect to the purpose they serve locally and within the behavioural economy of a larger system.[19]*

Leveraging an increasingly precise and widened study of nature (especially under the dynamic system simulation point of view), computers are designed to be the reflection of our minds (Warren Weaver was talking about an Artificial Brain, and wanted to feed it with music, not only raw perforated tags) meaning they work in a very similar way, only they are very different. Software and digital crafting machines are being transported by the same evolutionary tide in which adaptation, resilience, scalability, are characteristics that raise their chance of success along with the tendency to align to human behavior and survival strategy through opportunistic and convenient views of reality (in order to be able to operate on it allowing anticipation of effects: in a word, to project): simplification, optimization, approximation, discretization are all characters embedded both in the computer structure and operational software.

The above speculation on technology and computers is really pregnant for architects as they are world builders through environmental transformation (engineering nature): what we witness in terms of present architectural experience (which is almost entirely inherited from the modern age) is far from being the peak of a linear process of technical and cultural evolution, but is just one of the possible bifurcations of a complex evolution which is now giving way to more efficient and easily self reproducible processes. Within this evolutionary processes there are parts which are quickly evolving and shifting in the pursuit of a stable states and parts which are the inherited vestiges of a once useful organ, much like our sacred bones. Speaking in terms of recent and present computer-aided design tools there is a class of tools which were born as a mere digital double of the pencil. Any CAD system of this generation (Autodesk©Autocad being the most famous) integrated generic tools to draw and model generic geometric objects (points, lines, curves, polygons, solids) defined only by their set of absolute coordinates. A new class then entered, defining parametric objects derived by the Euclidean geometries mentioned above (ArchiCAD, AllPlan are two examples of such programs); yet, a limited understanding of the potential and a design logic still based on the repetition of the same (as object) in search of a perfect, optimized solution and a limited library of elements which limited the development of specific solutions and put a brake to an already promising development, relegating the computer more as a drawing tool than an active subject in the design phase. The subsequent introduction of NURBS geometries (from the automotive industry), the transfer of tools and techniques from other disciplines (especially the animation industry) and the theoretical enhancements towards an understanding of complexity triggered a new interest towards the computer as a design partner (Alias and Maya were leading the way in this path). Any of the

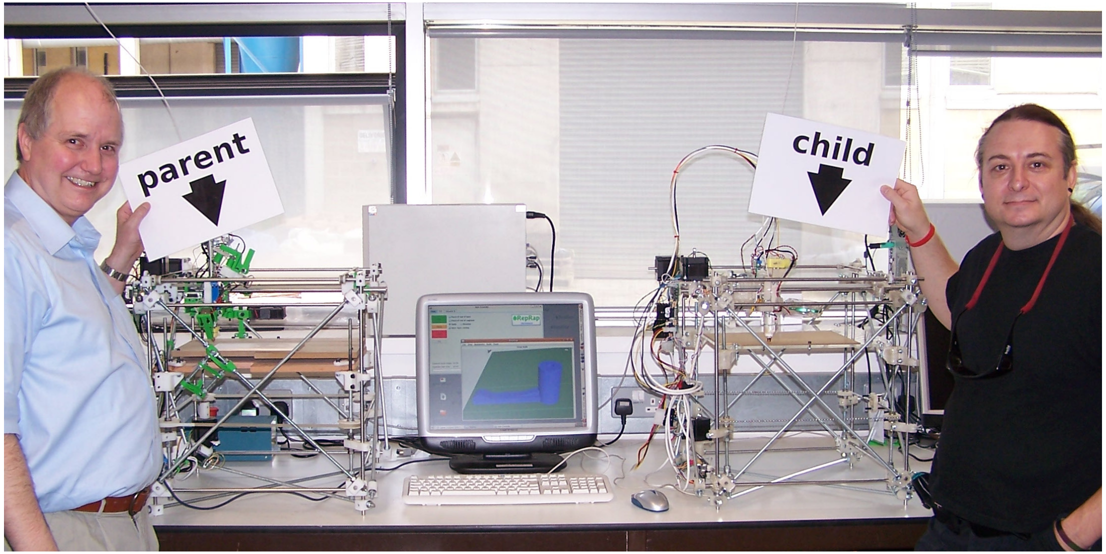


Fig. 6. RepRap machine: this 3D printer can produce about the 70 percent of its constituent parts.

