6th Conference on Computation, Communication, Aesthetics & X
Madrid, Spain

Isabel Clara Neves
isaclaraneves@ces.uc.pt

Centro de Estudos Sociais
Universidade de Coimbra
Coimbra, Portugal

The Emergence of Computational Design Research and Education

A Technical-Scientific Approach, 1950-1970.

Keywords: Computational Design Research and Education; Architectural Theory; Educational Project; Scientific Methodology; Computational Design.

Abstract:

A convenient framework of computational design research and education history in architecture is fundamental to formulate the possibilities of a "digital continuity" or "revolution in the discipline" (Oxman 2006). Contributing to this framework, this article presents an analysis of the cultural and technological context that led to the emergence of Computational Research and Design Education — HfG-Ulm and its American counterpoint — focusing specifically on the way teaching and architecture design approached science in the period 1950-1970. This is based in educational programs and places where a remarkable set of teachers, ideas and work converged.

1. INTRODUCTION

Nowadays the use of computational design processes in architecture has become a common practice thanks to theories connected to computer science developed in the 1950s across research centers in the US and UK.

Although there is an accelerated maturation of the integration of digital technologies in the architectural process, especially on teaching and research, there is no consolidated research on this perspective.

It is often observed that in architecture there is a transitional period in which technologies are initially applied as an extension of the established practice while in parallel, truly innovative approaches are developed in order to expand inherent potential of these technologies. This ultimately leads to a progressive transformation of the practice.

We are currently experimenting a transformational period (Menges 2013), in which the repeated search for innovation implies a deep understanding not only of digital design techniques, but also of a critical computational thinking that will guide future research. A convenient framework of computational Design Research and Education history in architecture is fundamental to formulate the possibilities of a "digital continuity" or "revolution in the discipline" (Oxman 2006).

Contributing to this framework, this article presents an analysis of the cultural and technological context that led to the emergence of Computational Research and Design Education, focusing specifically on the way teaching and architecture design approached science in the period 1950–1970. This is based in educational programs and places where a remarkable set of teachers, ideas and work converged.

The objective is to present an analysis of the computational design research and education, in two distinct technical-scientific contexts — Germany, through the HfG-Ulm, Hochschule für Gestaltung Ulm, founded in 1953, and United States of America, through some American institutions that were influenced by HfG-Ulm.

In order to carry out this analysis, this study uses the primary sources of archives and interviews. We will analyze the influence of emerging disciplines — Computer Science, Operational Research, Scientific Methodologies — in architectural thinking and project design.

As for HfG-Ulm case, this paper will examine and demonstrate the relevance of HfG-Ulm and the ideas developed by the aforementioned teachers, starting with the Max Bill Education Project, which proved crucial to build a new design approach and was also linked to the implementation of technical thinking and construction of a scientific perspective in architecture using an analytical approach of scientific research methods for information processing and design.

This article also contributes to the creation and mapping of an itinerary between institutions, works and key speakers that embody the defined theoretical framework, in a broader context composed of other institutions and systems of thought. It will advance research in the cultural and techno-scientific contexts that have contributed to the emergence of Research and Education of Computational design.

It ultimately aims to bridge a theoretical and historical gap in the interpretation of the relationship between computing and architecture between 1950 and 1970 through the belief that networked digital flexible architecture is capable of learning both past and present to evolve into a promising vision of the future.

2. STATE OF ART — EMERGENCE OF A COMPUTATIONAL PERSPECTIVE

The emergence of a computational perspective has not yet been documented and interpreted. However, we may already frame this ongoing research, that focuses on some research centers in Europe and in the United States, vital for the emergence period in the thought and practice in computational architecture (Keller 2005; Rocker 2010).

The starting point is the perception that the intellectual foundations of computational design's nature, based on the confluence of domains, from mathematics and computational science to biology and philosophy (Menges 2011). Publications that cover this spectrum of topics (Menges 2011; Vrachliotis 2010) are rare and the historiography of information technologies is a starting point for a global vision, essential for this theme.

During the first decade of the digital design materialization, in the 1990s, significant writings appeared, in isolated publications or exhibitions. This was a period of cultural transformation (Lynn, 1999).

An important threshold was reached with "Folding in Architecture" (Lynn 1993) and 20 years later with "Archeology of the Digital" (Lynn 2014). Later, the methodological and technological developments in digital design were the focus of attention (Kolarevic and Malkawi 2005).

On the one hand, since the turn of the millennium, the increase of publications on "digital design" is noticeable (Oxman 2006). On the other hand, while less concerned with issues of formal first-generation exuberance, the academic emphasis was placed on digital design (Oxman 2006) as a new set of technologies and communication media, that have been transforming definitions and traditional design concepts. The diffusion of digital equipment is linked to a series of changes in the definition and content of architecture, resulting from a much longer and more complex process of adaptation of designers to digital tools (Menges 2011; Picon, 2010).

Nevertheless, there are still very few studies on the meaning and progress of digital technologies in architecture (Picon 2010). Nowadays, the challenge of computational design does not lie in the mixing of computational design techniques, but in the "acculturation" of design thinking (Menges 2011), which is a distinction between computerized practice and the true computational design project. Examples of this appropriation of culture can be found in the history of architecture.

It is therefore relevant to focus on how design thinking is transformed and informed through technological advances (Menges 2011), in addition to discussing the impact of digital technologies on the discipline (Picon 2010). It is essential to reconnect the computational architecture with history, discourse and theory, by a systematic way and in an international context, thinking about the "emergence of computational Design Research and Education".

2.1. HfG-Ulm — The Educational Project

2.1.1. HfG-Ulm and its influence on post-war design in United States of America.

HfG-Ulm, in Germany, was opened from 1953 until 1968, during the transition of industrial society to post-industrial society.

