The Roots of 4IR in Architecture

A military drawing machine used for space perception in architecture

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This paper analyses how architecture became a pioneer discipline in digital interactivity research. It describes how that pioneer research derives from a lineage of researchers whose work spans more than two decades beginning in the early fifties. Military funds enabled the creation of the first computer graphic interfaces that evolved into a ``drawing machine'', the first interactive CAD, that made possible the role of architecture as a pioneering discipline in interactivity research. It is expected to demonstrate that the same architecture that nowadays uses mainly interactive digital design was one of first disciplines to research interactivity addressing a gap in the study of the link between architecture and interactivity.

Keywords: *CAD, interactivity research, architectural design, ,*

INTRODUCTION

The issue of digital architecture being of great importance for the change in architectural practice seems to be, simultaneously, a controversial and key issue. However, this article does not intend to discuss such issue, but rather to demonstrate the importance of architecture as a pioneer discipline in the use of interactive digital design.

It is our intention to show that architecture was a pioneer discipline in interactivity research and especially in interactive digital design research. That approach descended from a lineage of researchers that had begun in the early fifties with the first computer graphic interfaces, continued with the first interactive CAD and in the late sixties originated the creation of an architecture research center based on that interactive CAD. We show how a military "drawing machine", the interactive CAD, enabled architecture as a pioneering discipline in interactivity research.

This article is focused on design research made for the American military industry, that would led to the use of interactive CAD in architecture. We will highlight the links of a research project, created in late fifties for military purposes that would be followed within a decade by important research on interactivity and graphical interfaces. That project of creating a military "drawing machine" was called Project CAD.

Several authors (Rocha, 2004; Llach, 2012, 2015; Steenson, 2014, 2017) considered the study of the origins of the use of computational methods in the field of architecture as a part of the change in the creative process, in the methods of design and even in architectural research, however, as already mentioned, in the present investigation the objectives are different and here is shown how Architecture played

a pioneering role in the research of interactivity.

That study of interactive design was not only a pioneering research on interactive digital architecture but also a very important research of interactivity in the sixties. Thus, with this contribution, architecture played an important role in interactivity and in 4IR.

With this research we hope to demonstrate that the same architecture that nowadays uses mainly interactive digital design was one of first disciplines to research interactivity addressing a gap in the study of the link between architecture and interactivity.

METHODOLOGY

The adopted methodology is based on historical research. The criteria for data selection was based on the relevance to digital architecture history and on the links between the research and the scholars involved. The objective was to validate the less recognized direct relationship between interactivity in computer graphics and the use of that interactivity in architectural research.

The bibliographic collection involved primary and secondary sources, doctoral theses, books, periodicals and other publications, articles and scientific communications, bibliographical notes, in analog or digital format, audio and video formats as well as web pages and other documents in electronic format only.

ORIGINS OF THE FIRST INTERACTIVE CAD AT MIT

The beginnings of computer graphics research in the early fifties and the use of interactive CAD in architectural research in the next decade have in common not only the institution, Massachusetts Institute of Technology - MIT but also the military purpose of the research and especially the military industry production.

To understand the relationship between those two beginnings, it is important to understand the question of academic research made for military industries. The design process that was used by the main manufacturers of military, automotive, shipping and aeronautical industries in the fifties needed more complex geometries that could only be possible by using a design supported in computation. Therefore computer-aided design emerged as a solution to create those new geometries in those industries (Weisberg, 2008; Perry, 2014; Llach, 2015).

It is important to mention that, although there were important contributions to the development of CAD from the automotive industry like Bézier and Casteljau (Farin, 2002; Carpo, 2011) and aeronautical industry like William Fetter (Perry, 2014), this article targets MIT's research for the American military industry.

This article focuses on the role played by the MIT's researchers and it seeks to associate the origins of CAD in a Cold War military funded project with the beginning of interactive digital architecture and to demonstrate that a research project that intended to create a "drawing machine" for military purposes contributed to a pioneering use of interactivity in architectural design research.