aforementioned programs is really a sequence of instruction wrapped on a graphic user interface in order to be generic and understandable enough to the wider possible range of users. When the spread and use of computers in architectural practices reached a critical mass, a growing exchange of knowledge among the disciplines of architecture and programming focused the interest on the personalization of tools by re-writing its code in order to build specific tools for specific problems or just expand the expressive horizon of those programs. The practice of scripting took the lead as it became easier and easier to model set of relations through the scripted code than just static models. Starting from the first experiments in MAXscript (3Dstudio), MELscript (Maya), the appearance of Rhinoceros brought parametric design to a whole new plane, for the ease of scripting (through Visual Basic language, one of the most diffused and easy to learn at the time) that gave it a high degree of personalization, and its powerful treatment of NURBS surfaces. The recent appearing of visual scripting or relational modeling tools (such as Generative Components first and Grasshopper later) made it even easier to promote an understanding of geometry as the result of relational rules rather than the embodiment of a transcendent entity (in other words, the difference between building and drawing in the digital realm).

In a way, digital tools were always intended to be modeling tools (an extension of our brains and capacities to live in the environment through gaining control over it) except our theoretical and philosophical descriptions of the world evolved (in a nutshell) from an atomic conception to a Newtonian one (linear clockwork model) up to our present emergent complexity paradigm. Even under the point of view of representation, the means of representation, their related visualization technology as well as building technology and the architecture that was related with them, all of this can be seen as dependent from the evolution and refinement of our cognitive science and organs. For example there are evidences that the ancient Greeks had a very different color perception than us nowadays [20]. The same thought can be unfolded from many other points of view (for example the role of man in the vision of reality, from the "measure of all things" to the "sexual organ of technology", so to speak), each

Fig.7. Jake Sully bio-wiring its tail to the one of the Banshees in Avatar movie.

of them relevant as influence and none of them as the only isolated cause of the described issue. The point here is that the outcomes of our interaction with the environment evolve symbiotically with them, creating feedback waves on all hierarchical levels, from the physical evolution of our bodies to cultural and philosophic implications, up to the continuous redefinition of our role in the transformation of our environment, with particular regard to creative disciplines such as architecture.

In "traditional" (so to speak) design, rules (or the information layer encoded in relations) are kept separated from objects through a level of abstraction, mainly driven from the misconception that architectural potential beyond the mere construction could be extracted and managed as a separated subject, deprived from its interactions and feedbacks with its physical substrate: thus, design thinking and modeling coexist as two distinct moments in a project's life, typically embodied by the misuse of "concept" and "meaning" and a more or less complicated constructed neutral vehicle for their transmission [21]. Moreover, on the material side and under an ecological perspective, the heavy influence of linear thinking still exerts a strong resistance when it comes to discuss construction systems as integrated with space-making, environmental regulation and perceptive experience.

Today's approach crowns a relation-based design path, rules are encoded in objects form (intended as organization structure and rules of formation), blurring more and more the threshold between the act of designing and the one of modeling. We are modeling relations, systems, abstract machines. Those abstract machines embed all the possible configurations in the phase space of that particular system and are topological at their bottom, since they are made of pure relations (this is quite evident looking at a Grasshopper definition screenshot or a Generative Component definition diagram) and are also far from being transcendent since they do not resemble in any way their actualized outcomes. The efficient economy behind all that is to access a wider variety of expressions within a single design, thus facing specificity, redundancy and variation within reproducibility. It is a form of design ecology that thrives on morphological response and high number of test, simulations in a trial-error process

