# Digital technologies in Architecture and Engineering

## Exploring an engaged interaction within curricula

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**ABSTRACT**

*This chapter focuses on the development and adoption of new Multimedia, Computer Aided Design, and other ICT technologies for both Architecture and Computer Sciences curricula and highlights the multidisciplinary work that can be accomplished when these two areas work together. We describe in detail the addressed educational skills and the developed research and we highlight the contributions towards the improvements of teaching and learning in those areas. We discuss in detail the role of Digital technologies, such as Virtual Reality, Augmented Reality, Multimedia, 3D Modelling software systems, Design Processes and its evaluation tools, such as Shape Grammar and Space Syntax, within the Architecture curricula.*

Key-words: augmented reality, virtual reality, immersive environments, architecture curricula, mobility, design process, data collection, design evaluation, design representation, shape grammar, space syntax, ISCTE-IUL, ISTAR-IUL

## Introduction

New education methods and studio experiences are enabled by the advances in Computer Aided Design (CAD), Visualization and Multimedia technologies. The introduction of digital skills in the architecture graduation curricula is mandatory nowadays, due to the possibility that computing technologies bring to the resolution of several learning tasks (Duarte, 2007, Celani, 2012). Therefore being or not being digital is not anymore an option (Kruger, 2012).
The knowledge about digital processes in design allows students (future architects) to experience the advantage these tools bring to the design problem, and to choose to what extend they want to use them. Computers, CAD systems and Information and Communication Technologies (ICT)

have changed the architecture teaching schedule through the last four decades, shifting from a role of computers used as simple drafting machines, to the current role of being important pillars of the architecture curricula (Mark, Gross, & Goldschmidt, 2008). Initially ICT/CAD was seen as a separated technological subject in the architecture curricula. Nowadays those technologies have successfully liaised with design subjects, showing the true potential they bring to other curricula topics (Asanowicz, 1998). Recent research, development and commercialization of new products in multimedia, virtual reality, cloud-aware collaborative tools, 3D modelling and computer animation, among others ICT technologies, has played an important role in the introduction of computers in architecture curricula. This is becoming increasingly possible as technology enable better human-computer interaction and its use is getting more natural, obvious and straightforward, allowing designers not to get distracted from their goal which is design (Lawson, 2006).

One of the reasons by which CAD tools, at some point in time, have been rejected in design studio classes, was the controversial relations of designers with computers, due to the fact that designers believed computers could not answer design issues the same way a human designer could (Lawson, 2006). Nowadays computers increasingly perform more and better and may help designers to find and gather knowledge and perform tasks they would not be able to do, without computers and ubiquitous communication infrastructure. One of those tasks made viable by ICT, is the possibility of evaluating the quality of architectural spaces, prior to the construction phase, through the simulation of the designed space in virtual environments (immersive or semi-immersive), which has earned interest in the academia, from both the scientific and teaching perspectives. At the same time, digital tools have been used to predict peoples' behavior within built environments, to identify design problems and also its potentials (Hillier & Hanson, 1984; Hillier, 1984; Penn et al, 1997; Drettakis, Roussou, Reche, & Tsingos, 2007).

In this chapter we present the strategies for using Digital technologies in Architecture and Computer Sciences curricula in our school at ISCTE-IUL, regarding both the available facilities and equipment, the pedagogical methods used and results achieved so far. We end with some discussion on the advantages of adopting such technologies for teaching Architecture and its related studies.

## Digital strategies for Architecture and Computer Science education

Digital technologies are used in multidisciplinary methods for education and research in both Architecture and Computer Science. In the Integrated Master of Architecture (IMA) of our School (with five years graduation), the approach towards architecture education lies on the convergence of various scientific areas around the project activity, which promotes a practical and theoretical reflection in order to provide the student with informed, critical and autonomous thinking, regarding the various dimensions of space. Architecture is seen as a transversal practice within the scope of several knowledge areas. The IMA programme explores architectural design methodologies through the understanding of space and all the variables that affects it in terms of function, structure and plastic expression. Building technologies, representation and communication techniques are articulated with the design methodology, from the very beginning of graduation. On the other hand, since IMA is integrated in the School of Technologies and Architecture, it promotes a deep link with the areas of Information and Communication technologies, Computing and Multimedia that manifest themselves, besides education, also in research activities and in advanced lab infrastructures, available for several curricula practices.

The approach adopted in our School involves the introduction of multidisciplinary work in order to familiarize students with social communication, collaborative working and team working soft skills. Taking advantage of being part of the School of Technology and Architecture, our methodology introduces architecture students to Digital technologies, from a user perspective, since the very first year of graduation and, by suggesting its use in several courses with different goals, allows them to judge their effectiveness. In these first years, Digital technologies are presented in specific courses to extended groups of students. Later in the curricula, students are invited to explore digital skills in smaller research groups, in the scope of their Master thesis and integrate teams with Computer Science students, as well as Psychology, Ergonomics, Human-Computer Interaction, Serious Games, Computer Graphics, Computer Vision, Virtual Reality, Augmented Reality and Software Engineering researchers, geared at developing multidisciplinary research and foresting innovation. In this rich research environment, students define their own design questions and in such multidisciplinary teams, new digital tools are created in the context of MSc and Phd Thesis projects, enabling automation of prior manual and error-prone processes, introducing (for conceptualization, development, test, evaluation and design life-cycle enhancement), new paradigms and tools for Architecture design. Examples of such projects are, natural interaction (via speech) with life-size digital-mockups of buildings, described by BIM – Building Information Model, in immersive Virtual Environments, Augmented Reality interaction and visualization applied to Architecture scale models, or mobile digital tools.

### *Facilities and equipment*

The Architecture programmes at ISCTE-IUL uses several learning and research facilities that range from the traditional design studio room, to dedicated full equipped labs. We have specially gained interest with Virtual Reality – VR settings. One of the main advantages of VR is flexibility. The use of VR allows the systematic manipulation of the environment's layout, and different kinds of Architectural settings can be designed to create suitable experimental conditions for studying controlled variables. VR also allows monitoring and recording the behaviours through which an explorer gains spatial knowledge for further evaluation (Morganti, Carassa, & Geminiani, 2007). The studies of Vilar and colleagues (2013a, 2013b), Cubukcu and Nasar (2005a, 2005b), Moffat and colleagues (2001), Omer and Goldblatt (2007), and Umemura, Watanabe and Matsuoka (2005) are some examples of research using VR-based methodologies, targeted at the studies of human behaviour regarding the architecture variables.

The CAVE-Hollowspace (Costa, Pereira, & Dias, 2007; Soares et al., 2010) at Lousal in south of Portugal, is used by our team to develop dedicated research and two other Pocket CAVE VR facilities, are available in our school to support research in masters and doctorate programmes of the Architecture and Computer Science departments. The CAVE™ - Cave Automatic Virtual Environment (Cruz-Neira, Sandin, DeFanti, Kenyon, & Hart, 1992) - is a full-immersive virtual reality (VR) system that generates and projects stereoscopic images at interactive speeds (~60 HZ) on the walls and floor of a room-sized cube to provide the illusion of presence and immersion. The Lousal CAVE comprises four projection planes in a parallelipipedic U-topology with six pairs of stereoscopic (3D) high-resolution projectors. With this infrastructure, researchers are able to use immersive virtual reality environment with stereoscopic visualization to simulate real-scale virtual environments and create rich user experiences from the visual and aural point of views (Cruz-Neira et al., 1992). Additionally, the CAVE may also include haptic interfaces that recreate the sense of touch by applying forces, vibrations, or motions to the hands of the user, room temperature variation, wind, or smell, when provided with specific hardware and software.

The Pocket CAVE labs are part of the Information Science, Technology and Architecture Research Center (ISTAR-IUL, available at http://istar.iscte-iul.pt) that is located at our school. Both run the same in-house developed VR software of the CAVE at Lousal and therefore, we are developing projects that are also available for this facility. A Pocket CAVE, is a portable, single-screen, semi-immersive virtual reality system (Gutierrez, Vexo, & Thalmann, 2008) with a large-scale projection wall (4 meters x 3 meters), in which stereoscopic images are rendered through a 3D high-resolution projector (which supports HD 1280×720p in stereoscopy). Images are visualized using shutter glasses. As mentioned, we currently hold two such Pocket CAVE VR labs. Input interaction is enabled via natural means (speech), full body gesture (sensed by the latest Kinect for Windows sensor), or more traditional devices such as a Joystick. One of the labs (*VR Lab*) includes user pose tracking via infrared sensing (Optitrack). The same lab supports Ambisonics sound system, providing true 3D synthetic sound experience in order to consider the effect of sound renderings in the user's behavior interacting with architectural spaces. The other lab (*PocketCAVE Lab*), provides a 7:1 surround system and Binaural Headphones/microphones.

In our VR labs, users who participate in several experiments are monitored through non-invasive biometric sensors (Electrodermal activity, Electrocardiography and Electroencephalography), mainly used for studies that sense, process and statistically analyze some features of the physiological signals generated by the users themselves, while walking through pre-defined locations in Virtual Environment. We are especially interested in detecting events of arousal responses, from where we can derive emotional responses, such as the fear of falling during space use, to better understand the perception of architecture spaces by their inhabitants.

In each lab, there are also available for research purposes, stereoscopic head mounted displays (HMD – Oculus Rift 2.0) and a binocular eye-tracker system (Dikabilis Ergoneers) compatible with our VR technologies. The HMD is very useful when researchers need to develop more immersive context that are important to improve the sense of presence, promoting a reliable behavioral response. However, as it has higher occurrences of simulator sickness than the stereoscopic projected images, the VR setup with the HMD is mainly considered when interaction time is reduced. The binocular eye-tracking system allows researchers to go further on human-environment behavioral analysis and investigation. With this eye-tracking system, researchers are able to collect information about visual attention, visual exploration patterns, gaze fixations, time spent on gaze fixation, saccades, among others that have high impact on the analysis of space use.

The CAVE-Hollowspace in Lousal Science Museum and the Pocket CAVE infrastructures, were both developed by ADETTI-IUL (Advanced IS/IT Research Center, ISCTE-IUL) team in collaboration with several universities and institutes, with impact in the exploitation of virtual reality systems.