In the early decades of post-World War II, in the Cold War period, MIT's computer graphics research, was based on financing for military purposes, namely for defense industry and included research in areas that are in the origins of CAD and Computer Aided Manufacturing (CAM). That military funding at MIT had such level that several authors considered the institute to be the largest recipient of public research funds in the first decades of the Cold War (Weisberg, 2008; Perry, 2014; Llach, 2015).

It was a time when computers were very expensive, to the point that the cost of using a machine in the early sixties was almost ten percent of the total cost of a major research project in which three hours of computer use had the same cost as the monthly salary of a junior engineer - six hundred dollars (Weisberg, 2008).

In the aftermath of World War II, the US military started to fund human - machine interaction research to the point that in December 1951, only six years after the end of the War, MIT researcher Jay Forrester introduced Whirlwind, world's first computer with dig-

ital display, on a CBS television broadcast. It was a computer connected to a 256-pixel monitor used by the American Navy to simulate the ballistic missile course, its fuel and speed (Forrester and Everett, 1990; Weisberg, 2008; Llach, 2015).

This Whirlwind's interface, the first computer screen, worked like a fifties television set, through a cathode ray tube (Forrester and Everett, 1990; Llach, 2012, 2015; Perry, 2014). By the end of the fifties, Whirlwind, would have a second human interface, the light-pen, developed by Wesley Clark, which allowed data input directly on the screen, initially for military purposes related to radar coordinates (Llach, 2015).

By the end of the decade, and according to Llach (2015), Whirlwind, would allow the development of MIT's first computer-aided drawings. However, those drawings were the offspring of a noninteractive system and despite Whirlwind being an interactive computer, the design was programmed by punched tapes through a programming language, the Automated Programming Tool (APT). APT was created to control a milling machine and had been developed by the same Servomechanisms Laboratory that created Whirlwind, by then called Electronic Systems Laboratory - ESL (Weisberg, 2008; Llach, 2015).

APT was a language designed for manufacturing and in a few decades, it would become widely used in the aeronautics industry. The APT had been developed under the coordination of the electrical engineer Douglas Ross who would become one of the co-directors of Project CAD with Steven Coons, a design professor at the mechanical engineering department (Weisberg, 2008; Llach, 2015).

Project CAD was a joint venture between ESL from the department of electrotechnical engineering and the design division of the mechanical engineering department. In nowadays terms it could be said that was a partnership between IT coders and designers. A research project that had as generic objectives, stated in the military financing contracts, the improvement of the design in the manufacturing of airplanes, missiles and respective components. The project that would last from 1959 to 1970, through three contracts, had has as its real purpose to create a "drawing machine" for the military. (Weisberg, 2008; Llach, 2015).

The denomination adopted for the project was computer-aided design, with a hyphen between computer and aided. This name was a condition of the design division team to emphasize the idea that the design foreseen in the project was a human process in which a user would be assisted by the computer and not the computer automatically replacing the skilled design workforce (Llach, 2015).

That way, CAD became the acronym of the project's name, computer-aided design, which emphasized the idea that drawing was a human process and not an automatized computer drawing (Llach, 2015). Thus it was created the acronym that corresponds to the most well-known designation of the drawing on a computer procedure (Weisberg, 2008; Llach, 2015).

Coons and Ross had almost antagonistic views of computer design. For Coons, the computer would be an assistant or associate of the human designer, while for Ross, computers would be universal tools with the ability to make a fully automated design. On one side was the possibility of being creative using a computer to draw and, on the other side, was the automated machine intelligence to do the drawing (Llach, 2015).

In fact, Coons's vision of human - machine interactivity would prevail mainly due to difficulties of implementing Ross's design automation. Despite having a great deal of merit in choosing interactivity for digital design, Coons isn't recognized for its role as a design theorist in Project CAD but for its role in the development of computational geometries and, above all, for the creation of the Coons Patches, a mathematical technique for describing three-dimensional curved surfaces by the four boundary lines and their intersections (Llach, 2015).

Steven Coons's work in Project CAD can be con-

sidered the origin of how architectural design is mainly done today with a man interactively drawing on a computer (Llach, 2015). Project CAD can also be considered the first systematic investigation of human - machine interaction, before Douglas Engelbart have prototyped the computer mouse at Stanford (Licklider, 1969; Llach, 2015).