Despite its small existence, HfG-Ulm represented a continuous project of post war of rethinking social sciences rules, inside a beliefs on racional supremacy. HfG's mission of "good design" it was asserted as a moral project, with a strong belief in aesthetics as a sign of a democratic society, due to the personal history of its founders, of the era of Nazi Resistance.

Teaching at HfG-Ulm recognized the ideals of standardization and mass production, investigating a scientific approach that integrated systemic methods, data collection and processing objectives, to achieve the design solution. It would synthesize science and design in a new scientific humanism that recognized the pluralism of methods and methodological perspectives required by the designer to face the new problems of industrial culture. What emerged, however, was the beginning of an operational view of design science, which Maldonado called scientific operationalism.

Nowhere else has this question been focused on before, only amongst the designers of devastation, with large curiosity about all new scientific subjects and new ideas in the philosophy of science and mathematics (Buchanan 2009, 427). As Maldonado stated, “The mainspring of all our curiosity, our reading, and our theoretical work was our determination to find a solid methodological basis for the work of design” (Maldonado 1991, 222). In this way the scientific knowledge and the new methods could be applied in the search for solutions for design problems, within an industrialized environment.

With the emergence of new disciplines as a consequence of technological and scientific developments caused by World War II, decision-making processes and research about creative processes had a significant influence in the early years of exploration of product design and its development methods. In this context, exchanges of information between disciplines such as artificial intelligence, cybernetics and problem solving were fundamental, especially in Europe and in the United States. Although these subjects were being studied by several research centers of the time, HfG-Ulm preceded the international speeches that manifested interference with HfG-Ulm’s philosophy or protagonists. A key issue raised by these center, as Andrea Gleiniger and Georg Vrachliotis claimed, was to understand how the computer could operate and be used in the design process. In his own words:

> A quick look back at the almost 50-year-long history of architecture and the computer will show that, at the beginning of the 1960s, the computer was still unchartered technological territory for architects, and considered primarily an artifact by technicians for technicians. It opened to architects a still foreign world of codes and programs that was also appealing, because they were fascinated by the mysterious and alluring glamor of technology. Now, with this in mind, the question then emerged of how this new machine can be operated and used in the design process.[1]

1. Gleiniger, A., & Vrachliotis, G. (2012). *Code: Between Operation and Narration* (pp. 10).

As such, it is important to consider the discussion that emerged in the United States about the systematic design methods developed at HfG-Ulm.

At the International Design Conferences in Aspen, United States, some professors representing the Ulm School were present, including Max Bill, Konrad Wachsmann and Tomás Maldonado. They discussed their ideas with industry managers and designers, promoting international exchange between theorists and practice.

In this context, the “First Conference on Architecture and the Computer” in Boston in 1964 focused on the problem of professionally educating a new generation of architects, proposing problem solving within a computer language, rethinking the function of the machine and its relationship with designers. Walter Gropius posed this question to the public and the audience of the conference, promoting the debate about the potentialities and limits of the computer in architecture.

According to Gropius, the computer was a product of that time, which required a change of practices. In his welcome speech, Payne, the chair of architecture in Boston and Gropius’ assistant, said:

> Our topic, the computer, seems the most timely, the most urgent, the most serious subject that we could bring to the profession”, and he added: “Steeped in time-honored traditional methods of approaching architectural assignments, but this machine, a product of our day and our time, might require us to change and approach our task in some new manner. So we must begin to explore the subject immediately.

Gropius, at the beginning of this conference, spoke about “computer language” and “architecture assistants”, in the sense of needing to apply the computer to architecture in a useful way, developing a common language between computer and architecture.

According to Georg Vrachliotis, when asked by Payne about the possibility of using the computer as an architectural tool, Gropius’ answer was succinct: “Still I believe, if we look at those machines, the potential tools to shorten our working progress, they might help us to free our creative power".

Gropius believed that the machine could shorten the designer's work processes and free up creativity. However, the most interesting aspect of this discussion was based on the initial question of Gropius: If architects were ready to consider computers as a viable architectural tool, it would be necessary to create the role of an architectural assistant. Almost four decades later and looking at the increasing complexity of computer programs, it is important to reflect on whether Architecture is still a field consisting of specialists, translators and architecture assistants or whether the work of architects involved with the University and researchers, essentially turns them into algorithm designers.

Design has historically been considered the fundamental tool for engineers and architects. Architects used design in the form of sketches, plants, perspectives, for design presentations, and to shape the abstract contours of their imaginary world. Writing and drawing were closely related. In both cases a "phenomenalization of the thought process" took place. The algorithmization of design process unleashed a wave of methodological and conceptual uncertainty throughout the field of architecture and later altered the architecture in the form of drawing and even more as a discipline. It was finally time to spread technological progress and start researching the use of the computer and its potential for Architecture. Except for the large planning and construction companies, where it was already being applied as an administrative calculating machine, the computer was seen by architects in the early 1960s as an artifact of technicians for technicians. No one knew how to approach these new machines. Despite the pioneering spirit that Payne was trying to unleash in that place, most architects had not yet glimpsed how, or where, computers could be integrated into their creative design practice and planning processes. It was an unknown world of codes and programs but one with a mysterious and seductive character that could be seen in photographs where huge computers were portrayed and stylized, representing a sober and rational world of applied mathematics.

Architects did not imagine being able to operate a computer in the design process, not only because of their lack of knowledge, but also because (and for many this would be the real reason) they did not feel the use of computers as part of the architect's design component. Two worlds were colliding: on the one hand the universal design, creative and intuitive and on the other the performative techniques.

