Thinking With Computers and Fabricating With Machines

Philippe Marin\(^1\), Hervé Lequay\(^2\), Yann Blanchi\(^3\)

\(^1\)School of Architecture of Lyon, France  
BP 170 – 69 512 Vaulx-en-Velin  
philippe.marin@lyon.archi.fr

\(^2\) School of Architecture of Lyon

\(^3\) School of Architecture of Grenoble

Abstract

In this paper we examine some of the main characteristics of the transformations induced by digital culture. Our argumentation is based on a triple point of view. First we reconsider the architectural form as a significant instant inside a sequence of potentialities. Second we mark the renewal of the notion of ornament and its inscription into the digital culture. Third we return to the fabrication-conception continuum and we note the abilities of tools and technologies to stimulate perceptual entities. Finally we illustrate these topics with two examples of architectural algorithmic design. Based on these examples, we will mark the links between intuition and computation and the emergence of a digital materiality.

Keywords: generative design, digital fabrication, affect, digital materiality

1 Introduction

New technology is dramatically changing our approach to design. The digital dimension affects the way designers work within the new mode of discerning, conceiving and imagining space. The use of computers in the architectural field started early during the sixties with the work of Negroponte [1], and later with famous players such as Alexander [2], John Frazer [3], Paul Coates [4] and Kostas Terzidis [5]. More recently we can mark the increasing development of parametric modelling and digital fabrication; generative modelling and exploration processes; hybridization of digital and analogical tool all in used in order to assist the designer at each phase of the architectural conception. The expansion of scripting and the new characteristics of creativity in the informational age have both paved the way of algorithmic design and modelling.

2 Form in a Continuum

2.1 Invariant by variation

During the eighty, Gilles Deleuze [6] introduced the notion of “objectile”, in order to characterize a new paradigm following the transformation of our industrial production methods. Objects are no longer associated with a standard and a mass production but more
with a fluctuation and a continual variation. Digital machines are replacing the stamping methods. The form is inscribed inside a continual series of potentialities; the final shape is a singularity, an occurrence or an event among a larger and infinite sequence. Starting from here the development of the mass customization is possible.

Gregg Lynn [7] abounded in this direction with the concept of BLOB (Binary Large Object). Here the form is animated, modified and transformed by external forces; the deformations are smoothed and continuous. These forces could be invisible and represent the context of the project. Complexity, non-linearity and emergence become the characteristics and the properties of the projects.

To other contemporary architects the form is considered as a whole indivisible, they refer to the “searching shape” [8]. The morphogenetic principle is based on the use of transformation operators. The architectural form depends of the site limits, and then following external constraints like activities cohabitation, could suffer pressure and thus could be deformed. The final shape is informed by context, by external and invisible forces.

2.2 Digital creativity

These attitudes reformulate the processes of creation, which become less subjective, less arbitrary, no longer based on an artistic, individual or divine inspiration. The characteristics of creativity have changed in the informational age [9]. The individuals are connected, the modalities of cooperation allow the practice of open source developments, the re-using of code or tools, the sampling, the mixing of disciplinary. For Asut [10], creativity has to be collective, architects are one node of a net of people with common interests which collaborate, share information and generate solutions, the notion of authorship is transformed. In this context biology and natural processes are convoked in the architectural conception, and natural growth mechanisms or natural selection processes are implemented and interpreted to drive an architectural design and to help the designer to explore and formulate a solutions space.

3 New Ornament

3.1 From decorum to ornament

More recently we note the increasing interest for the surface treatment and the emergence of what is called a new ornament. This ornament acceptation is dramatically different from the common meaning. The sculptural and symbolic dimensions of the Renaissance concept of decorum, which aimed to articulate the building’s cultural and social context, are replaced by a thought on the surface, where patterns are repeated, emergent and digitally generated. Quite different from the tectonic role of the structure in the words of Godfried Semper, and on the contrast of Adolf Loos position in which he declared ornamentation a “crime”. The past decade has revealed a re-interpretation of the ornamentation. The works of Herzog and De Meuron architects or Foreign Office Architects are symptomatic of these practices and the literature is flourishing on this subject.

ornament relies on its application to an already existing surface and could emphasised the specific qualities of an object. The ornament is considered as functional when it is integrated to the building, thus particular treatment of the structure could be part of this category; ornament is mimetic when the symbolic and expressive dimension characterized the device.