Eight years after Whirlwind graphical interface had been created and shown on television, the same research facility was evolving to develop a "drawing machine".

THE FIRST INTERACTIVE CAD - SKETCHPAD

Nevertheless, Coons was not a computer scientist and his ideas of interactive CAD would be materialized by a young electrical engineer and military in reserve, called Ivan Sutherland.

As a teenager, Sutherland was already a computer enthusiast, he and his older brother, Bert, were some of the earliest microcomputer programmers ever, as they were able to program the division into the Simon, a proto-personal computer created by Edmund Berkeley, an acquaintance of Sutherland that presented him to his future advisor, Claude Shannon, an MIT's Ph.D. who, in 1948, had signed a groundbreaking and fundamental article for the digitally connected world of today, "A Mathematical Theory of Communication" (Sutherland, 1989, 1994)

Despite the notorious influence of Coons's ideas, Sutherland, had another motivation for the original idea of his Ph.D. Dissertation, the creation of an interactive CAD software. This other motivation was due to the fact that his father was a civil engineer, and, for this reason, he was able from a young age to read engineering blueprints from his father's work (Sutherland, 1989, 1994).

Sutherland would begin its activity at MIT, in 1960, in the Lincoln Laboratory, MIT's military research facility, using the then-powerful TX-2, a computer with interactivity guaranteed by the light-pen and through a seven-inch screen, complemented by a set of switches and rotating knobs that ensured the manipulation of the drawings, as well as the area and the image size. These mechanisms that manipulated the drawing in the screen, are of some importance for the understanding of the evolution of the digital drawing, since part of what we know today, as tools of digital design manipulation, correspond to Sutherland's inventions, patented in his name, years later, as are the cases of windowing, zooming and clipping (Kassem, 2014).

The interactivity of Sutherland's Sketchpad was inspired not only by Coons's ideas but also by the ideas of JCR Licklider's article "Man-Computer Symbiosis" (1960). Licklider was also an MIT researcher that would became the director of the important Information Processing Techniques Office (IPTO) from the Advanced Research Projects Agency (ARPA). In 1964, Licklider would have Sutherland chosen as is successor as IPTO's director (Sutherland, 1989). Sutherland would consider, years later, that the money spent on research by IPTO would have generated a return to the United States through the tax revenues of businesses and the jobs created. IPTO was also the place were ARPANET, the precursor of the internet, started (Roberts, 1978; Sutherland, 1994).

Even before the delivery of the Ph.D. dissertation, MIT would rush to disclose Sketchpad, still in a provisional version, during the spring of 1962, through the production of a film in which Sutherland drew on that version, since the thesis would only be delivered on 7 January 1963 (Sutherland, 1963, 1994). The film would be widely used in presentations for students, academics and journalists, making it a unique influence for all types of design students, architecture students included (Llach, 2012, 2015; Perry, 2014).

In that January, the first interactive CAD was converted into in a Ph.D. dissertation called Sketchpad, a Man-Machine Graphical Communication System. Coons was on the thesis committee with the Artificial Intelligence pioneer Marvin Minsky (Sutherland, 1963). Sutherland had created an interactive design system on the computer, the first interactive CAD made with a seven-inch screen, almost the size of a smartphone (Kassem, 2014).

Because Sutherland envisage Sketchpad without

the need of using punched cards or tapes to transmit commands to make the computer draw, it was a design system that could draw in real-time. The real-time fact which at present appears to have been taken for granted provided the system in 1963 an interactive feature. The system was innovative and introduced new concepts in several areas of computer graphics, such as dynamic graphics, visual simulation, graphic resolution constraints (Negroponte, 1995). "Sketchpad was the big bang of computer graphics"(Negroponte, 1995, p. 103).

The following decades would demonstrate that Sketchpad was a fundamental element for media development, a central part in the history of computational media (Wardrip-Fruin and Montfort, 2003) and a genuine graphic communication system (Manovich, 2013). In fact, Sutherland itself, in the title of his Ph.D. dissertation, identified Sketchpad as a system of graphic communication between man and the intelligent machine and not as a design system.