CaveH Spawner (or CaveH, for short) is the in-house software that enables real time rendering and interaction in the virtual environment. It was developed at ADETTI-IUL and Microsoft Portugal, as a standard software system with full support and troubleshooting by our team, enabling the development of new features each time a new request originates from Architecture, Psychology, Computer Graphics and/or other research teams (Soares et al., 2010). An in-house developed software for Augmented Reality - AR experiments (described later) is also available

at ISTAR-IUL, referred to as ARch. This system is the result of the extensive experience of more than 12 years of the team in Computer Graphics, Computer Vision and Augmented Reality, and was recently developed in the scope of three master thesis (two in Architecture and one in Computer Science), which targeted several aspects and requirements of architecture design, within an AR setting, using mobile devices. As a result, we have developed a software tool in which users are able to interact with a 3D virtual model in Augmented Reality, in order to visualize and interact with different projection plans, hide/unhide layers (different buildings specialties, such as architecture, structural engineering, water and sewage, etc), among other features, much like the interaction with a physical scale model.
Carvalho and colleagues (2013), in the scope of augmented reality applications, proposed an integrated analysis of object descriptors and appearance models through their comparison in a common object tracking solution, contributing to understand the object description methods and their impact on the tracking process.

In addition to these facilities, normal computer labs for software classes and extracurricular use by students and researchers, are also available. Studio classes and other theoretical courses are taught in large rooms. Studios offer large tables enabling collective work, where students can use their laptops (those are not considered to be the essential tools, but instead part of the workflow).

### *Multidisciplinary education and research*

Architecture education is based in a convergence of various scientific areas, promoting a holistic and interdisciplinary practical and theoretical reflection in order to provide students with informed, critical and autonomous thinking regarding the various dimensions of space.
Our University Institute allows for a unique set of synergies in Portuguese's Architectural education and research which considers also the contribution of other areas like Sociology, Economy, Computing, Anthropology, Business management and Public Policies. Architecture is integrated in the School of Technologies and Architecture which promotes a deep link to the areas of Computer Science that manifest itself in the areas of research and in the available infrastructures. We encourage students to take elective courses on other areas of knowledge ranging from Computer Science, Psychology, Sociology, Anthropology, Entrepreneurship or Economics, to pursue cross-disciplinary approaches on problem solving. This approach also attempts to bring students closer to what happens in industry and companies where expertise work in a multidisciplinary environment (Brindley, Doidge, & Willmott, 2005). It's known that work developed at courses attended both by students from Architecture and other areas like Computing or Multimedia, has the potential to be of higher quality (Entwhistle, Thompson, & Tait, 1992; Higgins, Maitland, Perkings, Richardson, & Warren-Piper, 1989). This is visible, e.g. in courses where technology meets the arts, or art related topics. For instance, in the Sound and Video for Multimedia (SVM) course, projects tended in the past to be less creative and "content dry", lacking the development of interesting ideas and focusing mainly in tech details. Since students from degrees, other than Computer Science degree where SVM is mandatory, started to enroll at SVM as an optional course, results have been very interesting since ideas are brought from outside the Computer Science "box", with mixed students' backgrounds producing overall much better projects. With the same goal of promoting interdisciplinary approaches, last year our School of Technologies and Architecture started to promote an annual competition on design with the target of developing innovative designs, combining architecture with ICT. Teams had to be multidisciplinary and the proposed design (a small shelter to place e.g. in an university or

airport) had to be feasible and innovative. This competition was a central starting point to promote multidisciplinary approaches to design.

Our research team gathers 3D Computer Graphics, Serious Games, Computer Vision, Virtual Reality, Augmented Reality, Human-Computer Interaction, Architecture, Ergonomics and Psychology researchers. This collaboration promotes the development of a more holistic approach towards research, enabling our team not to focus only on a specific area of knowledge, but to have a broader overlook on the research problems, by applying a system thinking process. In this multidisciplinary approach, we focus architecture education in architectural themes, keeping the goal to obtain broader competences in this area. Students are nowadays aware that the traditional way of working in architecture, although holistic, may not give them the skills to work in all the areas that we can now identify as prevalent in today's practice of Architecture. Therefore the number of students that attend elective courses of Programming, Computer Graphics, Entrepreneurship, Management and also Psychology, Sociology, Anthropology and other social sciences, is increasing. In our research activities, we try to balance the goals of each different scientific area so that there is not a predominant area. Usually architecture is the problem deliverer since our research is focused on the study of constructed spaces, both about the design process and the impact buildings have in users. In the early stages of this research process, the Architecture team usually takes the lead by defining the scenarios and personas that enable this group and other teams to understand and capture research problems. Then we derive research hypothesis and requirements that eventually drive Computer Science, Psychology and all other teams' research activities. In the end, the outcomes of our multidisciplinary research are very relevant to all the scientific areas involved, as all are able to draw relevant conclusions that are publishable in the best journals and conferences of each area. Recently, Mathematicians and Statistics researchers have also joined the team, contributing in more complex problem solving research. This collaboration within different areas of knowledge has proven to be extremely rewarding but at the same time very demanding, since it implies redefining research questions and methods outside the normal processes each area has established as "standard", as well as it considers new "out-of-the-box" understandings and views of phenomenon and research questions.

Work developed to analyses user's emotions while walking in simulated spaces (described later in this chapter) involves researchers and students from Psychology, Architecture, Ergonomics, Serious Games and Computer Science (Computer Graphics, Virtual Reality, Software Engineering), as well as Mathematicians, that contribute with tools for analyzing large sets of complex experimental data.

## Methods and Results in Architecture and Computer Science Education

The combined use of different Digital technologies for visualization, simulation, generation, and evaluation, allows designers to test several design solutions after getting more informed about their capabilities and weaknesses. For example, the CAD paradigm has changed from a passive tool to a powerful and active process of searching for design solutions and alternatives based on specific contexts and variables. Although CAD tools have nowadays a relevant role in architecture education and practice, the architecture design we envision does use these tools, but as part of the design process. Students are encouraged to employ manual techniques during conceptual design phase that usually requires designers to sketch while exploring and communicating their ideas to themselves and to others. Sketches and physical building models are part of the daily work of design in our university (Figure 1 and Figure 2).

These manual technics, as Ibrahim & Rahimian (2010) states, have nevertheless limitations with the increase of complexity of the design problems. For Lawson (2006), we can no longer immerse students in a few traditional crafts but instead, we should encourage them to exploit new technologies as they develop. Following this line of thought, we are providing the means for technology to be developed with the students themselves and according to what we have identified as new emergent problems in architecture. Digital tools are progressively introduced in courses so that the ability to think and design with a critical view, is still a skill not absolutely dependent on computer tools. With this approach, architecture students are able to develop new competences in a critical manner, considering not only architecture by itself, but also the many other valences involved in architecture design.

We address education and research in Architecture in four main areas, that are defined in more detail the subsequent sections, namely: Process, Data Collection, Evaluation and Representation. In the Process section, we focus on the entire design process and on how digital tools may provide aid. The Data Collection section, addresses methods to obtain data about buildings and how their inhabitants live in. The Evaluation section focuses on the digital tools used specifically to evaluate existing and proposed designs. Finally, the Representation section addresses digital tools used to represent architecture design.

*Figure 1.3D physical models of the conceptual design phase, Luís Coroado.*

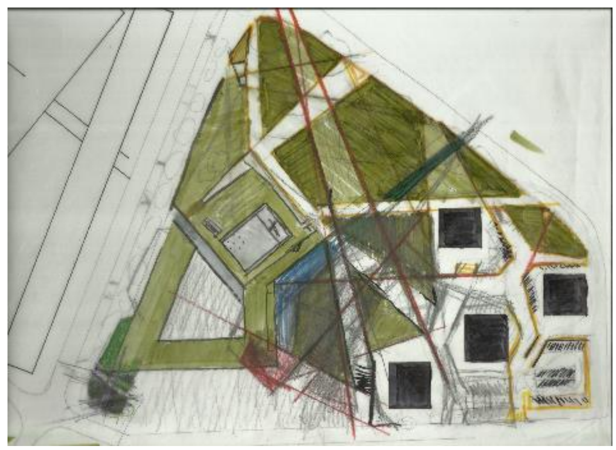


*Figure 2. Sketches of the conceptual design phase, Luís Coroado.*

### ***Process***

The development of efficient design methods is an important aim in Architecture. Advanced representation procedures and visualization systems may be combined with generative design tools and collaborative design processes, in order to enable efficient designs to be created.

The use of 3D modelling tools, VR systems and other Digital technologies like Augmented Reality for the early stages of the design processes, allow students to get to know better these technologies and make them part of their design processes from the start of their education as architects.  Later, when students have already knowledge about construction processes, Building Information Modelling (BIM) is introduced and the approach through the constructive thinking is related to the overall design process. These technologies are used in a second stage of learning, when the skills to define building construction are already required to students.

**Virtual Reality**

Interactive visualization systems like Virtual Reality (VR), enable real-time and real-scale perception of space and constitute relevant tools for architecture education in design studios and for collaborative tasks (e.g. Schnabel, Kyan, Kruijff, & Donath, 2001; Schnabel, & Kyan, 2003; Petric, Ucelli, & Conti, 2003; Horne 2008). According to Freitas and Ruschel (2013) VR would have a large impact in the learning process if it was applied in the early years of undergraduate courses, changing the status of students from observers to real participants in the learning process.

Our semi-immersive PocketCAVE facilities and in-house developed VR software (CaveH), are being used today by architecture students to visualize their design projects. These students have been defining new system requirements that emerged as needs from their own design projects. Architecture and computer sciences' students and researchers are continuously working on new features for the RV system to accommodate those requirements, so that all students, independently of their knowledge about technology, will eventually use the RV system to test their designs. Nowadays the system allows 3D models to be imported from various commercially available tools, widely disseminated in both academia and industry, such as Autocad, Rhinoceros3D, 3D Studio Max and Revit (Coroado, 2014). The data exchange pipeline, from 3D modelling (using the mentioned tools) to VR interaction and visualization in the PocketCAVE, follows a given recipe. Before being imported to CaveH system, all original 3D models have to be imported by Blender, where the 3D scene is composed. Each 3D scene requires the definition of a set of scene entities: light sources are added, material proprieties of the 3D scene objects are edited, animations are associated with scene objects and optionally, with the virtual camera, animated virtual characters are defined, Newton mechanics proprieties are set to all objects and other scene elements that constraint the user experience in VR are added, such as time-based and proximity triggers and actions, The resulting 3D scene with all the configuration, is exported by Blender in the native format that the CaveH VR system can parse and interpret, OpenSceneGraph or .osg (Figure 3).