Moussavi [12] as well, helps us to understand this renewal of interests for ornamentation. The growing number of large building types that are “blank”, department stores, shopping mall, cineplexes and museums, transforms the relationship between inside and outside; in addition, the necessity of flexibility in the architectural programs, both compel the architects to work on the external shell and to leave the internal definition to other designers. The envelope becomes the support of an architectural manifestation. The architects must give the building an expression that is independent from the inside yet participates to the urban structure. The environmental constraints and the energetic performances requirements of the building induce likewise a sharp definition of the building skin. This focuses the interest of architects.

3.2 Affect and sensation

Moreover the affect becomes one of the major issues of the architectural design. The sensation is often conveyed by the surface, and digital architecture plays a central role in the conception and construction of these spaces filled of affect. Following Bressani [13], the affect is immersive and is produced through a constant interaction between subject and object. Subject and object inform themselves mutually, architecture become active and performative. There is no longer a distinction between object and subject but more a sensitive immersion; the space participates in a sensitive experience in which the body is involved. Matter is embedded into virtual realities and smart components, space is no longer stable, autonomous and homogeneous, but becomes interactive, tactile, interface between our internal body, external experiences and distant communication. As in the experiment of dynamic ornament proposed by Maegher [14], data played an important aesthetic and cultural role in the design of architectural spaces, and could help occupants in the task of making sense of their environment. But the effect is also cultural; it depends on our education and cultural environment, our perception is inseparable of knowledge. Citing Baxandall [15] it is imperative to “live in a culture, grow and learn how to survive in it, is to make a specific perceptive training”.

The multicultural and the cosmopolitan society involve new symbolic communication and consensual icons that could be found in the technological culture. Thus the ornament represents the invisible forces of the culture, in order to create a collective meaning. The mixed, the continuity, the folds, the curves, the loop represent some imagination of creation based on an interactive and informational time and space [16]. Thus the digital fabrication allows new possibilities based on non-uniformity and non-monotony through the use of surfaces texturing and variable patterns.
4 Fabrication-Conception Continuums

4.1 Digital imbrications

Thanks to these digital fabrication technologies and advanced computing, a go and return system between bits and atoms are allowed; new representations have emerged with, for example the use of simulation, 3D printing, CNC cutting and robotic manufacturing. The status of the model has changed; these tools are blurring the boundaries between the make-up of an item and the thing itself [17]. The works of the architects, engineers and constructors are redefined. The characteristics of the fabrication, of the materials and of the construction are embedded in the design of the architect and convoked early during the design process. Technologies allow the realization of complex geometries; the designers are limited by the properties of the materials rather than by the difficulty of describing the designs.

The logics of digital processes have begun to re-organize the design methods. For Scott Marble [18] three main aspects should be considered. The first is “designing design” which addresses how design processes being influenced by digital workflow. The process of architectural design is integrated in a complex workflow in which geometric and parametric modelling is combined with simulation, analysis and optimization software could lead to the fabrication and manufacturing files generation. The second aspect is “designing assembly” or a material issue, and considers the way material properties and digital fabrication processes take shape in the design concepts. The final aspect is, “designing industry” which is concerned with the timing and sequencing of construction with the help of building information modelling and information management. In this context new industry sectors could be incorporated in the building construction.

4.2 Tools and design processes

We focus our point of view on the cognitive feature of the design process and specifically within its tooing. The notion of Critical Point of Changes (CPC) proposed by Parthenios [19] is illustrated in the non linear sub-sequences of the design process. The CPC represents the particular instant during which the designer is able to discern a specific component of the solution and takes a critical decision of modification, extension or calling into question. These CPCs are associated with the design instrumentation. For the author, tools should truly assist the architect during conceptual design in a way of transparency that would allow the architect to focus on the design and not on the tool. Moreover, there is no single tool providing the best solution for representing any idea, and there is no ideal sequence of tools uses. Each situation may engage a new spread of tools; the designer has the important role of making choices that will help his or her purpose. The designer’s skilfulness would be to choose the right media of figuration at the right time.