However, Sketchpad was also more than an interactive communication system, since it can also be considered as the beginning of today's computer animation. Sketchpad was also a pioneer in the field of programming languages, being the precursor of object-oriented programming, since it was the first computer program to instantiate inherited instances and properties between instances. According to Alan Kay, which is considered the "father of personal computer" (Negroponte, 1995, p. 134) and was a Sutherland's student, Sketchpad would have been the first object-oriented programming language ever since it did not use a list of programming procedures (Kay, 1996; Manovich, 2007; Gaboury, 2014).

Only eleven years after Whirlwind had been shown on American national television, that first graphical interface research made possible that a man could use the screen to draw in real time.

STEVEN COONS - CAD IN ARCHITECTURE

Steven Coons can be considered as the main mentor of Project CAD, idealizing a CAD to serve creative designers (Coons e Mann, 1960) like architects. A CAD for designers who started their design on the computer without having a definitive idea, unlike the engineering designers. For Coons, the computer stayed with the repetitive work and the man had the creative work. Coons envisioned the computer as a universal design machine, the "perfect slave" (Coons, 1966, p. 9) serving the man that could be a creative designer or not (Coons, 1966; Kassem, 2014; Llach, 2015)

Although CAD "paternity" appears to be the subject of doubts, recent historiographical investigations of CAD origins, such as Cardoso Llach (Llach, 2015), seem to show that it is safe to say that Steven Coons can be considered the "father of CAD" or at least the person responsible for the designation and the concept of computer-aided design. If on one hand, Douglas Ross who died in 2007, almost thirty years after Coons that died in 1979, claimed during that period that he was the responsible for the Project CAD ideas , on the other hand, the youngest members of Project CAD as Timothy Johnson have ensured, already in this decade that the merit of the Project CAD ideas pertained to Coons (Llach, 2015)

Just as Sutherland who invented the first interactive CAD, Coons is not one of the most well-known figures in architectural design. However, Coons can be considered, without a doubt, as one of the most influential characters in the development of its digital component, with important contributions to the introduction of an interactive technology culture in design. The importance of Coons for design, only began to be recognized in recent academic works like those of Cardoso Llach (2015, p. 54), that considers that Coons had a "key role as a design technologist and theorist" or Gaboury (2014, p. 143) that calls him the "grandfather of the computer graphics".

When Sutherland, after delivering his Ph.D., returned to the US Army, Coons became the main promoter of Sketchpad. The system's first presentation to an architect's audience was done by Coons at the "Architecture and the Computer" conference in 1964, reinforcing the importance of the symbiosis between architect and computer (Rocha, 2004; Kassem, 2014; Steenson, 2014).

Without Sutherland, Coons would continue research on the development of the "drawing machine" with Timothy Johnson, developing a three-dimensional version of Sketchpad, taking advantage of internet pioneer Larry Roberts's Ph.D. dissertation on computer representation of polygons (Roberts, 1963, 1978; Coons, 1967).

The three-dimensional version of Johnson, Sketchpad III, delivered as a master's thesis, five months after Sutherland's Ph.D., is nowadays possibly better known than the original version due to the 1965 documentary, broadcasted in National Educational Television (NET). In this movie, the Johnson is drawing in the screen with an introduction made by Coons in an interview (Johnson, 1963; Morash, 1965).

Sketchpad III was the first computer graphic system to implement three orthogonal views of 3D objects at different scales. The goal of Johnson and Coons was to enable prospective design if necessary. This way the user only needed to rotate the object with the computer's rotary knobs. With Sketchpad III the viewport concept was established continuing to be present in CAD software up to the present times (Weisberg, 2008; Llach, 2015)

Coons emphasized the importance of the symbiosis between creative designers and computer reinforcing the idea that the computer is only an aid to man "the perfect slave". An idea created by of Coons in a presentation that he made at a regional congress for arts teachers in 1966 to demonstrate the utility of the machine in artistic creation (Coons, 1966).

