From Τέκτων to Τέχνη: Going Back to the Classical Roots of Architecture using Virtual Reality

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In Classical Greece the design and construction of buildings were interconnected, forming a single activity. With the development of knowledge and technology, this process has fragmented, giving rise to different activities, performed by various professionals, such as the architect, the engineer and the builder, leading to problems related with information exchange between them. With the research projects Tecton and Technos, we intend to reunite these activities again, seeking to simplify the building production process. In Tecton, we propose an Immersive Virtual Reality Environment to sketch and model objects in an interactive way, using hand gestures and body postures, enabling architects to change between the viewpoint of the creator and that of the user, thereby designing buildings while experiencing them at full-scale at the same time. In the future Technos project, our vision is develop detailed 3D virtual models to serve both as supporting elements for the digital fabrication of building parts and as communications elements for the assembly and construction of buildings.

Keywords: *Human-Computer Interaction, Immersive Virtual Reality Environment, Immersive Interaction, Real Time Design, Construction Models*

1. INTRODUCTION

1.1 From Τέκτων to Τέχνη: using virtual reality to enable the design and construction of buildings in an interactive way

At the time of Classical Greece the design and construction of the buildings were interconnected, forming a single activity. With the development of knowledge and technology, the process of design and construction of buildings fragmented, giving rise to different activities and professions such as architects, engineers and builders. This process of specialization of knowledge and professions led to communication and information exchange problems between different areas of expertise (Duarte, JP: 2004).

With the Tecton (from the Greek Τέκτων: to build) and the Technos (Greek Τέχνη: literally craft or art) projects we intend to develop an approach to the activities of design and construction that seeks to intregrate and simplify the building production process. Our aim is to develop tools that support architects first, in the process of designing, and second, in the process of communicating information for construction. In the Tecton research project, we explore a way of designing inspired in the ancient Greeks, but using virtual 3D models instead of physical ones. The intention is to apply existing Human-Computer Interaction techniques to architecture design and urbanism, through which one can sketch and model objects using hand gestures and body postures. We propose an Immersive Virtual Reality Environment where architects can shift between the point of view of the creator and that of the user, that is, while allowing them to design buildings and urban spaces it also enables them to experience them at full-scale. From the Tecton project, we intend to evolve to the Technos project. As Greek architects developed and communicated their ideas to builders through rigorous and detailed three-dimensional physical models (Hewitt, M.: 1985), in the Technos project we propose to develop 3D detailed virtual models instead. Our vision is to use these models as construction models serving both as as supporting elements for the digital fabrication of building parts, and as communication elements for the proper assembly and construction of buildings and urban areas.

1.2 Architect: From Designer-Builder to Designer and Modeler in the Computer

In the initial phase of construction of shelters and of the first iconic buildings such as military and religious buildings, there was no distinction between design and construction. The same individuals conceived and built at the same time, in a relatively intuitive manner and according to tradition, the housing or the emblematic building they wanted, "using processes and materials improved with the contribution of each generation. Each generation had the possibility to build their houses using traditional materials and housing types, that were suitable to meet their needs and expectations. It was not necessary special expertise in terms of design." (Duarte, JP: 2004) This type of integrated design and construction activity was not practiced by architects, but by individuals to whom the term of "Designers-Builders" can be applied, they were the precursors of today's architects.

The Architect emerged in classical Greek civilization, with the term coming from the Greek word "arkhitektôn" meaning "the main builder." The architect as a profession stemmed from the need to order and organize the construction of larger and more complex buildings than ordinary housing, like temples. The Greek "Designers-Builders" did not use drawings, they conceived and communicated their ideas to other builders on site through words and full-scale physical models. It is possible to date this type of practice to as early as the year 725 BC (Hewitt, M.: 1985). Later, during the Middle Age, the Gothic Masons Masters also used full-scale physical models as an aid for the design and construction of complex cathedrals and churches. However, in some cases, they have also resorted to drawn plans as aids to conception. This medieval period is, nevertheless, regarded as experimental and exploratory concerning the use of drawing for the design and communication of ideas for constructing buildings, being the paradigm of the architect or master builder as a "Designer-Builder" the main trend still.