4.3 Tools and ideas

Laiserin [20] separated the notions of form finding and form making. In form-making, the mental construction arises before the representation. Form-making is a process of inspiration and refinement. In form-finding, representation arises before the mental
construction; the form emerges from analysis. Some media and representation afford form-finding more than form-making and vice versa.

Ranulph Glanville during his lecture in ECAADE08 marked the important distinction between a model of architecture and a model for architecture. In his view, tools for assisting designers have to focus more on stimulation and subjective meaning than on representation, especially during the initial phases of the design process [21].

We considered the verb, the sketch figuration, the mock-up representation and the digital model and simulation as the main tools of designing. Each of them bore their own cognitive characteristics, and each of them facilitated more or less such and such components of the perception and allowed such and such understanding of conception hypothesis. All media of representation have different affordances [22]. The creation of a tool represents the virtualization of the action, and the assumption of a new tool induces a mental representation of this one in order to be used. Once this virtualization is done, the user has access to a large range of novelties and new perceptions, and therefore the tools could evolve once more [23]. This externalization of functions help of the tools finds an ultimate stage with the externalisation of our memories. Thus conceptual tools such as shape grammar or other generative processes participate to the representation of the idea, they construct relations and allow evaluations of solutions.

4.4 New perceptive entities

Tools can be seen as an extension of the human mind involved in our mental activity such as thinking, imagining and interpreting. Computers are considered as an expressive medium, rather than just a tool in a workflow, they influence a designer’s thinking through the visual elements produced and generated in order to represent a meaning not only for expressing the designer’s idea to someone else but also for the designer within the complex feedbacks and interplays iterative loops of the design process. Architects work by manipulating these visual entities sometimes generated by algorithm within an autonomous process of the machine. In order to expand the limit of the human imagination, in order to help the exploration of the solutions space, a designer has to go beyond the software and has to get skills and knowledge in programming, writing code and algorithms, he or she has to be familiar with computer science, cognitive science and artificial intelligence [10].

Moreover the technologic environment in which we live takes part in the manner we perceive the world. For example, automobiles have dramatically transformed our perception of the speed; we are all familiar with the high-speed displacement and their sensitive body experiences. In the same way, computers, information technologies, immersive environments and ubiquitous technologies are progressively enhancing our common sensations and reflexes. New perceptual entities are emerging from the technological evolutions. In this context, the static architectural forms are replaced by dynamic flow, emergent patterns or computed geometries.
5 Cases Studies

The preceding topics are illustrated by the following two projects, each of which was executed under very different circumstances.

5.1 Genetic Algorithm and Environmental Parameters

Introduction

This first project aims to explore the evolutionary design through the implementation of a genetic algorithm and the development of a tool for use in creative architectural design process. This evolutionary process is evaluated by means of environmental parameters, passive solar qualities [24].

Figure 1: Overview of the process
Description

An overview of the process is illustrated in Figure 1. The tool is implemented as a plug-in within common software and is scripted and encoded with maxscript. An initial pattern matches the definition of an elementary genome, that is to say the first individual. The shape exploration is based on transformation through metamorphosis. Unitary operators were then applied: bent, tapered with, skewed, twisted and stretched (Fig. 2). The shape explorer takes the initial pattern as an input and stacks the operators in order to derive various shapes.

![Figure 2: Morphogenetic principle](image)

Natural evolution is simulated through crossover and mutation of genomes. Using genetic algorithms, each individual is represented on one hand by its phenotype, or geometric representation, and on the other hand by its genotype, or an encoded phenotype representation.