In the conferences referred to above, held in the United States, Tomás Maldonado stood out amongst the main mentors involved. His relations with the United States were sporadic, but left an important legacy. In 1963 he was a visiting professor in the United States at the Carnegie Institute of Technology in Pittsburgh. Later in 1964, he lectured at the Institute of Industrial Technology of Buenos Aires, requested by the UNO as a specialized technician. In 1965 he was a Curriculum Advisor at the College of Architecture at the Carnegie Institute of Technology in Pittsburgh and served as Lethaby Professor at the Royal College of Arts in London, England. In 1966 he was considered a senior member of the Humanities Council and a visiting professor at the Princeton University School of Architecture. From 1968 he occupied the chair "Class of 1933", at the Princeton University School of Architecture. In the interview granted for the scope of this investigation, Maldonado reports the beginning of his contacts with the United States:

> (...) I was the promoter of the enrichment of a theory that resorted to hard Semiotics, information theory and the theory of cybernetics. During these years we invited Nobert Wiener to give a conference and we discussed these ideas with him. Of course, we had relatively clear ideas of what we wanted, but there were still mixed issues, because we were leaping far ahead. In the 1960s, I believe that in the year 64 or 65 more specifically, the first contact with the American schools happened.

2. Tomás Maldonado, interview performed by author, at 2012, in the context of research.

I went to the United States, Princeton and Harvard a few times to give courses and training sessions.[2]

Maldonado anticipated the role of industrialized production methods, as we can conclude when we analyze the Fundamental Course that he coordinated. Some of the themes taught by Maldonado related to Information Theory, Cybernetics and Computational Theory, where the objective was the introduction of precise analytical methods in design that followed mathematical explorations or applications of precise recursive rules. They influenced the generation of design patterns (for example, early versions of fractals such as Sierpinski's Triangle and Peano or Hilbert Curve). These were continued through the work carried out by William Huff, student of Maldonado, who showed the construction of a project system based on geometric rules. Rather than focusing on the design of specific and limited forms, students sought to explore the generation of variable parametric standards.

Huff had a significant role in the expansion of some ideas launched at HfG-Ulm and developed in the United States. It can be stated that William Huff was instrumental in defining the scientific approach in school. William Huff emphasized this approach in HfG-Ulm, expanded it and deepened it in other research centers, especially in the United States of America. In the interview given for the scope of this investigation, Tomás Maldonado pointed out that one of Ulm's most brilliant students was William Huff:

3. Tomás Maldonado, interview performed by author, at 2012, in the context of research.

"He was an American, was very important because he later was also a teacher in school and was my best student. William Huff was Albers' student at Yale and it was Albers who told him to come and study with me because Albers had been a teacher in 1955 in Ulm and he was there for a year with me and I helped him, he was my assistant. "After his experience in Ulm, his performance was noticeable as an assistant professor at the Carnegie Institute of Technology (Pittsburgh) from 1960 to 1966, and later as associate professor at Carnegie Mellon University from 1966 to 1972, became a professor in New York State, in Buffalo, from 1974".[3]

In addition to the lessons he taught, his publications also represented outputs from the Ulminian learning, Huff attempted to develop a project methodology based on the system of thought, proposing a reciprocal structuring system to its respective environment. Thus, very easily, the system of thought was literalized through geometric structures and the differentiation of the system, being presented through differentiations of geometric structures and patterns. The purpose of Huff's pedagogy was to search for systems of structures that relate "to the arrangement of parts or elements. For the project, then, it is above all the structure and for me the study of structure (in the abstract)." For Huff, the study of physical and perceptual structures became very important. Like Bense, Huff understood physical structures as "a structure, as far as humanly we can determine, in fact, is from the microcosmic atom to the macrocosmic universe".

Much remains to be learned, however, about structure in both its manifestations, the organic form, and the inorganic form. The structure can be studied through biology, mathematics and physics, as indicated by D'Arcy Thompson, quoted in Huff's text. In particular, D'Arcy Thompson's works became important references to Huff, and consequently to HfG-Ulm, for they represented structures of matter: "cells and tissues, shell and bone, leaves and flowers, are different portions of matter and it is in obedience to the laws of physics that its particles have been moved, shaped and shaped".

From this point of view, Huff's pedagogy defended two types of structuring of a system: the physical structuring through transformations following rigid transition rules, which transformed geometric patterns, and the perceptual structuring through optical illusions. Perceptual structuring has been exemplified by patterns whose realization, through the perception of the observer, changes continually. The designer is then in a position to create structures of unstructured matter, in anticipation of its continuous restructuring through who sees it. Therefore, it is not just design or design projects, but also the likely perceptions of design. Consequently, much of the training at HfG in the 1960s focused on rigorous methods training that allowed the designer to arrive in a controlled fashion with structures that offer a maximum of likely readings. Part of this methodology reinvested itself in the role of symmetry as a structuring, ordering and generating device. Moving away from the fundamentals of the Bauhaus, "learning by doing", replaced by a rigorous rule-based design discipline that explores questions of symmetry, topology, and perception. In HfG, Gestaltung meant Gestaltung of the human, physical, perceptual and mental environment.

The course where Huff taught at the Carnegie Institute of Technology in Pittsburgh was based on the HfG-Ulm Basic Course, written and directed by Maldonado in 1956-57. None of the early American design studies at that time approached the contents of the Basic Course in Ulm, except, according to Huff, of the Department of Yale, led by Albers. According to William Huff's own testimony:

> I began to teach Basic Design course at the Carnegie Institute of Technology, Pittsburgh. I did this especially out of my mouting vexation the beginning studies of none of the American Schools of design approached anything of the consequences of the Ulm Grundkurs (that rare island at Yale's Department of Art under Albers, notwithstanding.

In 1963, which computer models operated responsible for Huff's classes at Carnegie Mellon for a month. Observing the success, the students' learning and the practice of design reform in class, he invited Huff to come back to Germany and teach an autumn course at HfG-Ulm. That year, Huff worked in the Department of Visual Communication and the Department of Industrialized Construction. What, then, was Huff's real contribution to the Basic Course of Maldonado of 1956–57? According to William Huff himself, "based on Bauhaus's experimentation and observation strategies, "they added layers "that redefined the basic design, what he called "geometrization", "perceptualisation" and "exercise".