It is only in the fifteenth century, during the Renaissance, that architects began to use drawings consistently, in particular linear perspectives, as tools for conceiving their projects. It is, therefore, in the Renaissance that a full separation between design and construction in the building production process occurs. The architect is solely dedicated to design activity, using drawings on paper to conceive buildings, and then using such drawings to communicating the construction process of the designed buildings to builders. From the paradigm of the "Designer-Builder" of Classical Antiquity and the Middle Age, the architect moves to the paradigm of the "Designer on Paper" in the Renaissance and in the subsequent ages. Only from the late eighteenth century, the Age of Enlightenment, when Neoclassicism prevailed as architectural style, did drawings in orthogonal projection prevailed over linear perspectives. Later on, from the nineteenth century until the third quarter of the twentieth century, with the advent of the Industrial Revolution and Modernism, perspective drawings were used again in the conception, representation, and communication of building designs, together with orthogonal projections, such as plans, sections, and elevations. However, the kind of perspective preferred in this era was the isometric perspective, instead of the linear or conical one to permit the accurate dimensioning of buildings.

In the last quarter of the twentieth century, in the Post-Modernism era, with the emergence and dissemination of the computer, this replaces the role of the paper as a support element for designing in architectural design. As such, from the "Project Designer on Paper", the architect turns into a "Project Designer and Modeler in the Computer". After an initial phase, in which the computer merely substituted the paper as the support of design activity, making faster and rigorous the process of developing an architectural project, another phase emerged, the present one, in which the focus is on modeling, making 3D computer models using the BIM paradigm (Building Information Modeling), and then extracting from these 3D models 2D drawings and 3D images. In a synthetic wayshort, this is the current context of architectural design activity. The evolution of architect types just described is depicted in Figure 1.

1.3 Human-Computer Interaction Paradigms

In the current type of architect, the architect as "Designer and Modeler in the Computer", two dominant paradigms of human-computer interaction can be identified to date (Figure 2).

The first paradigm is the interaction of designers with desktop computers and laptops, which we would call "Paradigm of Interaction with Intermediate Devices" given the fact that the interaction with the computer is mediated by intermediate devices such as the mouse, the touchpad, the keyboard

Figure 1
Architect types along the History

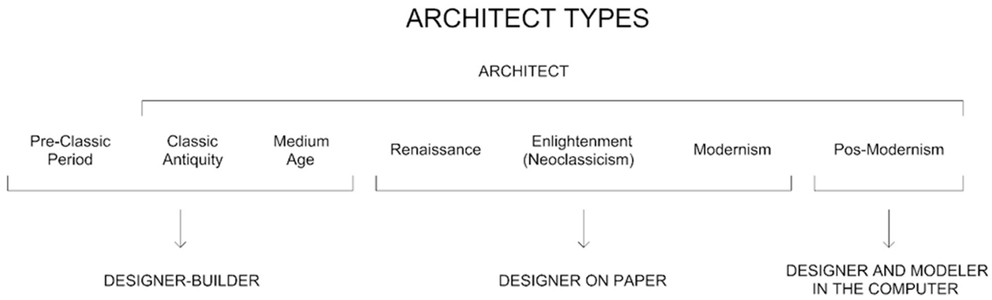
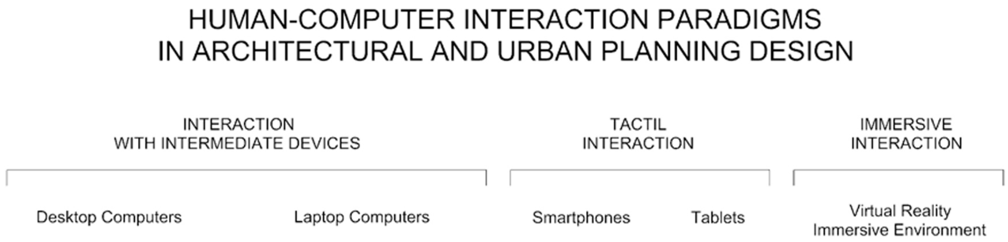


Figure 2
Human-Computer Interaction Paradigms



and the monitor, with the latter being used for the visualization of 2D drawings and 3D models on a two-dimensional screen. In this paradigm, a certain distance between the designer and the drawing is maintained, being the kind of interaction indirect. The second paradigm is the "Tactile Interaction Paradigm" and refers to the interaction of designers with tactile interfaces, such as tablets, smartphones and interactive multi-touch displays. In this case, interaction is direct, as the designers can use one or both hands to draw and model in the virtual environment; however, they still need to visualize their creations on a two-dimensional screen that simulates the effect of three-dimensions.