BIM modelling is increasing considerably within the architecture community, and the advantages of their use are now obvious to students. The use of Revit generated BIM models in our VR system, has been tested recently, using a similar data exchange pipeline with a special developed VR Visualization tool, referred to as VIARmodes. This tool allows switching between different visualization modes when navigating in VR, namely: opaque volumes, “x-ray” (translucent) volumes and textured volumes. These possibilities enrich the visualization and exploration of space by allowing the designer to acknowledge her/his designs in a greater detail. VIARmodes was created based on requirements extracted from a survey done to a large sample of architects, about the tools they use for a given design process stage (prior to construction activities) of the Portuguese practice, namely, Conceptual Base Programme, Previous Study, Base Project or Execution Project (Coroado, 2014). VIARmodes was designed to aid the design process specially in the stages where different specialities need to collaborate towards a final and coherent design, notably, during the Base Project stage. In VIARmodes, the 3D scene should be modelled so that it has several layers, where each one is associated with a given speciality or sub-speciality. VIARmodes allows the users to select all layers or a subset of them for visualization and discussion amongst different design specialists (Architect, Structural Engineer, Electricity Engineer, etc.). In the 3D scene presented in Figure 4, six different layers were selected when activated the Layers Mode: Structure (red), Walls (yellow), Pavements and Ceilings (Orange), Openings (Blue), Infrastructures (green), Equipment and Furniture (grey).

Besides the architecture use, this VR system is deeply explored by students from Computer Science as a tool to develop new Computer Graphics features.

*Figure 3.3D model in Blender to be exported to CaveH Spawner. Source: Moural, Eloy, Dias, & Pedro, 2013*

*Figure 4. From left to right opaque volumes and x-ray volumes with and without some elements. The model, Villa Savoye, was modelled using BIM. Source: Moural et al., 2013.*

**Building Information Modelling**

Although both the construction industry and designers are still adopting BIM at a slow pace, soon this technology will become the standard for design projects and all the players will have to adopt it. Providing students the knowledge and skills about the logic of BIM models is therefore mandatory.

BIM is part of the architectural curricula from the 3rd year of graduation and is treated both as a software tool and as a design process. BIM is introduced in a dedicated course as a tool to design and enable the representation and quantification of the architectural design and as a tool that enhances building construction knowledge and incentivises students to comprehend design in a broader way. Since the moment students start to use BIM, new aspects of design comes alive: incorporating knowledge, technology and collaboration within architecture and especially with other expertise and other stakeholders. The way BIM's models incorporate information that can later be used for several stages of design and construction, turns it a powerful tool for everyone related to the construction industry. The benefits that this technology brings of decreasing the risk of information loss as well as the possibility of evaluating building design and increasing its performance, are already recognised in the literature by several authors (e.g. Achten, 2009; Sanguinetti, 2009).

Thermal and acoustic evaluation as well as geometry and regulatory requirements evaluations, are subjects that are addressed in other courses of the architectural programme and may use BIM technology to make them clear and effective to students. As far as this relation between

geometry, information and building performance evaluations are clear to students, BIM starts to be used instead of traditional CAD systems.
As mentioned before, BIM is nowadays one of the most used CAD software and the goal is to integrate it with the other digital technologies we are working with, such as VR (*Figure 4*). Collaborating with industrial stakeholders, construction companies and other public institutions that have a decisive role in licencing projects, is a priority than can benefit our research and educational curricula.

### Augmented Reality

Three-dimensional physical models play a fundamental role in Architecture design work, not only as a useful instrument for communication across teams during all the design process stages, but also as media to communicate architecture ideas in exhibitions, meetings and client briefings. Besides the traditional building models that students still produce and are essential in early processes of conceptualization (Figure 5), representing and visualizing architecture designs by means of Augmented Reality - AR, can complement those traditional techniques and therefore is an area we are developing. In this context, we have specified and developed an interactive AR app for Windows tablet devices, referred to as ARch, to be used during the design process. The ARch app allows the 3D models to be visualized with AR on a tablet, using texture tracking based on computer vision, which requires a planar visual marker (a regular colour or greyscale image) that works as a plane for the registration of the model (Figure 6). The app was developed to be use in a tablet running Windows 8.1, with an in-house developed AR system called NUTTS (Natural Ubiquitous Texture Tracking System) (Bastos, 2008) and with 3D Computer Graphics technology based in OpenSceneGraph (Wang, 2010). Much like for CaveH and VIARModes, the used programming language was C++, common to all our systems (Lopes, 2014a). ARch composes four main modules: i) “Video Input” responsible for the video image acquisition; ii) “Visualization” to where the image with Augmented Reality effect is passed through; iii) “Tracking” that creates and tracks in each video frame, a virtual camera pose (position and orientation relative to the reference frame of the textured visual marker), that mimics the characteristics of the real camera and sends this camera information, in each frame, to the “Visualization” module, guarantying the perfect registration (alignment) between real and virtual worlds; iv) “Interaction” module receives the users’ commands and execute the requested actions on the virtual world as well as show the active functionality at each moment.
The system allows a number of features that makes easier the user experience (UX) and support its use during the design process. The available features are: i) visualization and interaction with the virtual 3D model by using touch in the tablet surface; ii) execution of vertical and horizontal cutting planes (sections and floor plans), that allow a visualization of the entire design’s geometry (Figure 7); iii) highlight of a group of objects gathered by layers corresponding to design specialties (Structural Engineering, Electric Engineering , Telecommunications, among others); iv) occlusion and selection of some construction element or group of elements and; v) change of the colour or texture of a preselected object (Lopes, 2014b). To enrich the viewing and interaction experience with the 3D model (Figure 6).

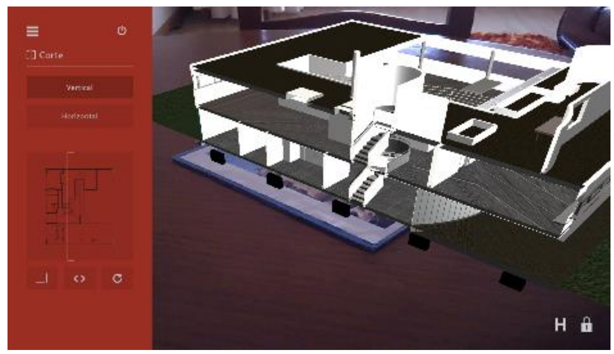


*Figure 5 (top left). Example of a physical model building,* Luis Coroado.

*Figure 6 (top right). Tablet interface and touch interaction. Source: Lopes et al 2014.*

*Figure 7 (bottom right). Execution of a section in ARch app. Source: Lopes et al 2014.*

**Generative Design tools**

The introduction of computing techniques in the conceptual process of architectural design have a large impact in the form generation process. Generative processes based on shape grammars aims at developing new methods of composition and design where the design principles, instead of the final result, are the main goal.

Shape rules explain the principles that regulate a design. Examining the use of those principles and the final results achieved allow to manipulate them in accordance to the evaluation one does to the final results. Shape Grammars (SG) are particularly suggestive and appealing to architecture because they address the relations between elements as proportion, symmetry and emergence. They constitute therefore a good intellectual learning method allowing an abstract and systematized approach on architecture.

According to Knight (1999) shape grammars should be addressed in design education by the means of simple formalisms, avoiding complex labels and parameters, which are useless for the first designs approaches. The use of this design method should start without the computer implementations but instead a manual computation scheme should be addressed which enable a better understanding of shape grammars logics. Although computers are powerful tools to use and explore SGs, there is still no friendly interface to work with them. In the scope of using shape grammars for the generation of architectural design our team is working on the development of a computer grammar interpreter (Reis, 2013).

We consider that the second stage of architecture education is the period to introduce these technologies related to generative design methods which develop in students the ability to define design strategies and principles that guide the design process into the definition of several solutions. SG's methods are used with students both in dedicated courses which introduce shape

grammars and they occasionally in architecture studio courses to enable the exploration of design strategies.
Shape grammars are used to create spatial compositions both two-dimensional and three-dimensional, and their non-deterministic characteristic enables students to explore several design possibilities. To take advantage of the SG potentialities students should have well developed design skills and a good spatial understanding of objects. In extended groups SGs were introduced in under graduation curriculum so that they can be used later, as a design process, in individual designs and master thesis when students are already comfortable with architecture design methods and are able to explore with confidence alternative methodologies.
To develop the mentioned skills SG is introduced through a series of practical exercises that enable the generation of designs and the understanding of the role of spatial relations between architectural elements (Figure 9).