It is noted that the interests of Huff and Maldonado, his mentor, were no longer focused on single isolated elements and whole forms, but rather on the search for algorithms based on process rules. In contrast to previous surface structures, patterns have been imbued with the complexity of their possible variations. Variation was both a feature of the elements of a final form, through various scales, and, at the same time, the various possible forms that a single algorithm could generate. Artists and architects were consequently less responsible for producing a final form than for producing an algorithm that could generate a number of forms. The work of art and architecture as such ceased to be regarded as an original singular form.

It could be said that there was a continuity of processes, both in a pedagogical and technological perspective, in relation to the disciplines that had already been tried at HfG-Ulm. It is thus considered that the maturation process only came to fruition at the College of Environmental Design in Berkeley.

Fig. 1. “Color Raster”. Student Louis Sirianni, CIT (Carnegie Institute of Technology) 1965. Teacher: William Huff. Source: Gregotti, V. (1984). The Diaspora. Self-Portraits of Twenty Protagonists of the HfG. In *Rassegna 19 — Il contributo della scuola di Ulm* (pp. 37). Bologne: Editrice CIPIA.

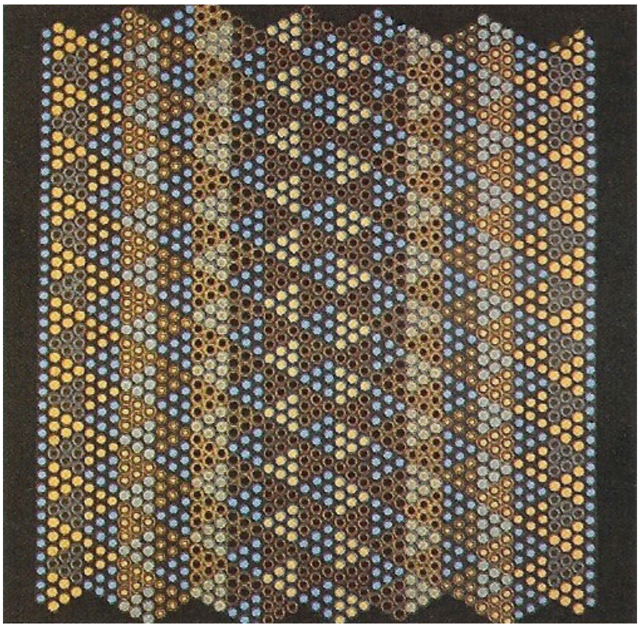


Fig. 2. Student Luís Golomb, CIT (Carnegie Institute of Technology) 1962. Teacher: William Huff. Source: Gregotti, V. (1984). The Diaspora. Self-Portraits of Twenty Protagonists of the HfG. In *Rassegna 19 — Il contributo della scuola di Ulm* (pp. 37). Bologne: Editrice CIPIA.

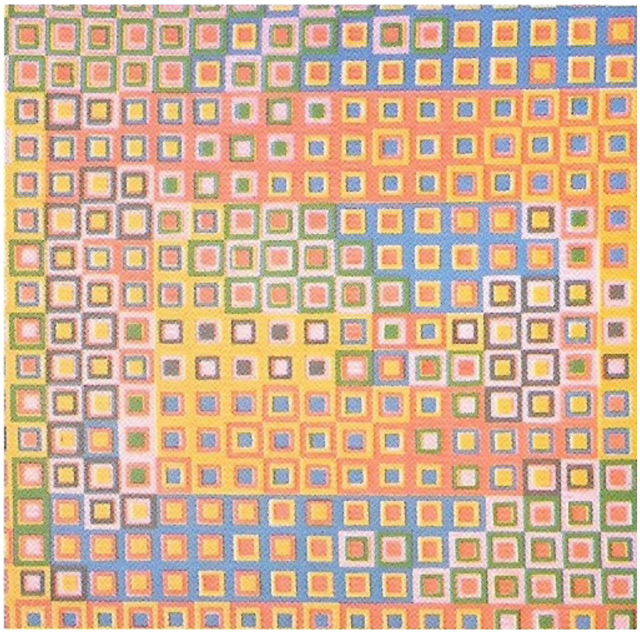


Fig. 3. Student: Yuqing Li, University at Buffalo, Teacher William Huff. Source: Cantz, H. (2003). *Ulmer modelle — modelle nach ulm*. Hochschule für Gestaltung Ulm 1953-1968 (pp. 189). Stuttgart: Ulmer Museum/HfG-Archiv Publications.