![Figure 3: Match Between Phenotypes and Genotypes](image)

The genotype symbolizes the individual's genome and is composed by two main chromosomes, the “material chromosome” and the “shape chromosome” (fig. 3). To begin with, a random population is defined. Each individual is evaluated by the UDD engine. Parents were treated two by two, and their chromosomes were cut at a random point, then
reconnected (the process being known as "crossover"). One “modifier” of the first parent replaced a “modifier” of the second parent. Material properties of the facets were combined in the same way. The “children” formed a new generation of population, and were evaluated once more (Figure 4). The cycle continued until an acceptable result was attained, or a given limit of generations was reached. Mutation mechanisms start from a selected individual, then randomly replace certain parameters of each chromosome. The mutation is placed in a new generation for evaluation and selection.

Fig. 4: Crossover mechanism

The material explorer makes it possible to modify the properties of each facet of the model, by evolving the opacity and the thermal resistance coefficient. These physical properties are stored and used by the evaluation engine. This one is based on the Unified Day Degree method. The environmental parameters are stored in an array: of solar radiation at specific angle and an orientation panel, external temperatures, internal inputs and inertial classes. Each individual in our population is rated according to heat needs.

Here the designer is no longer working on an unique solution but more on an entire family (Figure 5).
5.2 Voronoï Splitting and Spatial Organisation and Effects

**Introduction**

This project is the response of a real order and was constructed and delivered in the final semester of 2010. The client is the CEA (Commissariat à l’Energie Atomique), a French institution involved in research and development of advanced technology in the field of energy, electronics, nanotechnology and biotechnology. The initial brief focused on the development of a showroom, which aimed to represent the products and the innovation toward industrial partners and associated researchers. It was defined that this showroom would to stimulate creativity, imagination and serendipity through the construction of idea associations between the technologies. The showroom is a permanent space but must be upgradable in function of novelties.

**General Purpose**

Our purpose is based on a hypermodular concept. A cellular splitting allows a spatial structure in which smart partitions are installed. The positions of these partitions are movable in the limit of the splitting and thus permit a programmatic modularity. An energetic modularity is proposed with the feeder connection of each partition within the technical floor. Due to the flexible position of shelves on the partitions a functional modularity is reached. The partitions are made from wood and embedded with hidden RFID captors that allow a tangible interaction with the informational system. The space is open and visual associations
between thematics are possible, visitors wander around the partitions, inside the unified atmosphere.

![Figure 6: Interior View](image)

**Voronoi Splitting Description**

The focus of this presentation is on the use of the Voronoï splitting. A Voronoï diagram is a special kind of decomposition determined by distance to a specified discrete set of points. The geometry construction lead by the mathematical description can be found in nature, spots on a giraffe’s body, and the membrane of animal cells or plant tissue. Figure 7 shows the geometric rules of construction. A maxscript plug-in is used to autonomously generate the cells splitting.

![Figure 7: Voronoï Construction Principle](image)
This bio-inspired cellular zoning has three main advantages for us. First, it allows the inscription of the project inside a process in which collaboration and exchanges between architects and clients are possible. It determines the spatial structure as an effect of the process of collaboration. Secondly, it bears a symbolic expression and represents an interface between human and nature. Thirdly, it is used as a generative pattern and the whole ceiling is dressed with a lace based on successive Voronoï tesselations. This contributes to the unified atmosphere, and makes a light filter and creates a tension between the floor and the ceiling.

A process of collaboration

In order to fix the spatial organisation of the showroom a process of collaboration between architects and clients is implemented. Simple sets of circles represent each thematic of the showroom and their respective surface and position are determined by the client in function of the narrative frame and the strategic needs. This definition is made within a series of exchanges, backwards and forwards, allowing generation and representation of the 2D drawing and thus negotiations between the parties.

The Voronoï algorithm leads to an infinity of spatial organisation, the final one is fixed by the process of collaboration.
Process of Fabrication

The Voronoï cells are materialized on the floor using aluminium flat bars. The 80 nodes are cut with a water jet machine and put together on site. 504 metallic pans compose the ceiling lace: 171 standard pans, and 333 specifics. These are made of lacquered aluminium sheets, dimensions 600mm by 1300mm, cut with laser cutting machine (figure 10).
Figure 10: Pans Elements of the Ceiling Lace

Figure 10: Interior View
5.3 Overview

The following table presents an overview of the two projects. Even if they were executed under very different circumstances, we may mark a few common global characteristics directly linked with the digital environment.