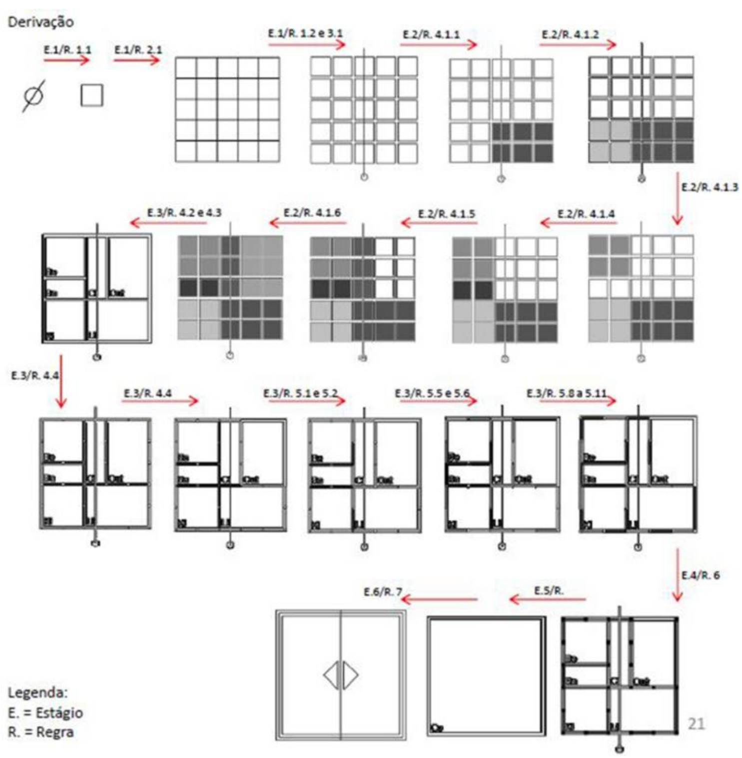



*Figure 8. Shape grammar developed to a modular wood frame construction system. Raquel Sousa and António Santos, 2011/2012. Course Shape Grammar and Digital Tools, teachers Alexandra Paio, Sara Eloy, Joaquim Reis*

The development of analytical grammars is another strategy used in SGs courses in order for students to understand certain styles and languages of design (Figure 8). According to Knight (1981) understanding past architecture through the development of a SG is the best way to get to know different design principles and allow students to focus on the simplicity of complex buildings or systems and get the essence of them. On the other hand, original SGs enables students to define principles of composition that respond to specific design problems and allow them to find several solutions which can then be compared and evaluated. This design method is used by students to define preliminary design solutions so that they explore a large diversity of semantically and syntactical correctly designs (Ferrão, 2013).
In design studio some students use SG as a tool in their early design stages. With few shape rules they can test and simulate a large variety of solutions that fulfil their design criteria and the predefined constrains (Figure 10 and Figure 11). The task of designing a grammar imposes on

the architect the need to be more consistent to the principles that structure his/her thoughts and design ideas and therefore the grammar should support in a precise way the design decisions. The interest SG brings to architecture design comes from the understanding that rules intervene not only with shape but also with design requirements. This means that when applying a shape grammar to an architecture design, functional predicates have to be introduced into the language of the grammar, otherwise an architectural problem may be considered as if it is a “shape game” (Mitchell, 2008, p.197).

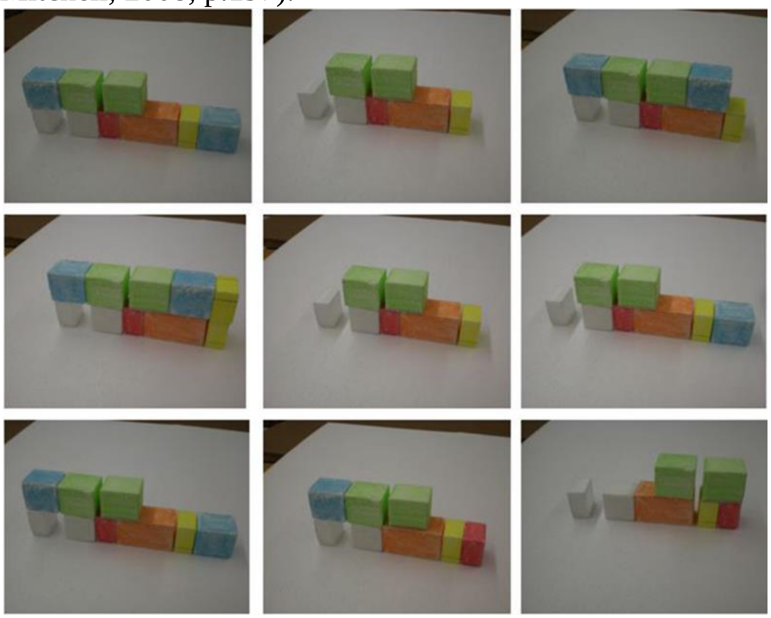
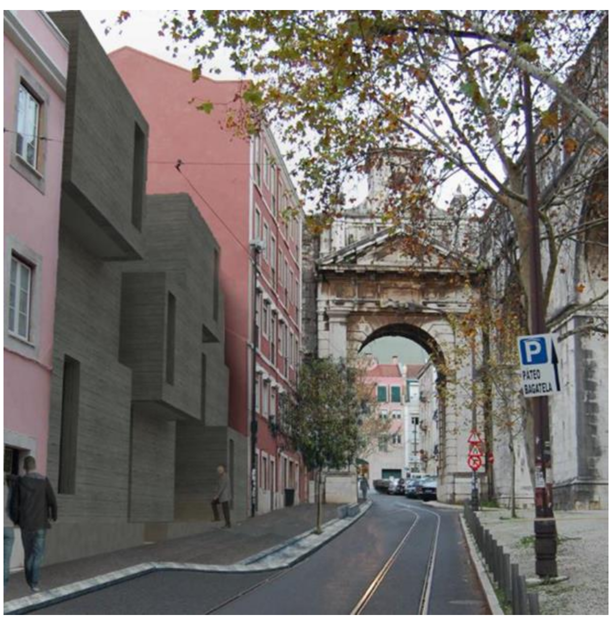


*Figure 9. Shape grammar developed to detached single family housing. José Luís Silva and Miguel Nóbrega, 2011/2012. Course Shape Grammar and Digital Tools, teachers Alexandra Paio, Sara Eloy, Joaquim Reis.*



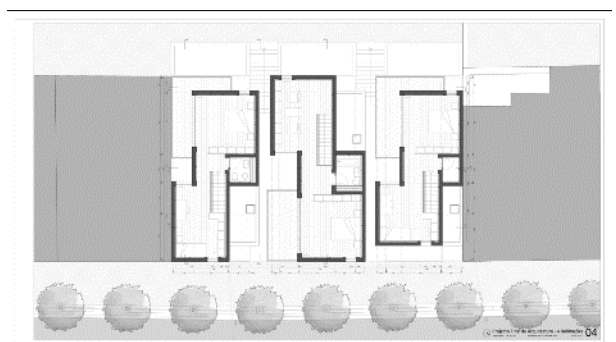



*Figure 10. (left) Design solution achieve by the use of shape grammar. Source: Ferrão, 2013*

*Figure 11. (top) Design solution achieve by the use of shape grammar, floor plan of 2nd floor. Source: Ferrão, 2013*

The integration of SGs in architectural curricula is also done by promoting exterior workshops where students are invited to work together with other participants from different backgrounds and countries. The workshop “Re-inventing ceramic tiles Using shape grammars as generative method for pattern design” was held in Porto and joined participants from Netherland, Australia, Turkey and Portugal. The workshop aimed at looking at traditional ceramic tiles design techniques as a starting point to re-invent patterns and textures using SG and its application in spatial compositions and considering the use of different design, materiality and three-dimensional solutions. Patterns where use to infer shape rules and then transform them to define new design languages (Figure 12 e Figure 13). Our approach enabled to investigate how different people can infer different rules from the same pattern to create a language of design (Benrós, Eloy, & Duarte, 2014).

*Figure 12. Work session ate the Workshop "Re-inventing ceramic tiles Using shape grammars as generative method for pattern design", Future Traditions eCAADe Regional, Porto, Portugal. Photo: Sara Eloy, 2014*

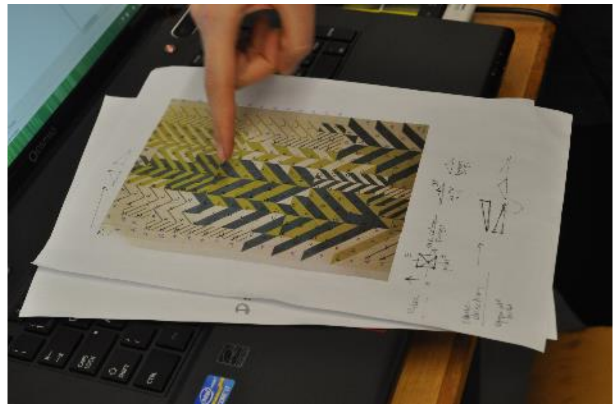


*Figure 13. Interpreting a ceramic tile pattern at the the Workshop "Re-inventing ceramic tiles Using shape grammars as generative method for pattern design", Future Traditions eCAADe Regional, Porto, Portugal. Photo: Sara Eloy, 2014*

**Development of auxiliary tools**

As a starting point for the implementation of a SG to the definition of customized housing layouts (Eloy, 2012) students from the Human-Computer Interaction course, from Computer Science degree, developed an app for the definition of the architecture functional programme for a house according to family profiles. The app enables the user, either a single person, a family or any other combination, to get a functional programme for their house to be defined in an automatic way. The functional programme, based on Portuguese literature and housing legislation, includes data on the required number and type of rooms as well as on the connections rooms are recommended to have with each other. The user introduces data on the co-habitation group, like ages, gender, family relationship and existence or not of a disable person and the software gives as an output a list of spaces and connections that respond to that cohabitation group (Figure 14 and Figure 15).

The requirements for the app come from Eloy (2012) and the process of developing the app implementation included several meeting between architects and computer scientist, professors and students, in order to redefine and debug the assignment requested. Through this multidisciplinary work is was possible to test both to students and researchers the difficulties of developing an app for a real client/context.

The app, for now working on the Android platform, was developed over a period of 5 months. A "low fidelity" approach (Rettig, 1994) was used to start the project, utilizing user tests early on, starting at the interface and interaction process definition, and along its different stages of prototype development. Direct observation of the app being used, users' evaluation and users' feedback enabled successive interface and interaction refinements for a better final app prototype.

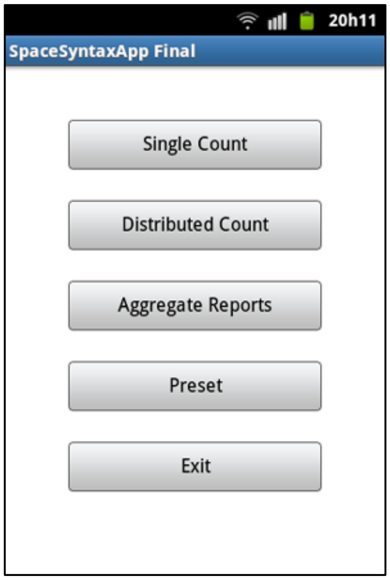




*Figure 14. (left) App House Generator, starting interface with the possibility of choosing a standard (typical) co-habitation group or personalizing it (custom)*

*Figure 15. (right) App House generator, interface to introduce data on the co-habitation group*

### *Data Collection*

According to Montello (2014) architecture influences human cognition, experience and behavior since it allows, facilitates, requires or prevents human perceptions, thoughts, emotions and acts. Our research goals are to map human emotions and reactions when moving in architecture spaces. To do so several techniques have been use and a joint multidisciplinary work has been developed between Architects, Computer Scientists, Psychologists and Ergonomists.