A few months later, Coons would have the chance to take interactive design to architecture by being one of Nicholas Negroponte's master thesis advisors in the architectural thesis The Computer Simulation Of Perception During Motion In The Urban Environment (1966). Negroponte was already beginning to realize the need for scientific research in architectural design (Negroponte, 1966, 2010). A vision that corroborate the ideas of the contemporary Design Methods movement and of Horst Rittel that considered the hypothesis of bringing NASA approaches to design science (Bayazit, 2004).

Already in the present decade, in an interview, Negroponte would highlight the importance of its three advisors, and in particular, Coons, due to its relevance to the evolution level of digital architectural design (Negroponte, 2010; Llach, 2012, 2015). The other two advisors were Kevin Lynch, specialist in urban planning, author of the important book The Image of the City and Gyorgy Kepes, a visual artist who had taught in the New Bauhaus de Chicago with Moholy-Nagy (Negroponte, 2010; Steenson, 2014).

However, the influence of Coons as Negroponte's advisor is far more important for the evolution of the interactive CAD, even by the fact that it has originated the start of Negroponte's teaching and researching activity at MIT. In fact, the architect would become professor of an MIT's engineering course due to Coons. Negroponte, in 1966, replaced Coons who had taken a sabbatical leave, to be able to work again with Sutherland, now at Harvard (Llach and Forrest, 2017). Negroponte was a computer-aided design assistant professor in the mechanical engineering course while Coons with Sutherland were working on a Virtual Reality pioneering research that would be published as "A head-mounted three-dimensional display" but would be better known as Democles Sword (Negroponte, 2010; Llach and Forrest, 2017; Steenson, 2017).

Negroponte would move from the mechanical engineering department to the architecture and planning school the following year. There he could create one of the first computer-based architecture research centers, the Architecture Machine Group (AMG) (Rocha, 2004; Negroponte, 2010; Steenson, 2014).

In just three years, after the departure of Sutherland, Coons would achieve important developments in the" drawing machine", helping to create the three-dimensional version of Sketchpad, disseminating interactive CAD to architects and visual artists and managing to find an architect to continue the development of Interactive CAD research in architecture.

NEGROPONTE AND AMG

In 1968, Negroponte received an invitation from the Dean of the MIT's School of architecture and planning, to become an assistant professor in the architecture department, creating one of the first computer-based architecture research centers, the AMG (Rocha, 2004; Negroponte, 2010; Steenson, 2014).

During the late 1960s and early 1970s, Negroponte, through the AMG, engages in several research projects, URBAN 2, URBAN 5, SEEK, or HUNCH, which linked interactive computing to space perception in architecture. Projects that used interactive design to improve the perception of the designed space, funded mainly through military funds (Steenson, 2014).

The initial projects, URBAN2 and URBAN5, used a simple graphical interactive CAD, combined with a robotic arm to move three meter cubes that came from an artificial intelligence research domain called Block Worlds (Steenson, 2017). The research enabled an interactive communication between man and computer. A communication established through the computer keyboard and buttons by question and answer (Negroponte, 1970; Steenson, 2017).

AMG's next project, an evolution of URBAN5 but in which the arm reconfigured the blocks according to the habits of the inhabitants. A research that tried to emulate a city with an environment reconfigurable by the inhabitants, a colony of gerbils (Negroponte, 1970, 1975; Steenson, 2014, 2017).

The inhabitants of the SEEK "city", the gerbils, were chosen for their curiosity and served to introduce the "chaos" element into the simulation of the real world. SEEK aimed to show the reflexes of a responsive environment, with a robotic arm correcting or amplifying the changes caused by gerbils (Negroponte, 1970, 1975; Steenson, 2014, 2017; Llach, 2015)

The technology that was included in the SEEK software was tied to other MIT artificial intelligence laboratory researches, related to computer vision and the ability to analyze incompatible data. The MIT's artificial intelligence laboratory, at the time, worked in researching the construction of a practical system of analysis of real-world scenarios and Negroponte developed investigation with the laboratory through its researcher, Marvin Minsky, the Artificial Intelligence pioneer who was with Coons on Sutherland's Sketchpad thesis committee (Negroponte, 1970, 1975; Steenson, 2014, 2017; Llach, 2015).