The goal of the Tecton and Technos research projects is to implement a new interaction paradigm between designers and the computer, which we would call the "Immersive Interaction Paradigm." In this paradigm, designers sketch and model directly with their hands in an Immersive Virtual Reality Environment, allowing them to see and experience with their bodies a three-dimensional virtual environment. The predecessor of this paradigm is the semi-immersive environment based on a stereoscopic multi-touch display, proposed by Araújo et al. (2012), which explored a direct modeling approach to create, edit, and manipulate 3D models, through asymmetric bimanual interaction on and above a two-dimensional display surface. This approach explored the continuous space as presented by Marquardt et al. (2011) combining it with the bimanual asymmetric model proposed by Guiard (1987). In the Tecton and Technos projects, we intend to go further, by exploring a complete immersive, three-dimensional virtual reality environment, increasing the degree of interactivity of designers with the computer, so as to permit design and visualization in real time. The goal is to facilitate and even encourage designers' creative activity, by making more natural and spontaneous to sketch, model, and experience the virtual objects and scenarios being created, thanks to the use of designers' own hands and body.

2. REQUIREMENT ANALYSIS

2.1 Task and Sub-Task Descriptions

The main objective of the Tecton project is the implementation of an "Immersive Interaction Paradigm" in an immersive virtual reality environment where it is possible for designers to interact more direct and spontaneously with the computer during their creative process than in conventional CAD systems. With this goal in mind, our research was initiated with a Requirement Analysis task, aimed at gathering relevant information for the creation of the intended 3D sketch and modeling system. The Requirement Analysis task consisted of three tasks, each with its own objectives, as follows:

- Sub-Task 1.1: Identify the benefits of mixed and virtual reality and the needs of users in the field of architecture, taking into account their workflow;
- Sub-Task 1.2: Define which modeling and editing operators are required during architectural design, and how these can benefit from interactive procedural techniques to increase efficiency in modeling tasks;
- Sub-Task 1.3: Define the interaction metaphors and the use scenarios that best fit the needs, preferences, expertise and capabilities of users in a viewing environment in mixed or virtual reality, such as stereoscopic table or glasses systems.

Under Sub-Task 1.1, the following activities were developed to collect the required information:

- A Generic Characterization of Users, where it was conducted a survey of architects registered in the Portuguese Association of Architects, over the internet, intending to collect information about their professional environment, the working models and the computer programs they use in the different phases and procedures of the architectural design process;
- A Review of the existing 3D Modeling Software, intending to analyze the features of

computer programs most commonly used in 3D modeling;

- A Case Study Analysis, namely an architectural design office, in order to complete the gathering of information through a closer contact with the target users, the architects. The case study analysis included an Interview with the main and the principal architects in the office, where we discussed topics like their work process, their use of computers and computer programs, and the organization of their presentations and meetings with clients and engineering teams. The case study analysis also included a monitoring people working in the office, to observe and analyze in loco the office's activity. A User and Task Analysis allowed a more thorough characterization of the studio's employees (age, experience and others) as well as learn more about the tasks they perform, in order to use such information in the course of the Tecton Project. This office was chosen for being known for their technology-oriented process and proficiency in the use of computers. Figure 3 shows some images collected at the office, depicting its working environment and tools.

Because of the extent of the gathered information, in the next sub-chapter we only present results extracted from such information that we considered more relevant for the development of the next tasks of the Tecton Project. Sub-Tasks 1.2 and 1.3 were initiated with the development of preliminary prototypes, described in Section 3, according to some preliminary ideas of the stakeholders in the research Project, while Sub-Task 1.1 was being developed. In a future phase, such prototypes will be reviewed to incorporate the results of Subtask 1.1 more extensively. As such, the next sub-chapter describes only the results of the Sub-Task 1.1, leaving the results of Sub-Tasks 1.2 and 1.3 for a future article.