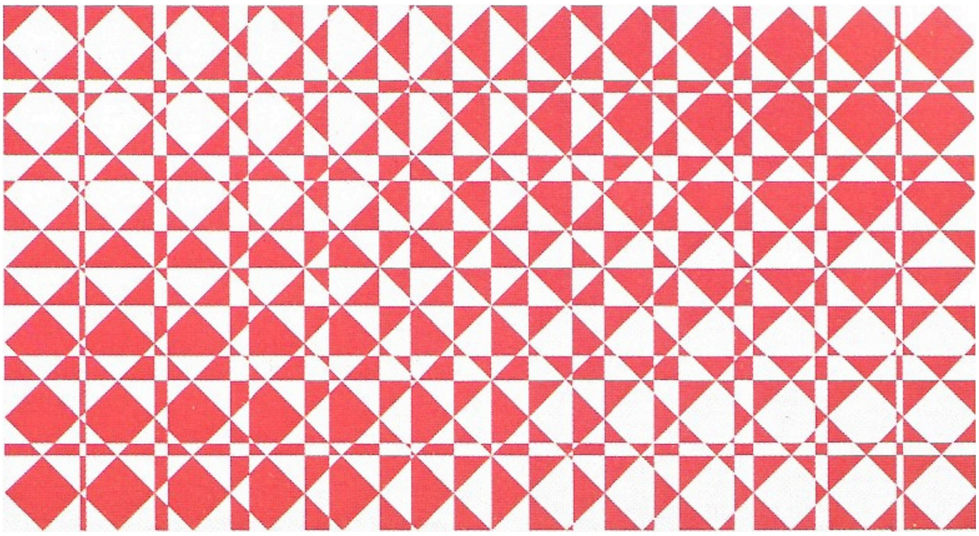
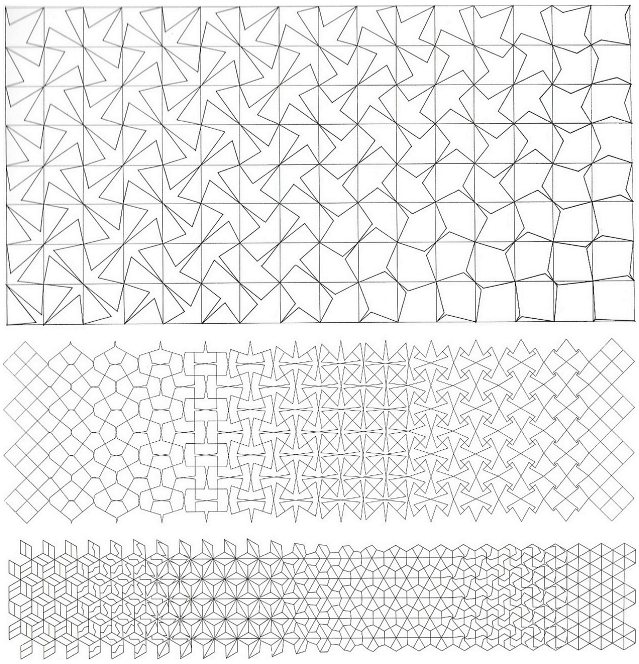


Fig. 4. "Symmetry or Programmed Design" Student James Eisenman, C.-MU (Carnegie-Mellon University) 1966. In Gregotti, V. (1984). The Diaspora. Self-Portraits of Twenty Protagonists of the HfG. Source: *Rassegna 19 — Il contributo della scuola di Ulm*. Bologne: Editrice CIPIA.



2.3. Ivan Sutherland's ingenious construction — interactive system for graphic images, based on graphic commands

Between 1961 and 1963, Ivan Sutherland[4] developed a graphic program — the sketchpad — claiming to be able to operate a computer with a visual base, beyond a logical and mathematical base. It was a "drawing machine" — that was his PhD thesis held at MIT. It was considered the first computer aided design (CAD) program and the starting point for research on human — computer interaction. With the Sketchpad, the concept of GUI-Graphical User Interface was inaugurated allowing interaction with the virtual world without typing long commands in scripting bars or programming algorithms. Users could use clicks to draw — a very familiar procedure, such as the ones used in current software programs like autocad.

In an interview given in the scope of this investigation, Maldonado said that he watched the development of this technology, stating:

> (...) At Princeton, in 1966 or 67, we began to talk about themes that were of interest to us in Ulm, as well as to them, teachers and students in the United States. American professors were also interested in these subjects. At that moment something very interesting happens. At the same time as my classes I am initially 3 months and then 6 months in Princeton) there was a teacher who gave a conference about the experiences that were being made at MIT on the subject of the computer. I was very enthusiastic, because that interested me a lot. I thought at the time the relationship between Information Theory and computerization. And then they told me that I would have to go to Boston because there were two young men who were doing their PhD thesis and they were approaching that. One of them was Ivan Sutherland. I met him and Timothy Johnson and realized what they were doing. They worked in a small room and I realized that Sutherland was mostly working on a pencil-like element that made it possible to modify images inside the computer. This was the subject of his doctorate. It represented a significant step forward, because it was the missing stage, not only to get to the image and the production of images, but to everything that had to do with computerization. Here our theory was linked to Cybernetics through their action that was very concrete, very applicative. Ivan Sutherland was practically the "father" of the mouse (mouse). From the pen to the mouse is a very simple step. So these 24 or 25 years old young men, were on the ground, to invent the operative elements. And in fact, when I

4. Tomás Maldonado, interview performed by author, at 2012, in the context of research.

went back to Princeton and then to Ulm, around 1964, I started to get more interested with these issues. What was a very abstract theory in the 50s, it begins to gain strength in the 60s and the interest grows for the technical part.

Sutherland's PhD thesis demonstrated the design operations that could be performed. This presentation was a pioneer in the notion of OOP (object oriented programming) and algorithmic language applied to drawing.

In the context of Architecture, the first discussions on the subject began to be published in the United States in the early 1960s and the most relevant investigations were conducted at the Department of Civil Engineering at the Massachusetts Institute of Technology (MIT) and at the University of Pennsylvania. On the other hand, the first applications of CAD realized in Europe, in England, presented different connotations of the American applications. There was inspiration in the Sketchpad formulation, and later a very sophisticated graphic interface was developed.

The "Conference on Architecture and Computer Graphics" held at Yale in 1968, another notable event in this field, focused on how architects dealt with computers. Steve Coons, a computer pioneer, said:

> No architect wants to become or should become an expert computer programmer. Architects want to do architecture. City planners want to do of city planning. They do not want to have to invent and manufacture the pencils they use. They want to have them at hand. The computer is a tool. We want to arrange matters so that the computer can be used naturally and easily as a pencil (...).

As expected, this statement was received with great approval by all architects, because above all, the architects wanted to communicate their ideas. According to the concept of Coons technology, it was the new technology that would have to change to meet the needs of architects.