Another important project of the AMG related to interactive CAD was HUNCH, directed by Negroponte with research done by James Taggart in his Master Thesis (Taggart, 1973).It was a project more closely related to Sketchpad and also to architectural digital design (Negroponte, 1975). It consisted on a system that deciphered early versions of hand sketches to the computer screen using artificial intelligence combined with cybernetics, architecture, behavioral cognition, construction and machine learning (Werner, 2018). In HUNCH, the sketches made by the human hand were considered a vehicle for computer learning, following the concept that much of the thinking involved in architectural design was made in the form of sketches drawn in napkins and scraps of paper. It was more than a drawing system through sketches, since it could also interpret the pressure and density of the lines drawn by the user and could also perform the rationalization of the drawing through B-spline techniques, a research area developed in that initial period of the seventies by Coons and his disciples (Negroponte, 1975; Werner, 2018).

The importance of Negroponte projects to the interactivity research would make JCR Licklider, the author of "Man-Computer Symbiosis" would consider it one of the few researchers to contribute to the advancement of interactivity research in the sixties with a research extent only comparable to Engelbart who invented the computer mouse (Licklider, 1969, p. 619). Licklider with "Man-Computer Symbiosis" (1960) had become one the most important theorists on the interaction between men and electronic computers.

AMG's research projects would provide Negroponte, material for the writing of two important

books for digital architectural design, The Architecture Machine (1970) e Soft Architecture Machines (1975). The latter would have a chapter called "Computer Graphics" with introduction by Steven Coons. However, more important than the authorship of the introduction, it may be the fact that Negroponte in that chapter considered his former supervisor as the "father of computer graphics"(Negroponte, 1975, p. 57) . The former advisee also pointed out that he attributed this distinction to the advisor because he considered that there was a great disproportion between the initial objectives proposed by Coons for the interactive computer graphics research and the objectives proposed by his research colleagues at the beginning of the sixties. Almost forty years after the publication of the book, Negroponte continued to emphasize the same idea of importance of its advisor Coons, considering him as the inventor of many of the CAD systems of the sixties (Negroponte, 2010).

In Soft Architecture Machines (1975), Negroponte would also recognize the little progress in computer graphics interactivity, based on the fact that computer graphics researchers were more focused on technical developments in image realism or in data efficiency. Negroponte (1975) even gave as an example of little progress in interactivity, the book Principles Of Interactive Computer Graphics coauthored by one of Sutherland's top students, Robert F. Sproull (Sutherland, 1994).

This marks the distinction between Negroponte's disciples and Sutherland's disciples. Being two of the most important computer graphics research groups of the seventies, they focused on different areas of computer graphics, the first working on interactivity research, the second researching splines, texture mapping and 3D animations. In Sutherland's group were important names that would become university researchers or prominent entrepreneurs in computer graphics, such as Henry Fuchs, Henri Gouraud, Bui Tuong Phong, James Henry Clark, James F. Blinn, Frank Crow, Brian A. Barsky, John Warnock, Frederic Parke, Tom Lyche, Alan Kay, Elaine Cohen, Richard Riesenfeld e Edwin Catmull (Carlson, 2008; Gaboury, 2013, 2015. Of these, the last two were also Steven Coons advisees and Catmull, in his Ph.D. Dissertation was responsible, in 1972, for the first 3D computer-animated film A Computer Animated Hand and after that would create Pixar and become president of Walt Disney Animation Studios.

Negroponte and his disciples were researching another area of computer graphics crossing interactivity with space perception. Authors who researched Negroponte such as Steenson (2014), emphasize that its influence is of a greatness that surpasses the architectural design and extends through systems architecture. Steenson in her doctoral thesis (2014) considers that Negroponte and AMG modeled design as a process of information search giving an important contribution to the notion of information architecture, associating architectural research with cybernetics, self-reflexivity and artificial intelligence approaches. In fact, already in The Architecture Machine, (1970) Negroponte, had a broad concept of architecture and argued that the work with audio, visual and other sensorial qualities was an architectonic undertaking, due to the reach of the architecture and the possibilities of creation of perceptual spaces, thus conceiving the idea of interfaces for architecture machines.