ISSN 1828 5961

rather than trying to improve an old model. The trial-error explorative process somehow discusses the foundation of common practice nowadays, from the ecological impact of construction techniques to form-function-performance predefined associations. It is a huge paradigm shift, but, borrowing a phrase from the physicist Achille Stocchi:

> *electricity would never have been invented if we had just tried to improve upon the candle.*

The foundational nature of paradigm shifts provokes friction in the attempt of framing a newly emerging boiling flow of ideas into the set of existing categories, and as such to read its performance in terms of nearness to the existing scale of expression: typical and very used in this sense is the exercise of straightness and flatness as judgment cornerstones of rationality, as opposed to the so-called "free forms" [22]: surely a curved surface is never straight or flat enough, but that does not imply it is less rational. Form and function are everywhere, and so is performance; they are not inscribed into a shape but they come from the emergent dynamic interaction with the environment. This does not mean that every shape is successful in fulfilling the same particular task, but that their success is measured precisely when they are applied to fulfill that task and not predicted in advance. Furthermore, digitally driven means of production (CNC machines, 3D printers, robots) have brought a double impact: they loosened the linkage between rationality and Euclidean geometry (fabricating a straight cube or a double curvature surface on a CNC machine has the same cost in terms of required information and energy) and repetition of the same (machining 100 identical objects or a 100 different objects makes very little difference in costs) while enforcing the convergence toward recursive application (iteration) of process for maximal differentiation in search of a multiplicity of specific solutions and shortened the linkage between design and production (file to fabrication processes), promoting the embedding of fabrication rules and material processes right from the design stage. The loosened link with Euclidean geometry and economy of production triggered a wider and fruitful exploration of a renovated and ongoing research on the relation between morphology and performance. As an example, current manuals on sustainability often claim for volume compactness and surface smoothness in order to minimize dispersion, while research evidenced that species such as cactus (which face the most extreme weather conditions) in order to maintain a stable internal condition thrive on highly corrugated volumes and surfaces (which have a much better response in terms of transmitted and absorbed heat radiation thanks to the self-shading effect), as well as exploiting population effects to enhance the self-shading performance.

On top of this renovated thinking, a further development is the growing research that tries to bridge communication and information exchange between different tools, thus expanding CAD systems with environmental analysis tools (such as Ecotect, DIVA or DaySim), structural analysis tools, physics engines and real time data processors, physical sensors for real time interaction (Processing and the Arduino board) and evolutionary computation solvers (Galapagos in Grasshopper); in all this the recent development of data protocols for communication between Grasshopper and other external tools are bringing further attention to this very open and generic parametric modeling software: its vague nature, its ease of use and the wide and growing community that is free to play and experiment with it are so far strong points that are difficult to match.

The aspect of fabrication, together with a growing sensibility towards the limits of digital simulation promoted also the development of software which embodies production and construction constraints. It is the case of Building Information Modelers, which define parametric classes (Industry Foundation Classes), an expanded version of parametric object which embed not only the definition of constituent parameters but also behavioral functions. Being that this is a complex and sophisticated process and that mostly still is fed by current construction industry, although being a very interesting way of encoding behavior (even the whole building can be managed as a unique huge parametric system in programs such as GT Digital Project or Autodesk Revit) still is implemented in the final design stage and is not a preferred experimentation environment due to its highly structured nature.

The shortening of the linkage between design and production through the use of digital tools also redefines the traditional role of drawings (and representation in general): machines do not need to see a technical drawing, they just need the data sequence in order to build, therefore the actual role of representation as a technical device for the communication of construction information is quickly becoming obsolete.

As mentioned before with regard to technology evolution, our design catalogue of efficient solutions is a database which has consolidated through an history of experiments, test, failures, records. It is the pattern of information related to contextual success that dynamically selected those solution among others, therefore taking those solutions for granted in periods of sudden change, especially when that same catalog has reached its limit in giving satisfactory responses and opportunities would be ignoring the dynamic nature of our environmental bond. Since we grew the ability to store and communicate patterns of information, once efficient solutions are found, the time and energy spent for their diffusion is exponentially faster than the ones required to find them. During this process, further selection in the context of application reinforces and consolidates some of them while at the same time creating local variations.