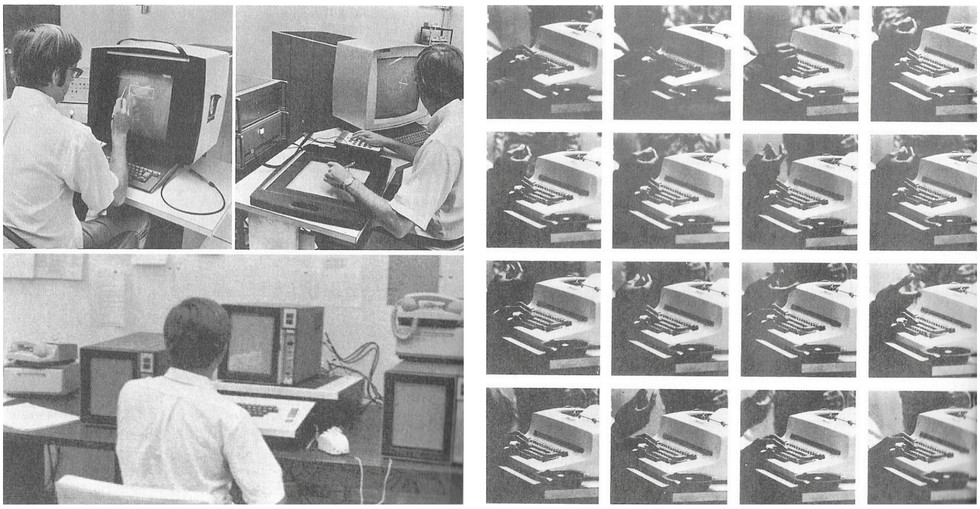


Fig. 5. Series of images of "The Architecture Machine", 1970. In Vrachliotis. Gropius question or on revealing and concealing Code in Architecture and Art. Source: A. Gleiniger & G. Vrachliotis (Eds.), *Code: Between Operation and Narration* (pp. 80-82). Basel: Birkhäuser GmbH. (2010).

3. THE EARLY ARTISTIC AS WELL AS THEORETICAL CONTRIBUTIONS BY MEMBERS OF THE STUTTGART SCHOOL AROUND MAX BENSE

Throughout the development of this movement in the United States of America, an artistic and philosophical tendency related to graphic computer was developed in post-war Europe. This trend differed from the approach of Coons and Negroponte in the fact that the graphic computer was programmed and not "drawn", as before. In the productive phase of Cybernetics, art and philosophy led to a culture of experimental programming that could spark a new artistic generation. The three central figures of this code culture were, above all, two young mathematicians Frieder Nake, Georg Nees and his mentor, the philosopher Max Bense, who transformed programming into a modern form of aesthetic craft, thus developing a new theoretical level.

Frieder Nake (1938, Stuttgart) is a mathematician, computer scientist and computer art pioneer. He is now known internationally for his contributions to the early manifestations of computer art, a computer field that made its first public appearances with three small exhibitions in 1965. Georg Nees (1926, Nürnberg) was a pioneer of computer art, honorary professor of computer science at the University of Erlangen, Germany. Nees and his companions, the also considered pioneers Frieder Nake and A. Michael Noll were designated as the "3N" of computational art. In 1968, Nees completed his doctorate at the University of Stuttgart, under the supervision of Max Bense his doctoral thesis was the first that focused on computer art. In 1977, he became an honorary professor at the University of Erlangen.

In this process a reciprocity has been developed between artisan aesthetics and aesthetic theory. On the one hand, the lines drawn by Nake and Nees seemed to contain traces of Bense's theory of art, and on the other hand, many of Bense's essays could be read as decoded philosophical aids, which were mandatory for reckoning Nake's abstract aesthetics and Nees' residual programming images.

As they explored playing on the computer, the images they created were sometimes presented in order, sometimes with irregular patterns. These machine-made drawings could be detected or assigned to a programming error, creating random patterns. The visual results of these program defects have charmed young mathematicians at the centre of computational investigations. At the same time, from a theoretical perspective, it was evident that these small black and white drawings contained an unimaginable explosive force.

Programming and design in this context implied thinking at the machine code level, regardless of what the drawing would represent, what kind of language had been used or what type of system had been coded. In this way, "one works at the level of the computer codes, meaning to use the logic of the machine". A code here consists of symbolic signs, being nothing more than a text, basically text, as Nake emphasizes. The computer has become a type of Semiotics, a technical artefact, or according to the computational scientist, a "Semiotic machine". In this way, one worked at the level of computer codes, using machine logic.

Drawing with code meant operating with "text". Nake and Nees' first computer designs shifted the emphasis from methodology to technology, giving a complete twist in programming theory. This was clearly demonstrated by the computer graphics program, which was organized in 1965 and where Nake and Nees showed some of their work. The authors showed that the programming codes gave rise to the drawings and, in other words, revealed the structural source and not just the result.

Presenting the code in this way, like an art form hung on the wall, was more than a didactic effort to make the new machine intelligible. The logical device of merging this link between artwork and method, computer graphics, and program codes became a prerequisite that, in art and architecture, would eventually lead a new faith in mathematics. There was now a double demystification — on the one hand the creative artistic process and, on the other hand the logic of the machine. The technical foundation closes the question of artistic creativity when the author is not only the machine, but also a set of systems. Nake's intention was to show the simplicity of the program code in order to reveal not only the complexity, but also how aesthetic the structures generated by the code can be, creating a discussion about the relationship between art, architecture, authorship, and technology.

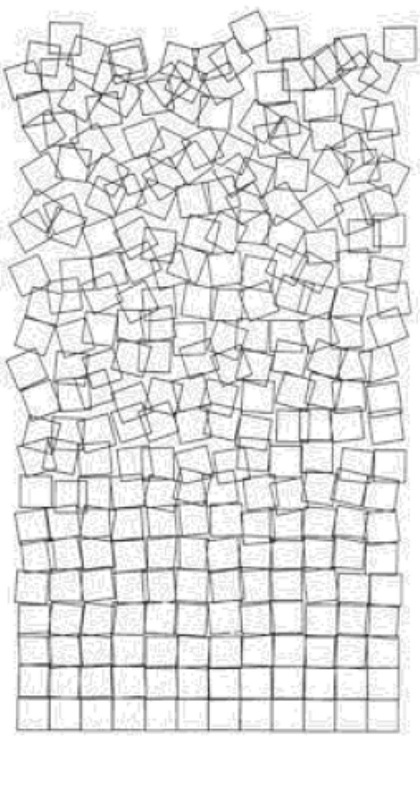
Max Bense saw in the programming of Nake and Nees a first step towards a future technical world of which he always spoke so passionately. Bense in his essay "Projekte generativer ästhetik", published in 1965, wrote that, in general, "the artificial" differs from the category of "natural" production by introducing a communication scheme between the creator and the work consisting of a program and in a programming language that introduces an unusual division of work and the aesthetic process. Bense was convinced that the human being needed to be fully integrated in the world of science and technology, to be intellectually incorporated and to be incorporated by science.