Studying the use of space requires time and the application of both observation techniques and powerful analysis tools driven by new technologies. In this scope our purpose is to assist the development of methods to study the social impact of build environments from the users' perspective. These methods include automatic and semi-automatic systems for capturing and monitoring data about how people use buildings and public spaces as well as models for mapping use patterns.

For specific studies it's not possible to use the real environment since e.g. the goal is to observe people behavior with and without certain space characteristics or to study a design proposal. In such cases the observation of the built environment through its simulation in full and semi-immersive VR systems allows us to highlight or hide the space characteristics we intend to study and to enable the user's experience to be in a the full-scale space. The use of VR environments constitute an observation technique that enrich the way students research about the social impacts of their designs and enables the reframing of design solutions according to the outputs of the analysis. When studying an existing space local observations are mandatory and they combine several empirical visits to the place, where students/researchers randomly photograph and register the behaviours of the people passing through or staying at the places. Time-lapse film technique as well as observations from fixed places (behaviour mapping and counting) are also observation techniques used in real space (Vaughan, 2001; Whyte, 1980). The observation results enable us to map what occurs in space so that, through an evaluation process, we can

assess the potential of a specific place to be successfully used and the importance of its configuration in shaping its social life.
Besides the semi-immersive PocketCAVE systems addressed previously, the use of a full-immersive system such as the Oculus rift HMD allows students to observe and register users' behaviour in simulated situations adjusted according to their research goals. Through this technology, students are able to test their design solutions as they were already implemented on real context, providing the users with a freedom of movements similar to those they had in real world. With this, higher degrees of immersion and presence are achieved, producing behaviours that are similar to the ones users had during real world interactions.

**Time Lapse**

The Time Lapse film, video or photography techniques have been used in several areas to study slow evolving phenomena, in Biology (plants growth and behavior; underwater and deep sea animal behavior), Chemistry (slow developing reactions), Weather studies (cloud formation and development; glacier dynamics and icebergs formation) (Bongaerts, 2014; James, 2012; Lopes, 2014b). As a rule, the study areas where normal/real time observation is not well suited for the data acquisition at hand can benefit from applying Time Lapse acquisition and processing. The fine time compression setting that Time Lapse enables, with control on the time compression ratio, amplifies its value and use: image capture can be set in different time intervals, from 1 second to hours or days, depending on the phenomena or event being studied. Once the record interval is established, it is fixed and used in one full complete Time Lapse recording. This interval is defined for each case: clouds evolution, depending on wind speed, can be recorded in 5 to 15 seconds interval. Recording a complete building being built, from its foundations up to completion, can be recorded in 24 h intervals. Studying the space (a street, a roundabout, a public garden or plaza, an interior in a building), being used, crossed, traversed by people can be done with 3 seconds interval or more, depending on the time compression needed. This information can then be used to input to a space analysis in combination with other technics as counting and tracking and Space Syntax (addressed in the next sections).
The relevance of Time Lapse in terms of making it useful in real life applications is to teach students the "how to" use the available equipment to maximize the results. Today film is too expensive to be used for Time Lapse recording. This rules out cinema cameras and photography cameras based on film recording. Video capture is an option if power constraints are met: either the video camera or the Time Lapse video control are self-powered and autonomous for a great period of time (and this is rare), or the main limitation is to find a usable place where a power energy source is available. Indoors use present no problem since access to the power grid is pervasive, but outdoors use can be quite limited.
This leaves digital photography as the current Holy Grail of Time Lapse recording. But specific knowledge is to be taken into account, or the expectations digital photography raises can very rapidly turn into low quality results or short lived recordings. Technical relevant details paired with digital photography techniques are explained with fundamental theory and practical demonstrations backup. Battery energy optimizations and Time Lapse use maximization strategies are explained. As a result, Architecture MArch thesis incorporate work done with Time Lapse outdoor capture, for instance seen in Romão (2013, p.168-169, 200-201), successfully mastering the acquired knowledge.

**Counting and tracking people**

In the scope of needs gathered from courses on urban planning and space analysis with space syntax, a counting app, for Android smart phones, was developed by students from the Human-Computer Interaction (HCI) course, from the Computer Science degree, to facilitate counting when doing local observations. Instead of using a sheet of paper, observers can use the app for more efficient counting of people/transports and the creation of automatic reports that saves time and avoids mistakes (Figure 16 and Figure 17).

Counting people is one observation technique used when we want to learn about the environment without taking account of people's intentions (Vaughan, 2001). The developed app enables to perform the Gate Method counting (Vaughan, 2001, p. 3) which can then be used to represent graphically and statistically the record numbers of moving people or vehicles that have passed through a gate or gates.

One difficulty Computer Science students have is to understand and how to address users' needs and user centered specifications. To develop awareness and foster better learning results, in the HCI course the user centered development approach is used, along with a "low fidelity" (lo-fi) development methodology (Rettig, 1994). This approach, along with real life situations involving students in real life projects and needs, such as the counting app, produce visible and usable results: in the app development, the students from the HCI course and from Architecture worked together and learned, from one side how to address the client's needs, interact with and understand the client's language and specifications, and from the other how to define the requirements, test and evaluate the prototypes being created in successive interactions, working in a multidisciplinary team. During the development phase several different Android smart phones were tested to ensure cross platform/maker uniformity of graphical interface and interaction. Usability tests were conducted with architecture students and professors. The app is now being used in architecture courses by groups of students as well as in research done in the scope of MArch thesis and will be in the near future used by students of psychology.



*Figure 16. (left) Counting app, start screen*

*Figure 17. (right) Counting app, one counting example*

Tracking people's movement is another observation technic that enables to investigate about patterns of movement from specific locations, the relationship between routes in an area, and the average distance people walk from specific locations (Vaughan, 2001; Whyte, 1980). Instead of using a traditional plan of the area where researchers trace the routes people are taking as they follow them, several technics have been developed from the more manual ones (Dalton, 2012) to the ones that automatically detect and track people (Ramanan, Forsyth, & Zisserman, 2007; Kuipers, Nunes, Pinheiro, Tomé, & Heitor, 2014; Mittal & Davis, 2003).
Eyetracking technology is very useful to study visual attention and eye movement and is an interesting approach to examine the influence of environmental cues on space use (Schütz, Braun, & Gegenfurtner, 2011). In line with recent studies about environment perception and use (e.g., Noriega, Vilar, Rebelo, Pereira, & Santos, 2012; Wiener, Hölscher, Büchner, & Konieczny, 2011), our team also believe that gaze direction, fixation and visual exploration patterns can be important predictors of space use. When doing local observations, both in real and virtual space, we use the Dikablis Eye Tracker from Ergoneers to track users's gaze along their path. This device allows us to collect eye fixations and saccade movements that are complemented with manual tracking for additional detail on subject path, visual attention points and landmarks.
Tracking people is an observation technique architecture students use to analyze social behaviors in the space they are designing for or researching about. Students also use tracking observation to compare between behaviors in different situations, both real and virtual spaces, varying specific variables as, e.g., with or without sound as we'll explain later in the Evaluation section. A research in this field is being developed considering that visual attention could be connected with sound perception influencing the users' movement in an architecture space.

### Emotions

For a long time the relation between the activity of nervous autonomous system and emotions have being studied as well as its representation in digital systems (Muass & Robinson, 2009; Kreibig, 2010; Peter & Herbon, 2006). Following this line of research we are exploring the use of biometrics sensing technology both in real space and within a semi-immersive VR environment, where users face architectural spaces which we state as an hypothesis that will induce them sensations. Users' physiological data is collected through electromyography (EMG) (Figure 18) and electrodermal activity (EDA) (Figure 19) aiming at detect users' emotional arousal while moving in space (Figure 20). To complement the obtained automatic responses we use questionnaires that give us the controlled perception. These measures can give designers basic information on people's emotional state when using the buildings they design.
The development of all these observation methods and mapping instruments allow us to map the behaviors and emotions people have in space to reach patterns of behavior related to space characteristics. Instead of defining a typology of spaces we want to propose a typology of experiences users have in spaces.

*Figure 18. Electromyography sensors placed in an experimental subject before an experiment in VR.*

*Figure 19. Electrodermal activity sensors placed in an experimental subject during an experiment in VR*

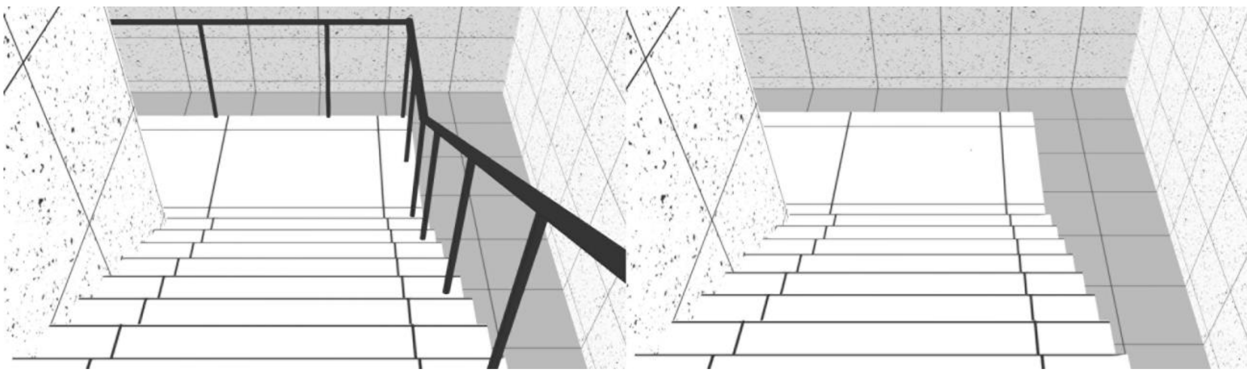


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*Figure 20. Building used for the experiment performed to capture users's emotions at (omitted for blind review)*

## *Evaluation*

The evaluation of buildings and public areas performance regarding specific criteria is a well establish practice nowadays assisted by several methodologies and software of analysis. In fact the relationship between building operation targets and user well-being in the built environment is driven the development of effective design methods centred on users and responding to their requirements. Simulation, prediction and evaluation methods are addressed by the use of particular solutions and methods. Research about people's behaviour in the building environment by using technological methods to evaluate its potential is being developed in our School in the scope of a Space Syntax and Complexity course, in master thesis and with applied research with immersive RV and objective assessment of emotions (Dias et al., 2014a, Dias et al., 2014b).