First, the two projects convoked natural processes yet in a radical different way. One explored the process as a way of optimization (genetic algorithm) and the other developed a physical geometry and a spatial structure.

In both examples, digital tools and algorithms were playing a central role. None would be possible without computed processes. The tools allowed an interactive process; these interactivities enabled multiple generations and feedback. Moreover, the chance took part in the process. The processes were clearly defined, it was a necessity imposed by the digital tools, yet the final solutions were unpredictable.

<table>
<thead>
<tr>
<th></th>
<th>Genetic Algorithm</th>
<th>Voronoï tesselation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Context</strong></td>
<td>Experimentation and prototype tool development</td>
<td>Real order, client needs and delivery necessity</td>
</tr>
<tr>
<td></td>
<td>Provide tools for designers</td>
<td>Provide a symbolic interface between man and nature</td>
</tr>
<tr>
<td></td>
<td>Use environmental parameters during the conceptual design phase</td>
<td>Facilitate the emergence of ideas during a visit with the help of free connections and analogies construction</td>
</tr>
<tr>
<td><strong>Parameters used</strong></td>
<td>Environmental efficiencies</td>
<td>Spatial organisation and sensitive affect</td>
</tr>
<tr>
<td><strong>Bio-inspiration process</strong></td>
<td>Natural selection theory. Natural process</td>
<td>Natural shape</td>
</tr>
<tr>
<td><strong>Digital technology</strong></td>
<td>Development of a algorithm</td>
<td>Reuse of available algorithm</td>
</tr>
<tr>
<td></td>
<td>Development of a fitness function and evaluation system</td>
<td>Digital fabrication and materiality constraints</td>
</tr>
<tr>
<td><strong>Aims of the design</strong></td>
<td>Enhance the designer’s creativity</td>
<td>Define a spatial organisation and propose a physical order</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Enhance sensitive affect and provides an unified atmosphere.</td>
</tr>
<tr>
<td><strong>The resulting shape</strong></td>
<td>Shape are disconnected of the process</td>
<td>Shape is directly linked with the algorithm. The algorithm is a shape generator.</td>
</tr>
<tr>
<td><strong>Final result could not be anticipated</strong></td>
<td>A specific morphogenetic processes is defined</td>
<td></td>
</tr>
<tr>
<td><strong>Interaction and generation</strong></td>
<td>Numerous generations and</td>
<td>Numerous generations in</td>
</tr>
</tbody>
</table>
6 Conclusion

Finally, these projects exemplify the designer’s role, which shift from the definition of a single solution to the design of a whole range of solutions. The designer works on the conception of a system enrolled in a process, able to generate multiple solutions through collaborative interactions or iterative generations. Thus the designer becomes a meta-designer and the form becomes a meta-form. The shape is multiple faced and unfixed, a significant indetermination is included in the conception. We can speak of a “trans-form” in order to characterize this acceptation of the architectural form.

Moreover, a link between intuition and computation seems to emerge within the use of algorithms and generative tools. These enhance the possibilities of exploration, representation and expression of ideas within complex cognitive mechanisms which interplay. Visual and verbal thinking, analogical and logical structures are all stimulated through the use of computers.

Finally, the notion of digital materiality arises. It could be the result of digital loops and complex geometries, it could be constructed with the help of machines or it could be envisaged as an interface between physical and human sphere. Materiality could be interlinked with a digitally-equipped individual with new expectations and requirements. Anyway the accent must be put on sensory stimulation and spatial structuration.

In appreciation of:
Jacques Scrittori, JP Angei, Mariane Janda, Tiana Delhomme and her team.

References

[23] Levy, Qu'est ce que le virtuel ? La Découverte, 1998.