The evolution of Bense's communication scheme marked an important difference between the origins of computer graphics in America and Europe. According to Vrachliotis, the theory lacking on one side (United States) is abundant on the other (Europe). The lightness on one side is the weight on the other. The confrontation of "buildings without drawings" to "program culture" in the arts could even today trigger a reflection on which of these two forms proved to be most effective and useful for architecture.

Nake showed us a productive path out of this comparison in his 1974 book, "Aesthetics as Information Processing," which addressed the potential of computing in architecture and questioned how computers changed current ideas, stating that the architects had had a similar experience to the linguists for when they tried to solve problems with computers, they discovered its very limited knowledge. The emergence of the new machine, a new production tool, proved to be inspiring and motivating. It was, according to Nake, a new vision and an innovative way to acquire knowledge.

Nake also refers the linguists, making references to the revolutionary wave of the late 1950s, initiated by the work of the computational linguist Chomsky, who captured the attention not only of Bense but also of architects such as Christopher Alexander. The Sketchpad of Sutherland was an interaction model that introduced an abstraction zone between the user and the actual hardware, and the electronic representation of the data that the user wanted to have in his interface, that is, the user was the first interface of computers. It was also a first step towards the end of computing conceptualization, since the user can enter data without ever having to conceptualize the computation logic. In this sense, one could speak of a "house-training of computing", in the sense that the graphical interfaces allowed to directly transfer known design conventions to the computer. As computers became ubiquitous they provided interactive and more accessible interfaces in a practical application of the "known", which was not interested in the conceptualization of current and potential processes to structure the environment, but rather in the implementation of known processes and conventions".

Fig. 6. *Georg Nees Graphic "Schotter"* and the computer code that generates the graph, 1968. Source: Vrachliotis, G. (2010). Gropius question or on revealing and concealing Code in Architecture and Art. In A. Gleiniger & G. Vrachliotis (Eds.), *Code: Between Operation and Narration* (pp. 86). Basel: Birkhäuser GmbH.



```
'BEGIN' 'COMMENT' SCHOTTER.,
'REAL' R, PIHALB, PI4T.,
'INTEGER' I.,
'PROCEDURE' QUAD.,
'BEGIN'
'REAL' P1, Q1, PSI., 'INTEGER' S.,
JE1.=5•I/264., JA1.=–JE1.,
JE2.=PI4T•(1+I/264).,
JA2.=PI4T•(1–I/264).,
P1.=P+5+J1., Q1.=Q+5+J1.,
PSI.=J2.,
LEER(P1+R•COS(PSI),
Q1+R•SIN(PSI)).,
'FOR' S.=1 'STEP' 1 'UNTIL' 4 'DO'
'BEGIN' PSI.=PSI+PIHALB.,
LINE(P1+R•COS(PSI),Q1+R•SIN(PSI))
'END'., I.=I+1
'END' QUAD.,
R.=5•1.4142.,
PIHALB.=3.14159•.5., PI4T.=PIHALB•.5.,
I.=0.,
SERIE(10.0,10.0,22,12,QUAD)
'END' SCHOTTER.,
```

4. CONCEPTUALIZATION OF COMPUTER — COMPUTATIONAL THINKING IN ARCHITECTURE

Conceptualization of Computer was precociously presented in the HfG-Ulm investigation, and in some works developed in other contexts by HfG-Ulm mentors, as we have seen in this article, through the case of William Huff's work.

HfG-Ulm schooling stimulated a different approach towards Project and developed this computational conceptualization: instead of focusing on drawing and the pursuit of specific and conclusive shapes, students aimed to explore the conceptualization of a geometrical set of rules in order to control the definition of the shape itself. Thus, evoking scientific disciplines and methodologies, they developed a practice of Project that embodied an idea of a system, where a field of information is interactively structured in an open way so it can generate actual Project solutions.

The exercises with patters are a clear example of this approach. In it, one can see as students codified a set of rules of variation, from a given basic input, a module, in order to sustain the generation of a pattern, in which the module ceases to act as a fixed and repetitive entity, and becomes an element that shifts geometrically at every stage, but in an orderly way.

Despite this geometrical shapes were handmade, they reflect a Computational Thinking facing Project that can be recognized in the different contemporary approaches towards Project, based in the exploration of digital processes of parametric design.

Following the analysis of the article "Computing without computers"[5] from John Frazer, we may consider that, also on HfG-Ulm, it was perceivable a Computational development without computers. The computer emerges as a conceptual model, such as is perceived in Frazer's article, where it is interpreted as an electronic programmable device, and as a conceptual model.

5. Frazer, J. (2005). Computing without computers. *Architectural Design: The 1970s is Here and Now, 75*(2), 36.

Despite their coincidence, this two strands could develop from independent shapes. The emphasis, though, was on the demonstration of the theoretical model and its technical viability, and also on the functionality of a thinking experience.

Frazer claimed still that computation without computers was perhaps the most important lesson to be learned from the conception of those tools. As Frazer argued, it was clear that also in HfG-Ulm one could perceive that it wasn't necessary to build those tools in order to simulate its behavior.