### Space Syntax

The use of space syntax analysis allows architecture students to evaluate the potentialities and limitations of any space configuration and interpret the relations occurred between space and society according to the principles set out by Hillier and Hanson (1989).

Space syntax proposes a quantitative analytical methodology where the space is defined by a set of syntactic measures, based on mathematic formulas, with the goal of understanding how the formal characteristics of a space and its relations with the rest of a system affects social experiences. In addition space syntax aims to be both a descriptive tool, allowing us to understand the operation of existing social structures, and predicative, allowing to evaluate the performance of proposed scenarios (e.g. Hanson, 1984; Hillier & Hanson, 1989; Hillier 2003). In design studio students that are already familiar with space syntax methods use it to analyse existing urban morphologies and understand their development through time or a particular phenomenon of urbanity (e.g. the gated condominiums by Lopes (2013) or the opening of the inner yards of urban squares by Romão (2013)). Informing a design with space syntax analysis enables students to explore between different design solutions and evaluate them in accordance to the requirements they are looking to fulfil. Always with an approach of complementarity to their own design methodologies, students use space syntax analysis as a method to quantitatively evaluate their proposals and with that data take more informed decisions.

**Patterns of behaviour**

For several years now the interest of applying Space Syntax as a complementary analysis tool to Spacial Cognition has been explored. In recent decades and with the emergence of Virtual Reality systems we witnessed an integration of this tool in the analysis performed by Space Syntax. Today the combination of both technics Virtual Reality and Space Syntax to research on Spacial Cognition, namely on Wayfinding, represents one of the important aspects of this theory development (e.g. Dalton & Holscher, 2006; Meilinger, 2006).

A system like the PocketCAVE allows to have users experimenting the interaction with a virtual environment and feel they are present in the scenes, therefore enabling researchers to evaluate spatial characteristic and designers to act according to the output data.

We are concerned with how other stimuli rather than the visual one affects people's perception of space. To study these phenomenon we are now starting a multidisciplinary research experiment on how various sounds in real and VR environments, affects architectural space perception and use. This experiment aims to study the perception of space with sound/noise auralization and the relation between users' movement in space with and without sound. The results of this experiment will be correlated with space syntax outcomes on the potentialities of the tested space. The experimental setup-up will be in the semi-immersive stereoscopy VR environment and we will use full 3D auralization, stereoscopic vision, eye tracking, EDA sensing, ECG sensing, 3D user tracking in the environment, Kinect One sensing (Heart Beat rate via vision, Speech input) and speech output.

In the experiments already undertaken, which involves a large number of participants, statistics control methods and objective and subjective assessments were used. The objective assessment is given by the use of non-invasive Electrocardiography (ECG) sensors and Electrodermal activity (EDA) sensors. Subjective assessments include properly structured questionnaires (Pre and Post Test) and are done in a close cooperation with Psychologists by means of retrospective questionnaires.  For this experiment, Dias and colleagues (2014) aim to investigate fear of falling reported by older users while interacting with architecture spaces considering a VR-based methodology. Architecture spaces composed by stairs, ramps and neutral rooms were arranged in order to create a virtual indoor space. Two experimental conditions were considered, a safe condition in which handrails were placed on stairs and ramps, and an unsafe condition in which handrails were removed (Figure 20). ECG and EDA were collected during the entire interaction and at the end the Implicit Association Test (IAT) was applied to measure associations between concepts that often reflect an attribute (Greenwald, McGhee, & Schwartz, 1998). In this case the strength to which a person holds an ageing stereotype. Main results point that there are a heart rate acceleration and higher electrodermal activity that could be associate with the fear of falling when comparing the neutral room with the top of a stair in both conditions (safe and unsafe). Participants also reported higher perceived fear for the unsafe conditions. IAT results shown that the unsafe condition seems to increase the ageing stereotype. According to Levy (2003), the representations that older persons have about their age group negatively influence their behavior. This author has shown that negative ageing stereotypes are related with the decrease in walking speed, worse memory performance, greater physiological stress and less will to live. In this way, attained results make clear the high impact of architecture elements on users' performance and well-being. For this study, students and young researchers from computer science, architecture and psychology could interact with each other to develop a multidisciplinary experimental research, developing and expanding their expertise.

### *Representation*

Advanced representation procedures and the development of more efficient visualization systems constitute areas of research closed related to practice and education and in which the joint work enable to achieve results that may be immediately used by students.

At a first stage of design students develop their ideas partially sketching with manual tools exploring space, light and textures (Figure 21). Realistic renders are used at later stages in order to reproduce rigorously all the features of the designed buildings enhancing materials, illumination and space itself (Figure 22).

The technologies addressed in the previous sections have been also developed to enhance the representation of architecture in the final stages of the design process. For this propose the VIARmodes application includes a Realistic Model which aims to achieve a more photorealistic visualization to where the designers can add textured environments as well as present it to the client or other stakeholders. In the satisfaction test performed to evaluate the app the Realistic Model was considered mainly relevant to the communication and presentation of the project between the architecture team (for 22% or the surveyed) and meetings with the client (for 30% or the surveyed) (Coroado, 2014).

The representation and exhibition of already existing architecture and urban settlements has brought us the understanding of design processes, building technologies and cultural believes that inform nowadays architecture. Several authors have use digital technologies in order to enhance the knowledge about past cultures and architecture through a better visualization using immersive virtual reality (Ibrahim, Jahnkassim, Ali, Latip, & Abidin, 2007; Zara, 2004; Campagnol, Clayton, Caffey, Kang, & Glowacki, 2014) and augmented reality (Noh, Sunar, & Pan, 2009) in heritage studies and in the architectural curricula. Virtual and augmented reality and animation tools are used to study architectural and constructional details and relate them with the social structure of the time. The possibility of doing a walkthrough and decompose buildings and cities' models into e.g. layers of time periods, enable a more broader understanding of how societies live at certain periods in the history.

We want to use digital technologies to show a specific type of architecture and building construction in an interactive way that could allow users to have more information than they

would have with traditional physical model building or traditional drawings. For that propose the digital technologies developed at our school are used as a link between History and Building Technologies in order to develop a complete digital exhibition in which the digital technologies would enable to inform visitors in an unexpected way by allowing them to interact with the exhibit architecture. In 2013 we did an educational innovation joining several courses around a common theme - "School of Chicago: digital skyscrapers ". Our aims were to display and revel the architectural culture of the final period of the 19$^{th}$ century to the first decades of the 20$^{th}$ century, by enhancing the historical knowledge as an active tool in today's digital universe.
This work ended in an exhibition focused on the deployment of paradigmatic skyscrapers in Chicago, allowing multiple radiographic looks through the use of digital technologies. The pocketCAVE was moved to the exhibition room allowing visitors to freely navigate through the streets of Chicago (Figure 23). Urban morphology was drawn in the room floor at scale 1:75 and some buildings emerged from it to be used as containers to Augmented Reality and 3D video mapping. In the exhibition two tablets with the ARch augmented reality app showed 3D models of some of the buildings enabling the frame structure and the architectural elements to be explored by the visitors (Figure 24). With these models visitors could explore the buildings by showing or hiding some parts of the model or doing real time sections. 3D video mapping was used to explore the potentiality of this technology in architecture exhibitions. For this technology two projectors were used to enable the projection on four elevations of the building (Figure 25). All technologies and contents of the exhibition were produce by bachelor and master students and young researchers in a joint collaboration to empower research in early years of the architecture programme. This real test was used as an experimental test in the scope of master thesis researching on how 3D video mapping and AR could be useful in architectural exhibition contexts.
At the end of this exhibition visitors were asked about their opinion on the advantages of using digital technologies to show architecture and if these technologies enable them to better understand architectural design. From a group of 25 surveyed 44% totally agreed and 32% agreed that 3D video mapping helps the understanding of a building in an architecture exhibition. For the ARch app, 13% of the users said that the available options at the app enable a very good understanding of the building and 36% rate it as good. When asked if the digital tools used in the exhibition where able to add more clear information to the users in comparison to traditional architectural exhibitions, 36% of the users ranked it as very clear, 36% as clear and 28% as neutral.
The use of 3D video mapping was studied in the scope of two master thesis, one where the use of the technology was approached for being used in architecture exhibitions (Figure 25) and other as a tool during the design process (Figure 26). Velhinho (2014) developed an app that enables the projection of different modes of representation allowing the user, with a keyboard, to shift between them in an easy way in order to obtain several types of visualization of the building: textures, dimensions, insolation, sections, floor plans among others that can be created.