2.2 Summary of Requirement Analysis Results

From Sub-Task 1.1 of the Requirement Analysis, it was possible to extract the following results for the Tecton Project:

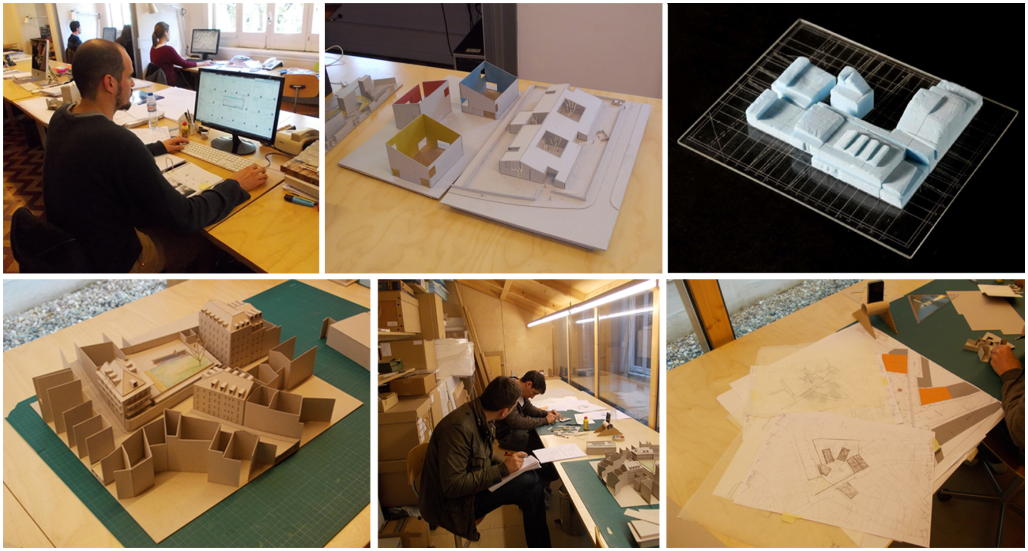


Figure 3
Images from the architectural office used as a case study, from left to right and top to bottom, main room (left-up), physical mockups, physical mockups room and sketch drawing

- Architects prefer a model like "Sketch by Hand" in the conceptual stage of the architectural design process. They consider "Sketch by Hand" easier to learn and to use than computer tools. They consider it a "fast" tool, meaning that it allows one to test and experiment ideas in a faster and more spontaneous way. "Mockup by Manual Manufacturing" is also considered a good tool because it enables to test and visualize three-dimensional ideas, in a physical way. It presents, nevertheless, the disadvantage of not being a tool as easy and quick to use as "Sketch by Hand" and "Drawing in the Computer". The use of "Drawing in the Computer" is used essentially to ensure greater rigor and precision in the architectural design project. In the construction design phase, when it is necessary to produce accurate drawings and written pieces, the computer is the most used tool because it makes the production process faster and more efficient. Another important result is that "Sketch by Hand" and "Mockup by Manual Manufacturing" are considered tools that enable greater freedom of creativity than drawing software. Interviewed professionals also think that it is easier and faster to interact with and communicate ideas to clients and engineering teams using sketches by hand and physical models than using computer drawings and software.
- Architects seem to prefer primarily tools that allow them to explore easily and quickly their ideas in a creative and appealing way, as well to produce drawings and written pieces in an efficient, fast and accurate way. They also consider important the use of presentation and communication tools that facilitate the interaction and communication with clients and engineers, engaging them and stimulating their participation in the design process.
- One of the key tasks in Architecture is to design buildings to be constructed in the three-dimensional physical space. As such, Architects resort to three-dimensional elements to test and try out their ideas whenever they can, be it sketching in perspective on paper, making a physical mockup, or making a 3D model on the computer. For clients themselves, it becomes more understandable and appealing a 3D image or object than a two-dimensional drawing. However, it is worth to mention that tools like sketches by hand and 2D and 3D drawings in the computer only simulate the effect of depth, they are not three-dimensional tools in the strict sense of the term. As such these tools have their limitations in terms of conveying 3D spaces.
- Some drawing and 3D modeling software, in addition to the basic modeling (direct creation and editing of three-dimensional shapes, as cubes or spheres), enable the use of Parametric Modeling and Procedural modeling. The former allows one to create and edit three-dimensional shapes by defining and assigning values to parameters like length, width and height, while the latter permits one to create and edit three-dimensional shapes by defining and controlling generative procedures, such as algorithms and shape grammars. These more sophisticated tools allow the generation of complex 3D shapes, which in the case of Procedural Modeling are not directly drawn by the architect, but rather the result of a procedure defined a priori, taking into account various criteria, such as structural performance, thermal comfort, and so on. Future trends in the development of 3D modeling software seem to be the simultaneously integration of the three modeling techniques: the basic, the parametric and the procedural, ensuring diversity and complementarity between them.