By exteriorizing and materializing the internal procedures of the computer, the physical models act as any other model of architecture, helping to visualize and also to understand. The models aren't just tools that help the conceptual design, but also explanation tools. According to Frazer's words:

> The late 1960s and early 1970s became a prolonged thought experiment for myself and fellow students at the time. There were no affordable computers to speak of, so the only option was to imagine that they existed and imagine all the rest of the technology and social and political change necessary to realize dreams. This is what I mean by computing without computers; a mental rehearsal of what architecture and a built environment would be like at beginning of the 21st century.[6]

6. Frazer, J. (2005). Computing without computers. *Architectural Design: The 1970s is Here and Now, 75*(2), 36.

The record that Frazer describes, in which there were no accessible computers, and the only option was to imagine that they existed, was in fact the context in which HfG-Ulm emerged. There, computing was discussed not so much as a technology, but rather as a way of thinking and practicing, which altered the understanding of design and designer, and influenced other schools and teachers.

The HfG of Ulm, pioneered in the mid-60s heuristic procedures related to the power of the new computational era. This pedagogy clearly emerged from Ulm, constituted a legacy of computational thinking that evolved till today. Its cultural and technological context requires the pursuing of a historical reading that would enhance the interpretation of architecture own contemporary history. In HfG-Ulm the theoretical foundations through which computer models operated, with a "language of the computer", together with the language of "architectural assistants", began to make possible the application of the computer to the field of architecture, being necessary a translator who knew the language of both: computer and architecture.

The few who had access to computer systems in universities and companies in the 60s shared their knowledge in writing or in lectures organized several times by Tomás Maldonado. Thus, through these exposures and interferences, computer technology also found its way into HfG, feeling the implicit impact of new computer technology through the diffusion of general concepts related to hardware, as it happened throughout the work accomplished.

Computational thinking in architecture has led to an increase in the use of models and simulations in architecture. This development implied a predisposition for architecture to take the model, which explains that in places like HfG-Ulm, theoretical information, Operational Research, cybernetic and semiotic models were, despite their abstract nature, well received. Computers would also function as laboratories, where genuine computing processes were exploited, where the simplest computational rules led to more complex and unassignable results in results that could not have been predicted before their computation. It was there that theorization and conceptualization of computing found the real praxis, turning the computer into a tool for projections and speculations. The consequences for the role of the architect and architecture were significant, and the architect was now the author of an algorithm rather than a single architecture. The architect defined through his work a multiplicity of possibilities, in which architectures could or did not arise. This approach was different from previous ones, focused on the definition and design of a single piece of architecture.

There was a shift in thinking from architecture as a singularity to architectural thinking as seriality. This development is comparable to the development of Nees and Nake and computer art in the 1960s, when a single algorithm produced not a single piece of art, but rather a whole series of pieces of art, as can be seen in composition instructed by William Huff. These are symptoms and signs of an emergence of a computational perspective in Design and Architecture.

Acknowledgements:
Thanks to the staff at the HfG Archive at Ulm. To Fundação para a Ciência e a Tecnologia (FCT), Portugal.

References:

Bense, Max. *Introducion a la Estetica Teorico.Informational Fundamentacion y aplicacion a la teoria del texto*, in Corazon, Alberto (ed.), Madrid, 1972.

Buchanan, Richard. “Thinking about Design: A Historical Perspective” in Meijers, Anthonie and Gabbay, Dov. (eds.), *The Handbook of Technology and Engineering Sciences*. New York: Elsevier Press, 2009.

Frazer, John. Computing without computers. *Architectural Design: The 1970s is Here and Now, 75*(2), 36. [5] Wiley Publications, 2005 .

Gleiniger & Vrachliotis. (2010). Gropius question or on revealing and concealing Code in Architecture and Art. In A. Gleiniger & G. Vrachliotis (Eds.), Code: Between Operation and Narration (pp. 75). Basel: Birkhäuser GmbH.

Keller, Sean. *Systems aesthetics: architectural theory at the University of Cambridge, 1960-75: a thesis*. PhD Thesis, Harvard University, Massachusetts, EUA, 2005.

Kolarevic, B and A. Malkawi. *Performative architecture: beyond instrumentality*. New York: Spon Press, 2005.

Lindinger, Herbert. *Ulm design: the morality of objects. Hochschule for Gestaltung, 1953-1958*. Cambridge: The MIT Press, 1991.

Lynn, Greg. “Architectural curvilinearity: the folded, the pliant and the supple” in G. Lynn (ed.), *Folding in architecture*, AD 8e15 Profile no. 102, 1993.

Maldonado, Tomás. *Communication and Semiotics*, in *Ulm 5*, 1958.

Maldonado, Tomás. *Glossário de Semiótica,* in Crosby, Theo (ed), *Uppercase 5 HFG Ulm*. London: Whitefriars Press, 1959.

Maldonado, Tomás. Looking back at Ulm. In H. Lindinger (Ed.), *Ulm design: the morality of objects* (pp. 222). Cambridge, MA: MIT Press. 1991.

Menges, A. and S. Ahlquist. *Computational Design Thinking: Computation Design Thinking*. Chichester: John Wiley & Sons, 2011.

Oxman, Rikva. Theory and design in the first digital age Design Studies, Faculty of Architecture and Town Planning Technion, Haifa 32000, Israel, 2006.

Picon, Antoine. *Digital culture in architecture: An introduction for the design professions*. Basel: Birkhäuser, 2010.

Protzen, Jean-Pierre and David Harris. *The Universe of Design: Horst Rittel´s Theories of Design and Planning*. New York: Routledge, 2010.

Rocker, Ingeborg. 2010, Emerging Structures: Information Aesthetics and Architecture of the Digital Medium, PhD Dissertation, Princeton University.

Spitz, René. *HfG Ulm and the view behind the foreground: the political history of the Ulm School of Design*, 1953-1968, Menges, Axel (ed), Stuttgart, 2002.