*Figure 21. Sketches of a design proposal, Luís Coroado*


*Figure 22. Realistic render of a design proposal, Luís Coroado*

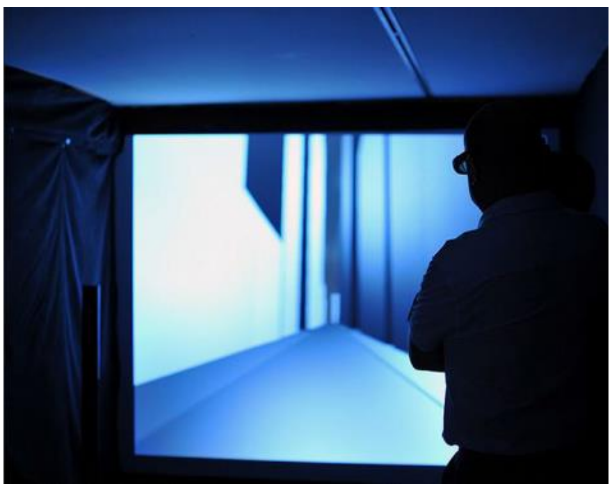


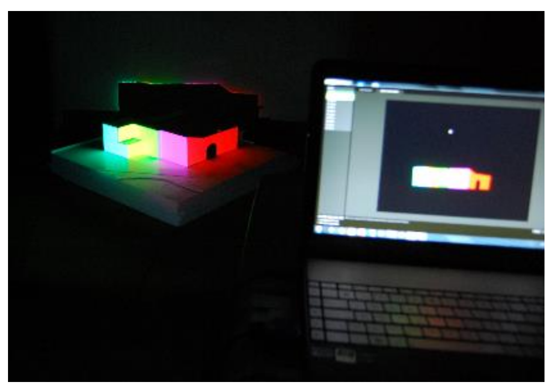
*Figure 23 (left). 3D model of Chicago in the PocketCAVE. Photo: Hugo Cruz, 2014*

*Figure 24 (bottom left). Augmented Reality app showing one of the Chicago's buildings. Photo: Christine Trevidic, 2014*

*Figure 25 (bottom center). 3D Video mapping over one of the Chicago's buildings. Photo: Sara Eloy, 2014*

*Figure 26 (bottom right) . 3D Video mapping projected to a model building and interaction interface. Photo: Sara Eloy, 2014*





An elective course on Sound and Video for Multimedia is offered to students. In this course, technology on digital sound and digital video is taught along with topics and techniques on developing a Title, Storyline, Storyboard and Planning to produce and direct a video project that tells a story and captures the targeted audience attention, applying in the way the grammar of the audiovisual (video) language. The areas of application of the acquired skills can be put to use whenever and wherever a time based visual and sound media (narrative video built or acquired observational video data) is usable: the main objective is to give students the mastering of another expression tool, the digital audiovisual speech.

## DISCUSSION

The simulation of real space in VR environments allows us to evaluate several parameters of a space which in any other representation mode would not be possible. This simulation of use and the consequent evaluation, done during the architecture conception phase, have a decisive influence on the design process and on the decisions undertaken allowing to reframe design, correcting the identified problems. The introduction of a three-dimensional immersive visualization, by the CAVE system, in the usability assessment of the built space complements the evaluation currently performed by digital tools which run over bi-dimensional representations of the space to analyse. The possibilities brought by the CAVE environment combined with the multidisciplinary research under development are empowering students with new tools for design based on more informed decisions.

The digital skills we are using and developing with students and researchers have been well integrated in the architecture curricula and the progressive acquisition of IT knowledge through the years, in a close cooperation with Computer Sciences researchers and students, enable architecture students to slowly learn how to integrate computers skills in design tasks. In the later years of Master Graduation in Architecture students are proficient in using digital design tools and their use is now volunteer, rather than imposed or suggested by professors. With this background, several Master students opt to develop their master thesis in subjects related to the use of digital design tools in order to transpose the user perspective to the developer of CAAD software team.

## REFERENCES


Achten, H. (2009). Experimental Design Methods - a Review. *International Journal of Architectural Computing*, 7(4), 505-534.

Asanowicz, A. (1998). Approach to Computer Implementation in Architectural Curriculum. In *Computer Craftsmanship in Architectural Education: 16th eCAADe Conference Proceedings*, 8-Ar. eCAADe: Conferences. Paris, France: Ecole d’Architecture de Paris Val de Marne.

Bastos, R. (2008). Automatic camera pose initialization, using scale, rotation and luminance invariant natural feature tracking. *Journal of WSCG*, 16(1-3), 97–104.

Benrós, D., Eloy, S., & Duarte, J. P. (2014). Re-inventing Portuguese ceramic tiles: Using shape grammars as generative method and the impact on design methodology. In *Sixth International Conference on Design Cognition and Computation* (DCC’14).

Bongaerts, P. (2014). Underwater time-lapse shows secret life of a coral reef. The Deep Reef Survey, Global Change Institute, The University of Queensland, Australia. Available at WWW: http://www.coraltimelapse.com/?page_id=57

Brindley, T., Doidge, C., & Willmott, R. (2005). Introducing alternative formats for the design project review. In Nicol, D., & Pilling, S. *Changing Architectural Education: towards a new professionalism* (pp. 108-122). Taylor & Francis.

Campagnol, G., Clayton, M., Caffey, S., Kang, J., & Glowacki, K. (2014). Unreal Projects: Using Immersive Visualization to Learn about Distant and Historical Locales. In *Proceedings of the 12th International Conference on Urban Urban History: Cities in Europe, Cities in the World (EAUH 2014).* Lisbon, Portugal.

Carvalho, P., Oliveira, T., Ciobanu, L., Gaspar, F., Teixeira, L., Bastos, R., Côrte-Real, L. (2013). Analysis of object description methods in a video object tracking environment. *Machine Vision and Applications,* 24(6), 1149-1165.

Celani, G. (2012). Digital Fabrication laboratories: pedagogy and impacts in architectural education. *Nexus Network Journal*, 14(3), 469-482.

Coroado, L. (2014). Visualização e Interação em realidade virtual imersiva: Modos de Visualização no Processo de Projeto (Unpublished master thesis). Lisbon, ISCTE-IUL.

Costa, V., Pereira, J. M., & Dias, M. S. (2007). Tecnologias CAVE-HOLLOWSPACE para a Mina do Lousal. In *15º Encontro Português de Computação Gráfica* (pp. 69-78). Oeiras, Portugal.

Cruz-Neira, C., Sandin, D. J., DeFanti, T. A., Kenyon, R. V., & Hart, J. C. (1992). The CAVE: audio visual experience automatic virtual environment. *Communications of the ACM,* 35(6), 64-72.

Cubukcu, E., & Nasar, J. L. (2005a). Influence of physical characteristics of routes on distance cognition in virtual environments. *Environment and Planning B: Planning and Design*, 32(5), 777-785.

Cubukcu, E., & Nasar, J. L. (2005b). Relation of Physical Form to Spatial Knowledge in Largescale Virtual Environments. *Environment and Behavior*, 37(3), 397-417.

Dalton, R. C., Holscher, C. (2006). Understanding Space: the nascent synthesis of cognition and the syntax of spatial morphologies. In Holscher C, Dalton R C, Turner A (eds) *Proceedings of the Workshop Space Syntax and Spatial Cognition* (pp. 1-10). Bremen.

Dalton, N., Dalton, R., Hoelscher, C., & Kuhnmünch, G. (2012). An iPad app for recording movement paths and associated spatial behaviors. In *Proceedings of Spatial Cognition 2012* (SC 2012) (pp. 431-450). Berlin: Springer Verlag.

Dias, M., Eloy, S., Carreiro, M., Proença, P., Moural, A., Pedro, T., … Azevedo, S., (2014a). Designing better spaces for people. Virtual reality and biometric sensing as tools to evaluate space use. In *Rethinking Comprehensive Design: Speculative Counterculture, Proceedings of the 19th International Conference on Computer-Aided Architectural Design Research in Asia* (CAADRIA 2014) (pp. 739-748). Kyoto.

Dias, M., Eloy, S., Carreiro, M., Vilar, E., Marques, S., Proença, P., … Azevedo, S. (2014b). Space Perception in Virtual Environments. On how biometric sensing in virtual environments may give architects users' feedback. In Thompson, Emine Mine (ed.), *Fusion - Proceedings of the 32nd eCAADe Conference,* Volume 2 (271-280). Newcastle upon Tyne, England: Department of Architecture and Built Environment, Faculty of Engineering and Environment.

Drettakis, G., Roussou, M., Reche, A., & Tsingos, N. (2007). Design and Evaluation of a Real-World Virtual Environment for Architecture and Urban Planning. *Presence: Teleoperators and Virtual Environments*, 16(3), 249-297.

Duarte, J. P. (2007). Inserting New Technologies in Undergraduate Architectural Curricula: a Case Study. In *Proceedings of eCAADe 2007 Conference* (423-430). Frankfurt.

Eloy, S. (2012). *A transformation grammar-based methodology for housing rehabilitation* (Unpublished doctoral dissertation). Instituto Superior Técnico, Universidade Técnica de Lisboa, Lisboa.

Entwhistle, N., Thompson, S., & Tait, M. (1992). *Guidelines for Promoting Effective Learning in Higher Education*. Edinburgh: Center for Research on Learning and Instruction, University of Edinburgh.

Ferrão, J. (2013). *As Gramáticas da Forma aplicadas ao processo de Criação Arquitetónica*. (Unpublished master thesis). Lisbon, ISCTE-IUL.

Freitas, M. R., & Ruschel, R. C. (2013). What is Happening to Virtual and Augmented Reality Applied to Architecture? In *Open Systems: Proceedings of the 18th International Conference on Computer-Aided Architectural Design Research in Asia (CAADRIA)* (pp. 407-416). Singapore: The Association for Computer-Aided Architectural Design Research in Asia.

Gaitatzes, A., Christopoulos, D., & Roussou, M. (2001). Reviving the past: Cultural Heritage meets Virtual Reality. In *VAST'01 Virtual Reality, Archaeology and Cultural Heritage* (pp. 103-110)

Greenwald, A. G., McGhee, D. E., & Schwartz, J. L. K. (1998). Measuring individual differences in implicit cognition: The implicit association test. *Journal of Personality and Social Psychology*, 74(6), 1464-1480.

Gutierrez, M., Vexo, F., & Thalmann, D. (2008). *Stepping into Virtual Reality*. Santa Clara, CA: Springer-Verlag Telos.

Higgins, J.S, Maitland, J., Perkins, S., Richardson, S., & Warren-Piper, D. (1989). Identifying and Solving Problems in Engineering Design. *Studies in Higher Education*, 14(2), 169-81, London: Taylor and Francis.

Hillier, B., & Hanson, J. (1989). *The Social Logic of Space*. Cambridge: Cambridge University Press.