3. INITIAL PROTOTYPES

3.1 Description

Along with the requirement analysis, preliminary prototypes were developed to test initial ideas for the desired 3D Sketch and Modeling Systems. The developed prototypes are: Air Sketching, World Builder, Virtual Explorer and City Wave. They allow one to sketch, model, visualize and experience three-dimensional simple geometric shapes in an immersive virtual reality environment, through hand gestures and body postures. Such prototypes represent a first approach to the sketch and modeling instruments that we propose and they intend to respond to the results that have been achieved during the requirement analysis.

3.2 Air Sketching

Results of requirement analysis showed that "Sketch by Hand", on paper, is the work model most commonly used by Portuguese architects, in the design process of architectural projects. This preference is due to the fact that it is a tool with execution speed, easy to learn and easy to perform. It allows one to experience ideas in a fast and spontaneous way, thereby promoting creative freedom in the design of three-dimensional shapes. However, "Sketch by Hand" only permits to represent and explore imagined 3D shapes on paper, being therefore a tool that uses techniques such as three-dimensional perspective to simulate the effect of three dimensions on the two-dimensional support that is paper. Through the prototype Air Sketching (Fig. 4), we intend to develop an instrument that enables architects to sketch directly in three dimensions, in an immersive virtual reality environment. We believe that it can lead to faster and easier execution and facilitate the learning of sketching by hand as a tool in the design process. The aim is to provide architects with a new instrument that stimulates the creative process in the early stages of the design process. Users of the system can draw freehand and move their own body in virtual space, watching and experiencing their designs at the same time.

The Air Sketching system consists of a virtual reality display attached to the head (Oculus Rift) and a motion capture device (OptiTrack) in a physical interaction space of 24 cubic meters (4 x 3 x 2 meters), providing the user with the ability to move freely within a virtual scenario. With stereoscopic vision display, the user can see the three-dimensional virtual space and move in that space as it moves in the real world. The user interacts with this virtual space through a Wii-Remote command, simulating the use of a "virtual pen", through which he may sketch and outline ideas. The command is used in the user's dominant hand. In the non-dominant-hand it is placed another device that serves to enable and disable a menu of options in the graphic interface, depending whether the hand is facing up or down, respectively. The prototype runs by combining data received by the Op-

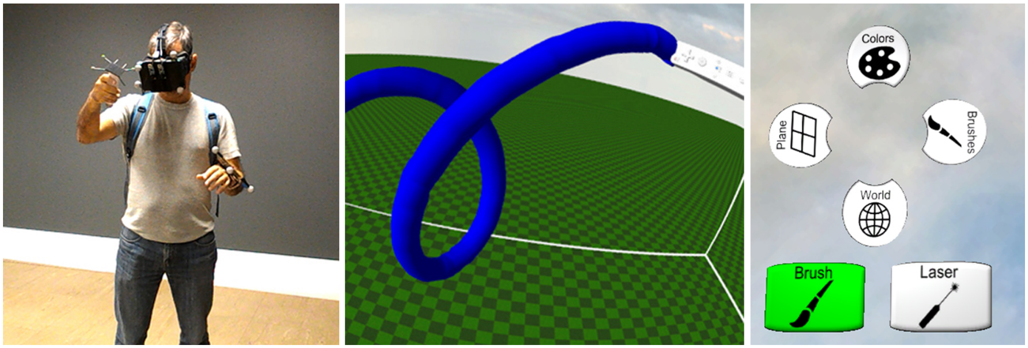


Figure 4
User using the Wii-Remote control (left), freehand sketch in 3D using the Wii-Remote control (middle) and the Options Menu (right)

tiTrack device, by the Wii-Remote command, by the signal buttons of the command, and by the device in the non-dominant hand, processing this information through a Unity 3D rendering engine, which in turn returns a visual result to the user through the Oculus Rift display.