The diffusion potential of digital tools [22] makes them also cheap and affordable as well as widespread and finely deployed in very specific and diverse contexts: this democratization of design and fabrication is of great social impact and opens the way to very localized and specialized architectural solutions, far from the risks of a digital homogenization.

Digital tools (or at least they are tools until we can call them just “tools”) are then tightening and fusing together the phases of design, fabrication and construction, going beyond the “layered assembly” technique driven by optimization logics (which reached its pinnacle in the modern period, mutually exchanging reason and support with economies of production and diffusion as well as the dominant scientific and philosophic theories) fostering a more sensible design ecology as they may facilitate a better understanding of synergies between systems and environments, or subsystem interaction. But the tools themselves are already undergoing an evolution, and, with respect to what was said about computers and technology, our relations with them will eventually more and more grow towards the way we relate to progressively more intelligent species (giving ‘intelligence’ its broader meaning). It is possible also to use a set of analogies to describe our relation with tools so far and in the near future: the pencil and its analog derivates put us in total control of the data we spread and embody in the project, while making it extremely hard to study and develop dynamic relations. In the present age of digital tools the analogy could be with driving: we feel like driving a car, giving input information and learning how the car responds. Once we understand the translating relation between input and output we get a hold on it. Unpredictability comes not from the tool rather from exogenous factors. But when we ride an animal (which could be the next stage in the development of tools intelligence) the relation is far more complex, the animal interprets the input, learns and gives a complex feedback, which the rider should understand, learn and adapt to. The most explanatory image of where this relation might lead us (even if still aesthetically influenced by a slightly picturesque take on nature) is the riding sequence in James Cameron’s “Avatar” movie, when the Banshee is first captured and ride by Jake Sully/Sam Worthington, connecting the tail to get symbiosis. The image is not intended to promote Cameron’s depiction of an alien arcadia, but it is instrumental to clarify that the role of digital tools in architecture under this framework is evolving to a point where we are not just dealing with a mere instrument but we are exploring the behavior of a system that is becoming closer to our mind structure.

A common question that arises when speaking about the use of tools, machines or computers in creative disciplines is if their use will in time kill creativity. I think this question is mainly driven by the fear of obsolescence, the resistance opposed before abdicating from a role that we, as specie, have claimed once but we found now a valid competitor. All innovations bring with them creative potential, and generally they are not a substitute of something existing but a integrate as a complement and amplification of creative potential. The sooner we play with technology and the sooner we embed it in our lives, the sooner we’ll find creative paths within that potential. In a way this is what, on a purely aesthetic intent, stylist Alexander Mc Queen did in his Spring-Summer 1999 collection, where he used two robotic arms to spray paint over a white dress in a poetic and dramatic dance performance. Robots are moving in a programmed choreography, but the aesthetic is already totally up to the process which leads to a performance in the interaction between the robots and the model. There is no metaphor here, not the easy - and cheesy - fear of the machine nor a blind faith in their power (the slight fragility and aggression shown in the very beginning soon give way to the awe in front of pure creative explosion), rather a both mature and playful understanding that they can be addressed within a creative process leading to some quite unpredictable but yet beautiful results. What if, for example, we can orchestrate a swarm of machines choreographing their movement and behavior in order to exploit their full creative combinatorial potential? What if we can feed in construction rules in search of self-organization architectural principles? And if the interaction becomes denser, more intricate and more complex with an increasingly intelligent subject, then we have the great chance to explore even more novel and interesting territories.

Ever since the invention of technology, man has engineered nature to create living environments. Now we are witnessing the primitive stage of a new catastrophe in architectural thinking and practice, running on a path that gives us another great chance: to get closer and closer to the behavior of nature as a system, in the pursuit of more sophisticated strategies to be an integrated part of it and not an obsolete one. Explorations that are tampering with higher mathematics (such as differential equations) in order to hack more sophisticated biological processes (such as the reaction-diffusion formula), agent based modeling or the implementation of physics with real time data processing software are moving in search of a more and more physically and biologically refined (a more natural) behavior simulation in search of efficient solution within a broad design ecology.