But if the Sutherland's disciples research was important for simple everyday things like digital animation, the work of the disciples of Negroponte was also very important for nowadays levels of interaction with computers. Research that comprised projects like Aspen Movie Map (Bender, 1980; Mohl, 1981; Negroponte, 1995) predecessor of the street view applications or the interactive media room Spatial Data Management System (SDMS) (Donelson, 1977, 1978) but especially by the development of the interaction that had been started with HUNCH with the ability of the computer to interpret the pressure and density of the lines drawn with pioneering touchscreens research, of, predecessors of tablets and smartphones, in a project called "One-Point Touch Input of Vector Information for Computer Display" (Herot e Wein-

zapfel, 1978). Such projects, also backed by military funds, can today, with no great margin of error, be regarded as appearing to be two or three decades ahead of their time. But more important than being projects of Sutherland's disciples or of Negroponte's disciples, those were projects that descended from Coons and from the ideas that he conceptualized for the military "drawing machine".

Less than 10 years after Sketchpad, the "drawing machine" was turned into a sketch-recognition research at an architectural research center. Five years later it was the turn of finger-drawing on the computer screen, research that preceded the touchscreens, and nowadays smartphones and tablets.

However, it would be decades before the use of interactive CAD in architecture in schools and project offices could be generalized, as can be demonstrated in Mitchell (1977) or Cross (2001).

DISCUSSION AND RESULTS

The article establishes a series of connections between the conceptualization and development of the first interactive CAD and the use of interactivity in architectural research that in previous studies had not been fully articulated. It is revealed a link between the conceptualization of real-time drawing on the computer screen and the ability of using digital interaction in architectural research. Through the academic relationship between Steven Coons, Ivan Sutherland, and Nicholas Negroponte, it is shown a new insight into the early days when interactive digital architecture was launched.

The relationship between three scholars, Coons, Sutherland and Negroponte demonstrate a progression of the interactive design ideas, in the sixties, after a period, in the fifties, when the first computer with graphic display was created and then equipped with a data input, the light pen. First, Coons conceptualized the use of that screen and light pen to enable the interaction between man and machine, through drawing. Then Sutherland, had the ability to create a design software that materialized the ideas of Coons that although not being his adviser, he was a member of the Sutherland's thesis committee. The last of those scholars, Negroponte materialized Coons idea of extending interactive CAD to creative designers. Negroponte would use interactive CAD and interactivity in architectural research to create AMG, a pioneering research center devoted to the use of computing in architecture and to the study interactivity in architectural environments.

It can be concluded that Coons conceptualized a graphical computation with an interactive design, long before all the others that researched in the area. Sutherland had the capacity to materialize the design interactivity envisioned by Coons, creating the first interactive CAD, initially for engineering design. However, Coons considered that an interactive computer could be also a partner of creative designers. This way, he managed to take Project CAD's ideas from the exclusive domain of engineering to architecture, through the work he did as a mentor to Negroponte, bringing interactivity to architectural design. Later, Negroponte took the research of interactivity in architecture to create environments with greater capacity of perception and interaction with the user, outside the strict scope of architecture.

It is shown a link between Coons's original interactive design ideas at MIT's Project CAD and the pioneer work of Negroponte that made architecture one of the firsts disciplines to made research in interactivity. Negroponte, professor and researcher in the department of architecture, adopted the theoretical ideas of his advisor Coons in the study of space perception in architecture linking architectural design to interactivity.

The start of a change in the way that design is made in architecture, through the tools created by engineering, is a fundamental element to emphasize the connection between all the parts of the article. Those tools have brought more than a simple change from analog to digital, bringing also the use of computation in architectural design with architects interacting with a computer and using programming languages, something that nowadays is used in parametric design, for instance.

This article targeted the research made to improve the design of industrial production for military purposes, revealing that a research project which intended to create a "drawing machine" made it possible the pioneering use of interactivity in architectural design research. That research has made architecture one of the first disciplines to research the digital interactivity on which nowadays smartphones and tablets depend.

Although digital interactivity took time to be a generalized architectural practice, the importance of architecture in the research of interactivity has contributed to the discipline's pioneering role in the roots of 4IR.

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