3.3 World Builder

The "Mockup by Manual Manufacturing" is also a commonly used work model in the design process of architectural projects. During the requirement analysis, in the case study of the Portuguese office, it was observed that this work model is the preferred design tool, having "Sketch by Hand" a more secondary role, serving essentially as an aid to the development of mockups. The choice of the mockups as work models is due to the fact that they are three-dimensional elements that represent objects and spaces that also are three-dimensional. As such, they constitute a more direct approach, compared to sketching by hand, given the three dimensional nature of architecture. With the prototype World Builder (Fig. 5) we intend to provide the user with a mockup elaboration system in a virtual environment rather than a physical environment. The aim is to provide greater speed and ease of implementation to the development of mockups, allowing further exploration of design ideas and shape hypotheses, with ensuing benefits for the creative process in architectural design. World Builder is, in this way, dedicated to 3D modeling, allowing users to model basic solids such as cubes, parallelepipeds, cylinders, cones and spheres, and to develop more complex models through the composition of these different solids. The user can select the solids he wishes to work with using a menu that can be activated in the graphic interface.

Modeling proceeds by using two-hand gestures. In one hand rests the Wii-Remote control, like in Air Sketching and, on the other hand, a device similar to a ring with two buttons, which is an additional instrument relative to Air Sketching that gives the user more options for the control of modeling activities. From the joint action of the gestures of the two hands, it is possible to control the position and scale of the modeled solids. The prototype operates in the same manner as Air Sketching, combining data from the various devices and processing this information using a Unity 3D rendering engine, which in turn returns visual output to the user through the Oculus Rift display.

3.4 Virtual Explorer

It was also possible to verify during the requirement analysis that architects consider important how objects and spaces are visualized, either during the design process or during the process of communicating their designs to clients or engineers. The use of computer 3D images is a feature used often to visualize and communicate design ideas. Mockups produced by hand also serve for this purpose, being widely used in the architecture office used as case study. With the prototype Virtual Explorer (Fig. 6), we intend to overcome difficulties caused by the use of still 3D images, which represent only partial views of

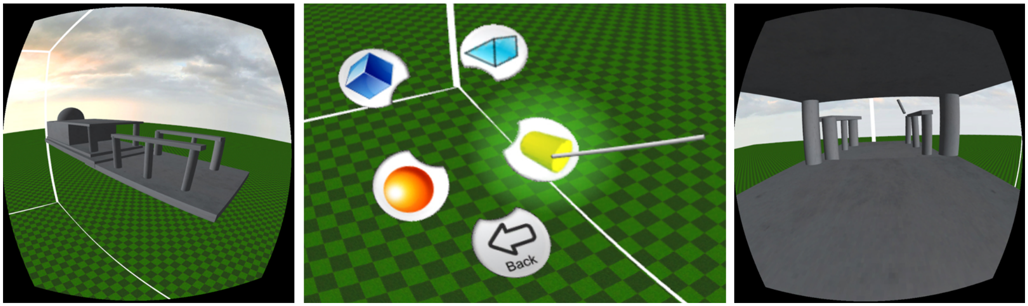


Figure 5
World Builder
Mockup (left, right)
and Options Menu
(middle)

the designed building. In addition, we want to overcome difficulties connected to the scale of the mock-ups, which is normally smaller than the scale of the designed buildings. Virtual Explorer is a system that allows one to navigate in a virtual environment using the navigation technique known as "Walking-in-Place" (WIP). This system allows users to explore the modelled objects and spaces at full scale, by walking along them and observing them from different viewpoints, either during the design process to test and guide design options, or during the review process to communicate the design to clients and engineers.