NOTES

[1] CAS are complex, self-similar collection of interacting adaptive agents. The study of CAS focuses on complex, emergent and macroscopic properties of the system. In the definition of John H. Holland: "A Complex Adaptive System (CAS) is a dynamic network of many agents (which may represent cells, species, individuals, firms, nations) acting in parallel, constantly acting and reacting to what the other agents are doing. The control of a CAS tends to be highly dispersed and decentralized. If there is to be any coherent behavior in the system, it has to arise from competition and cooperation among the agents themselves. The overall behavior of the system is the result of a huge number of decisions made every moment by many individual agents".
MITCHELL WALDROP, M., Complexity: The Emerging Science at the Edge of Order and Chaos, quoted in Wikipedia under Complex Adaptive Systems.
CAS are operating far from equilibrium (at the edge of chaos) where a network of agents interacts simultaneously: left to itself, the system is capable of generating order out of chaos (self-organization), showing emergent properties and levels of complexity and autopoiesis (self-generation). In these kind of systems order is emergent as opposed to predetermined: properties and levels of organizations in the system become emergent (they are empirically detectable but not logically deducible) thanks to a structure made of unitas multiplex (unity and multiplicity at the same time, without the dissolution of the one into the other), where the whole is more than the sum of the constituting parts. This is possible because each agent is a hologram: every node in the system network has almost all the information about the whole. Autopoiesis means that the effects and products of the whole (system) are necessary constituent parts of the system, making problematic to state clear definitions of cause and effect. More generally, any clear and close concept does not apply: the borders between the concepts of cause/effect, product/producer, object/subject, organism/environment, one and multiple dissolve. Autonomy is based on the dependence to the environment. To be autonomous, organisms must be dependent.
This paragraph is adapted by the author from: SOLA-MORALES, P., Genetic vs Generative, Lecture held at the Biodigital Architecture Master at ESARQ, Barcelona, June2008

[2] Emergence is the manifestation in a system of properties not shared by all of it constituent parts. Those properties are not possessed or inscribed in the single parts but they are detectable as the system unfolds in space and time, and generally initially simple rules lead to complex outcomes. Typical emergent processes are cloud formation, birds flocks, and other collective behavior such as the ones regulating the life of ant colonies. A termite mound is a wondrous piece of architecture with a maze of interconnecting passages, large caverns, ventilation tunnels and much more. Yet there is no grand plan, the hill just emerges as a result of the termites following a few simple local rules. Cities are emergent formations themselves. For further insight on emergence see the references at the end of the article.
[3] "A machine is defined by a set of abstract operations, satisfying specific conditions. An abstract machine is the system of inter-relations which is itself independent of the actual components which 'realize' the machine. [...] What matters is not the specificity of a given component but the specificity of its relationships.". Being that this model is purely relational "our abstract model here is topological at root".
In ATKINS, T. and WEISSMAN, J., Machinic Autopoiesis, from http://fractalontology.files.wordpress.com/2007/11/machinic-autopoesis.pdf
The concept of abstract machine (see note above) comes from the ontology of Gilles Deleuze, and it is also referred to (although with slight variations in the definition) as multiplicity or, as Manuel De Landa does in his book A thousand years of non linear history, as body without organs.