Hillier, B. (2003). The knowledge that shapes the city: the human city beneath the social city. In *Proceedings of the 4th International Space Syntax Symposium*.

Hanson, J. (2003). *Decoding Homes and Houses*. Cambridge University Press.

Horne, M., & Thompson, E. (2008). The Role of Virtual Reality in Built Environment Education. *Journal of Education in the Built Environment*. 3(1), 5-24.

Ibrahim, M., Jahnkassim, P., Ali, M., Latip, N., & Abidin, N. (2007). Virtual reality in heritage studies and historical reconstruction through – a case study of a 16$^{th}$ century university complex in the ottoman world. In *7th International Conference on Construction Applications of Virtual Reality*.

Ibrahim, R. & Rahimian, F. P. (2010).Comparison of CAD and manual sketching tools for teaching architectural design. *Automation in Construction*, 19(8), 978-987.

James, T. (2012). Helheim Glacier, South East Greenland, July 12, 2010 Calving Event. 10 second Time Lapse video, 18:40 - 20:10 GMT (1.5 hours) in 537 images, Glaciology Group, Swansea University, United Kingdom, 2m54s video. Available at WWW: <https://www.youtube.com/watch?v=ovMhspvwpmw>

Knight, T. (1999). *Applications in Architectural Design, and Education and Practice*. Report for the NSF/MIT Workshop on Shape Computation. Available at WWW: <URL: http://www.shapegrammar.org/education.pdf> (accessed on 2014-10-25)

Kruger, M. (2012). Digial Turning: uma mudança de direcção?. *Revista JA Ser Digital*, 244, 26-32.

Kuipers, M., Nunes, M. S., Pinheiro, T., Tome, A., & Heitor, T. (2014). Building Space-Use Analysis System - a Multi Location/Multi Sensor Platform. *Automation in Construction*, 47, 10.23. Elsevier.

Kreibig, S. D. (2010). Autonomic nervous system activity in emotion: A review. *Biological Psychology*, 84, 394–421.

Lawson, B. (2006). *How Designers think: the design process demystified*. Architectural Press.

Levy, B. R. (2003). Mind Matters: Cognitive and Physical Effects of Aging Self-Stereotypes. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, 58(4), 203-211.

Lopes, M. (2014a). *Realidade Aumentada para Design em Arquitetura* (Unpublished master thesis). Faculdade de Engenharia da Universidade do Porto, Porto.

Lopes, M., Silva, J., Dias, M. S., Eloy, S., Gaspar, F., Miguel, R., & Mendonça, N. (2014). Sistema de Realidade Aumentada para Apoio ao Projeto de Arquitetura. In *Proceedings of EPCG 2014, 21º Encontro Português de Computação Gráfica*. Leiria, Portugal.

Lopes, P.F. (2014b). *Time Lapse com fotografia digital*. Versão 4. Lisbon, Portugal: ISCTE-IUL.

Lopes, S. (2013). *As Novas Fronteiras Urbanas e suas Repercussões na Cidade. A teoria da sintaxe espacial no planeamento urbano* (Unpublished master thesis). ISCTE-IUL, Lisbon.

Mark, E., Gross, M., & Goldschmidt, G. (2008). A Perspective on Computer Aided Design after Four Decades. in *Proceedings of eCAADe* 26 (pp.169-176).

Mauss, I., & Robinson, M. (2009). Measures of emotion: A review. *Cognition and Emotion*, 23, 209-237.

Meilinger, T., Franz, G., & Bulthoff, H. H. (2006). From Isovists via Mental Representation to Behaviour: First Steps Toward Closimg the Causual Chain. In Holscher C, Dalton R C, Turner A (eds) *Proceedings of the Workshop Space Syntax and Spatial Cognition* (pp. 1-10). Bremen.

Mitchell, W. J. (2008). *A Lógica da Arquitectura: projeto, computação e cognição*. Campinas. Brasil: Unicamp.

Mittal, A., & Davis, L. S. (2003). M2Tracker: A Multi-View Approach to Segmenting and Tracking People in a Cluttered Scene. *International Journal of Computer Vision*, 51(3), 189-203.

Moffat, S. D., Zonderman, A. B., & Resnick, S. M. (2001). Age differences in spatial memory in a virtual environment navigation task. *Neurobiology of Aging*, 22, 787-796.

Morganti, F., Carassa, A., & Geminiani, G. (2007). Planning optimal paths: A simple assessment of survey spatial knowledge in virtual environments. *Computers in Human Behavior*, 23(4), 1982-1996.

Moural, A., Eloy, S., Dias, M.S., & Pedro, T. (2013). How space experimentation can inform design: immersive virtual reality as a design tool. In *SIGraDi 2013, Proceedings of the 17th Conference of the Iberoamerican Society of Digital Graphics* (pp. 182-186). Valparaíso, Chile.

Montello, D. (2014). Spatial Cognition and Architectural Space. Research Perspectives. *Architectural Design*, Empathic Space, Sep/Oct 2014, profile n.231, pp.74-79

Noh, Z., Sunar, M. S., & Pan, Z. (2009). A Review on Augmented Reality for Virtual Heritage System. M. Chang et al. (Eds.), *Edutainment 2009*, LNCS 5670 (pp. 50–61). Springer-Verlag Berlin Heidelberg.

Noriega, P., Vilar, E., Rebelo, F., Pereira, L., & Santos, I. (2012). Eye movement and environmental affordances in a emergency egress task: A pilot study. In F. Rebelo & M. Soares (Eds.), *Advances in Usability Evaluation Part II* (pp. 660). Boca Raton - FL: CRC Press.

Omer, I., & Goldblatt, R. (2007). The implications of inter-visibility between landmarks on wayfinding performance: An investigation using a virtual urban environment. *Computers, Environment and Urban Systems*, 31(5), 520-534.

Penn, A., Conroy, R., Dalton, N, Dekker, L., Mottram, C., & Turner, A. (1997). *Intelligent Architecture: new tools for the three dimensional analysis of space and built form*.

Peter, C. & Herbon, A. (2006). Emotion Representation and Physiology Assignments. *Digital Systems. Interacting With Computers*. 18(2), 139-170,

Petric, J., Ucelli, G., & Conti, G. (2003). Real Teaching and Learning through Virtual Reality. *International Journal of Architectural Computing*, 1(1), 02-11.

Quinas, J. (2013). *O diálogo da forma arquitetura: exploração do mapping 3D* (Unpublished master thesis). ISCTE-IUL, Lisbon.

Ramanan, D., Forsyth, D. A., & Zisserman, A. (2007). Tracking People by Learning their Appearance. *IEEE Pattern Analysis and Machine Intelligence* (PAMI).

Reis, J. (2013). A Shell Tool for Visual Creativity Support. In *ISDOC 2013, International Conference on Information Systems and Design of Communication* (pp.56-63). Lisboa, Portugal, Carlos J. Costa e Manuela Aparício (eds.), ACM.

Rettig, M. (1994). Prototyping for Tiny Fingers. *Communications of the ACM*, 37(4), 21-27.

Romão, N. (2013). *A lógica social do espaço e a sintaxe espacial: análise do impacte de uma intervenção no tecido consolidado das Amoreiras* (Unpublished master thesis). ISCTE-IUL, Lisbon.

Sanguinetti, P. (2009). BIM in academia: Shifting our attention from product to process. In *Joining Languages, Cultures and Visions: Proceedings of the 13th International CAAD Futures Conference* (pp. 395-409). Montréal, Canada: Les Presses de lUniversité de Montréal.

Schnabel, M. A., Kvan, T., Kruijff, E., & Donath, D. (2001). The first Virtual Environment Design Studio. In *Architectural Information Management: 19th eCAADe Conference Proceedings* (pp. 394-400). Helsinki, Finland: Helsinki University of Technology (HUT).

Schnabel, M. A., & Kyan, T. (2003). Spatial Understanding in Immersive Virtual Environments. *International* Journal of Architectural Computing, 1(4), 435-448.

Schütz, A. C., Braun, D. I., & Gegenfurtner, K. R. (2011). Eye movements and perception: A selective review. *Journal of Vision*, 11, 1-30.

Soares, L. P., Pires, F., Varela, R., Bastos, R., Carvalho, N., Gaspar, F., & Dias, M. S. (2010). Designing a Highly Immersive Interactive Environment: The Virtual Mine. *Computer Graphics Forum*, 29(6), 1756-1769.

Umemura, H., Watanabe, H., & Matsuoka, K. (2005). Investigation of the model for path selection behavior in open space. *Electronics and Communications in Japan* (Part III: Fundamental Electronic Science), 88(1), 18-26.

Vaughan, L. (2001). *Space Syntax - Observation Procedures Manual* (original version of Tad Grajewski, 1992). London: Space Syntax Laboratory, Bartlett School of Architecture and Planning University College.

Vilar, E., Rebelo, F., Noriega, P., Teles, J., & Mayhorn, C. (2013a). The Influence of Environmental Features on Route Selection in an Emergency Situation. *Applied Ergonomics*, 44(4), 618-627.

Vilar, E., Rebelo, F., Noriega, P., Teles, J., & Mayhorn, C. (2013b). Signage vs. Environmental affordances: Is the explicit information strong enough to guide human behavior during a wayfinding task? *Human Factors and Ergonomics in Manufacturing and Service Industries*.

Velhinho, G. (2014). *Projeção Vídeo Mapping como ferramenta de exposição de arquitetura* (Unpublished master thesis). ISCTE-IUL, Lisbon.

Wang, R., & Quian, X. (2010). *OpenSceneGraph 3.0: Beginner's guide*. Packt Publishing Ltd.

Wiener, J. M., Hölscher, C., Büchner, S., & Konieczny, L. (2011). Gaze behaviour during space perception and spatial decision making. *Psychological research*, 1-17.

Whyte, W. (1980). *The Social Life of Small Urban Spaces*. New York: Project for Public Spaces.

Zara, J. (2004). Virtual Reality and Cultural Heritage on the Web. In *Proceedings of the 7th International Conference on Computer Graphics and Artificial Intelligence (3IA 2004)* (pp.101-112). Limoges, France.

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