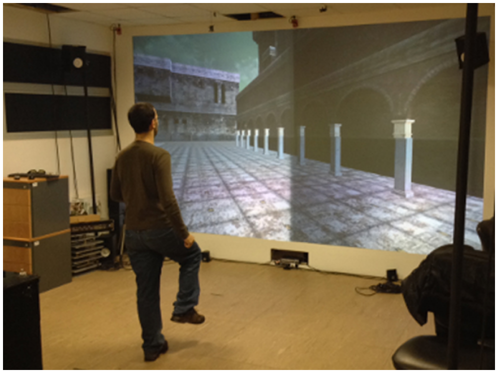


Figure 6
Walking-in-Place technique in Virtual Explorer

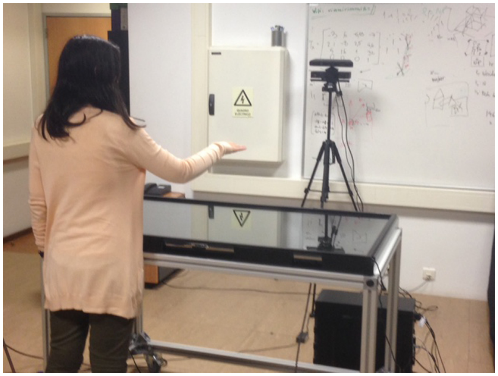


Figure 7
Hand movement over the stereoscopic table

The WIP system works by having users walking on the same spot (hence the name walking-in-place), within a small sized area of interaction. In this way, users control the position of an avatar (virtual replica of a person) that remains invisible in the virtual three-dimensional model. The views generated by the effect of this technique can be viewed in different types of displays: Head-Mounted Displays (HMD), Cave Automatic Virtual Environments (CAVE) and flat screens of different sizes. The data generated by the movement of the user's legs and feet are captured during lifting and lowering, being used by the system to control avatar speed using a series of algorithms based on different variables, like stepping frequency.

3.5 City Wave

Another fact observed during the requirement analysis task was that few software are equipped to deal with the complexity of urban planning, which involves the acquisition, management and manipulation of a considerable amount of information. The prototype City Wave (Fig. 7) aims to overcome this limitation. It consists of a prototype of a more interactive instrument for urban planning and design, as it allows the expeditious creation of urban scenarios through hand gestures performed in space over a stereoscopic table. Used in early stages of urban planning, it may provide the means to explore different urban scenarios and assist processes associated with urban planning that are not supported by current tools. In fact, the City Wave captures hand gestures and uses this information to adjust urban predefined parameters, allowing the visualization of the resulting three-dimensional scenarios.

As an initial test, it was created a virtual model to generate scenarios in which land value and buildings' heights are parameters that can be controlled through the movement of hands. In this case, the scenarios are generated based on the position of the hand in space over time: the horizontal position of the hand on the table is mapped to the corresponding coordinates of the land map and the distance of to the table's surface is mapped to the land value. As a result, the higher the hand is located, the greater the value of the property in the corresponding area and, consequently, the higher buildings will likely be.

The City Wave may also be used in different scenarios than the one developed for the initial test, as it provides the means to adjust different parameters considered in urban planning. As such, it can be applied to a wider variety of scenarios, thereby enabling planners to create, edit and interactively explore their ideas.

4. CONCLUSIONS

In the research project Tecton 3D, we explore a design process inspired in the architects of Classical Greece, but using virtual 3D models instead of physical ones. We propose to apply modern techniques of human-computer interaction in an Immersive Virtual Reality Environment, where architects and urban planners can switch between the creator and the user point of views, designing buildings and urban spaces, while being capable to use and test them at full-scale. The project began with a requirement analysis task, which was intended to gather relevant information to support the creation of the proposed 3D sketch and modeling systems. The collected data allowed us to elaborate four preliminary prototypes: "Air Sketching", "World Builder", "Virtual Explorer" and "City Wave". These prototypes allow one to sketch, model, visualize and experience three-dimensional simple geometric shapes in an immersive virtual reality environment.

Future developments of the Tecton project are to further develop the prototypes described above, following the stipulated work plan, namely the project tasks and sub-tasks, with a special emphasis on establishing, in an immersive virtual reality environment, means of connecting shape grammars and procedural modeling techniques in the design of buildings and urban areas. The intention is to create complex three-dimensional shapes that are not predetermined but obtained through procedures established by architects.

From the Tecton project we want to evolve for the Technos project. As the Greek architects communicated their intentions to builders through rigorous and detailed three-dimensional physical models, in the Technos project we intend to develop 3D projects in Virtual Reality that go beyond the initial conceptual process of Architecture and Urban projects. Our vision is to develop accurate and detailed three-dimensional virtual models that may be used as construction models serving both as supporting elements for the digital fabrication of building parts and as communication elements for the proper assembly and construction of buildings and urban areas. It also is worth noting that along the History of Architecture, the tools and instruments used by architects and urban planners influenced their creative activity and the buildings and cities that they have created. We believe that the Tecton and Technos projects can help to develop new instruments for architectural design and urban planning, thereby opening up new paths for performing these activities, which may lead to novel and innovative solutions.

ACKNOWLEDGEMENTS

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