[4] "machinic: the existence of processes that act on an initial set of merely coexisting, heterogeneous elements, and cause them to come together and consolidate into a novel entity; [...] phylum: borrowed from biology where it denotes the evolutionary category just under "kingdom"[...], but which also involves the idea of a common body-plan, which through different operations (embryological foldings, stretchings, pullings, pushings) can yield a variety of concrete designs for organisms. The idea of a "machinic phylum" would then be that, beyond biological lineages, we are also related to non-living creatures (winds and flames, lava and rocks) through common "body-plans" involving similar self-organizing and combinatorial processes. As if one and the same material "phylum" could be "folded and stretched" to yield all the different structures that inhabit our universe."
In DE LANDA, M., The Machinic Phylum, from http://framework.v2.nl/archive/archive/node/text/.xslt/nodenr-70071

[5] As stated by WHITEHEAD, A. N. in The Concept of Nature – the Tarner lectures delivered in Trinity College, November 1919, available at Project Gutemberg: http://www.gutemberg.org/ext/18835;

[6] It is not within the scope of this paper to discuss at large all aspects of Deleuze's virtual philosophy and ontology. For further insight on material self-organization, morphogenesis, phase spaces see the References section "On Deleuze".

[7] About approximations and models of reality see: LYNN, G, How calculus changed architecture, video on TED.com.

[8] "Patterns do not develop by chance, but result from the permanent struggle for better flowing performance when the flow configurations are able to morph in time." MIGUEL, A. F. and BEJAN, A., The principle that generates dissimilar patterns inside aggregates of organisms, available at http://www.elsevier.com/locate/physa.

[9] For more insight on material systems and principle of minimal effort see DE LANDA, M., Material Elegance, in AD 77-01, 2007 Wiley Academy.

[10] See MARKRAM, H., "Designing the Human mind", video on http://seedmagazine.com/design-series/henry-markram.html.

[11] LYNN, G, How calculus changed architecture, video on TED.com.

[12] for how difficult it might be to imagine now, survival highly depends on finding food and avoid becoming food for other species.

[13] As Chip Walter says: "Toolmaking not only resulted in tools, but also the reconfiguration of our brains so they comprehended the world on the same terms as our toolmaking hands interacted with it." WALTER, C. - Excerpted from Thumbs, Toes, and Tears, Walker & Co. 2006. Published on KurzweilAI.net March 4, 2008.

[14] Paragraph adapted from Ray Kurzweil's introduction to WALTER, C. - Excerpted from Thumbs, Toes, and Tears, Walker & Co. 2006. Published on KurzweilAI.net March 4, 2008.

[15] To that extent, all species interact and change their environment, and respond to its change with adaptation: plants have colonized and changed the aspect of the whole planet in order to maximize their chances of reproduction. Nor we are the only one using tools or building stuff. What is different is the use of tools as extension of our ability in such a complex and sophisticated way and the unique system of communication we have developed for its transmission.

[16] KELLY, K., Humans are the sex organs of technology, in http://www.kk.org/thetechnium/archives/2007/02/humans_are_the.php

[17] See PRUSINKIEWICZ, P., Modelling plant growth and development, in Vivian Irish and Philip Benfey (eds), Current Opinions in Plant Biology 2004, Special Issue: Growth and Development, Elsevier, 2004.

[18] HENSEL, M, Computing Self-Organisation: Environmentally Sensitive Growth Modelling, in AD 76-2-2006 "Morphogenetic Design", Wyley Academy, 2006.

[19] "It is possible, in light of evolutionary theory, that the retina of the Ancient Greek was not evolved to the point of full color perception", from http://serendip.brynmawr.edu/exchange/node/61.

[20] In this perspective such a thinking ignores the fundamental teaching about media, messages and their mutual inflections started by Marshall McLuhan as well as the contextual nature of languages and their arbitrary association between signifier and significance.

[21] The (mis)use of the term "free-form" is another way of fostering the prevalence of rationality of the linear and flat through the association of a negative inflection to the term "free", generally indicating every shape that deviates from flatness or linearity; moreover this terminology swaps and confuses "form" (which is related to rules of formation, structure and organization of systems in general) and "shape" (the external result of the application of those rules) and does little or no justice to the fact that there is no real "free" form as even the most complex shape comes from rules of formation, both in the natural world and in the digital realm (the wildest

double curvature NURBS surface you can imagine is still generated and controlled by mathematical equations).

[22] See RepRap (http://reprap.org) or Makerbot (http://makerbot.com/), or other free internet schemes for building CNC machines like http://buildyourcnc.com.

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